Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI

Annual report 2021/2022

Mission food security: ConstellR lifts off

The goal of ConstellR, the first spin-off of Fraunhofer EMI, is to collect data in order to ensure food security for the people in the future through the targeted use of water in agriculture. With the help of ConstellR technology, it could be possible to increase the crop yield of the Earth by up to four percent without using more water.

The technical demonstrator LisR (Longwave Infrared Sensing Demonstrator) is currently already providing proof that this is possible — from the International Space Station ISS.

LisR (picture above, in the clean room of Fraunhofer EMI) has been transported to the ISS on board an Antares rocket. The cover picture shows the launch of the rocket on February 19, 2022, on Wallops Island, Virginia, USA.

In this annual report, you can read more about our activities in the Space business unit starting on page 58.

"Focus on transfer."

Dear reader,

“Transfer” is a major keyword for the Fraunhofer-Gesellschaft. We define the quality of our research via the extent of transfer regarding knowledge, brains and innovation that we achieve for industry and society. In order to optimize our transfer performance, we organize and evaluate it on the basis of defined transfer paths. This is how our successes in contract research are measured in parallel with those regarding licensing, spin-offs or organized forms of continuing education. This annual report is also a documentation of our outstanding transfer success. Our spin-off ConstellR as well as the fact that this start-up activity is also followed by joint projects in contract research are milestones for EMI. Furthermore, the LisR demonstrator offers completely new, space-based options for ensuring global food security, thus speaking for itself when it comes to its transfer into society. Security, especially urban security, has been a core topic at EMI for many years. With our participation at the Fraunhofer Center for the Security of Socio-Technical Systems SIRIOS, we go one step further and lay the foundation for transfer in a research field which can only be shaped successfully on an interdisciplinary basis. EMI integrates its simulation competencies that have evolved over decades and with which resilience becomes plannable.

Excellent science is the prerequisite for any form of successful transfer at Fraunhofer, and we show you examples of this in this report. I want to especially point out our research results in the characterization and modeling of transparent armor ceramics. This material class is an essential factor of current and future armor systems protecting against ballistic threats. Before our ground-breaking research, illustrated from page 14 on, it was not possible to simulate the protection performance of transparent ceramics in a predictable way.

The safety of occupants in the event of an automobile crash continues to be at the core of our efforts in the development and operation of our in situ X-ray crash-test facility. To ensure that everyone involved in the experiments remains safe and sound during operation of this highly complex high-energy facility, installation work is still underway to secure the infrastructure, but will be finished in a few months. After its completion, we will be able to carry out experiments such as the X-ray instrumented wheel crash, which is also documented here, to a far greater extent. I want to thank all our partners, customers, and colleagues from research, economy and politics for their constant trust in us.

Enjoy reading!

Sincerely,
Stefan Hiermaier

Prof. Dr.-Ing. habil. Stefan Hiermaier
Director of Fraunhofer EMI

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ERNST infrared payload integrated with detector-cooler unit, filter wheel and optics in the additively manufactured optical bench.

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False color rendering of process light emission during the perforation of a plate of carbon-fiber reinforced plastic by a high-energy laser beam.

Business unit Defense

Business unit Defense

"Our research identifies new possible solutions for analyzing equipment decisions — in terms of both national and European security."

Dr. Matthias Wickert

Dr. Matthias Wickert
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The German Federal Armed Forces (Bundeswehr) need future-proof systems and technologies for land, air and sea, as well as for cyberspace in the course of digitization.

As a strategic partner of the German Federal Ministry of Defence (BMVg) for research and technology in the field of high-speed dynamics and extreme material loadings, Fraunhofer EMI explores scientific and technological issues regarding protection and effectiveness as well as security and system aspects using state-of-the-art technologies and the possibilities of digitization.

Our research identifies new solutions and expands the knowledge base available for analyzing equipment decisions — with respect to national as well as European security.

In the following, researchers report first on deepening the understanding of the mechanical material behavior for ballistic loading of protective materials and how this understanding can be used specifically to tailor materials to ballistic applications using the capabilities of 3D printing.

Critical processes are characterized scientifically to provide the necessary base for hazard classification in the context of defense applications.

Finally, the improvement of simulation methods for fragmentation processes is reported, which are of great relevance for describing material response to high dynamic loading.

People in Defense research

Here, we present six individuals from Defense research — a small sample of the many employees who do excellent work at Fraunhofer EMI.

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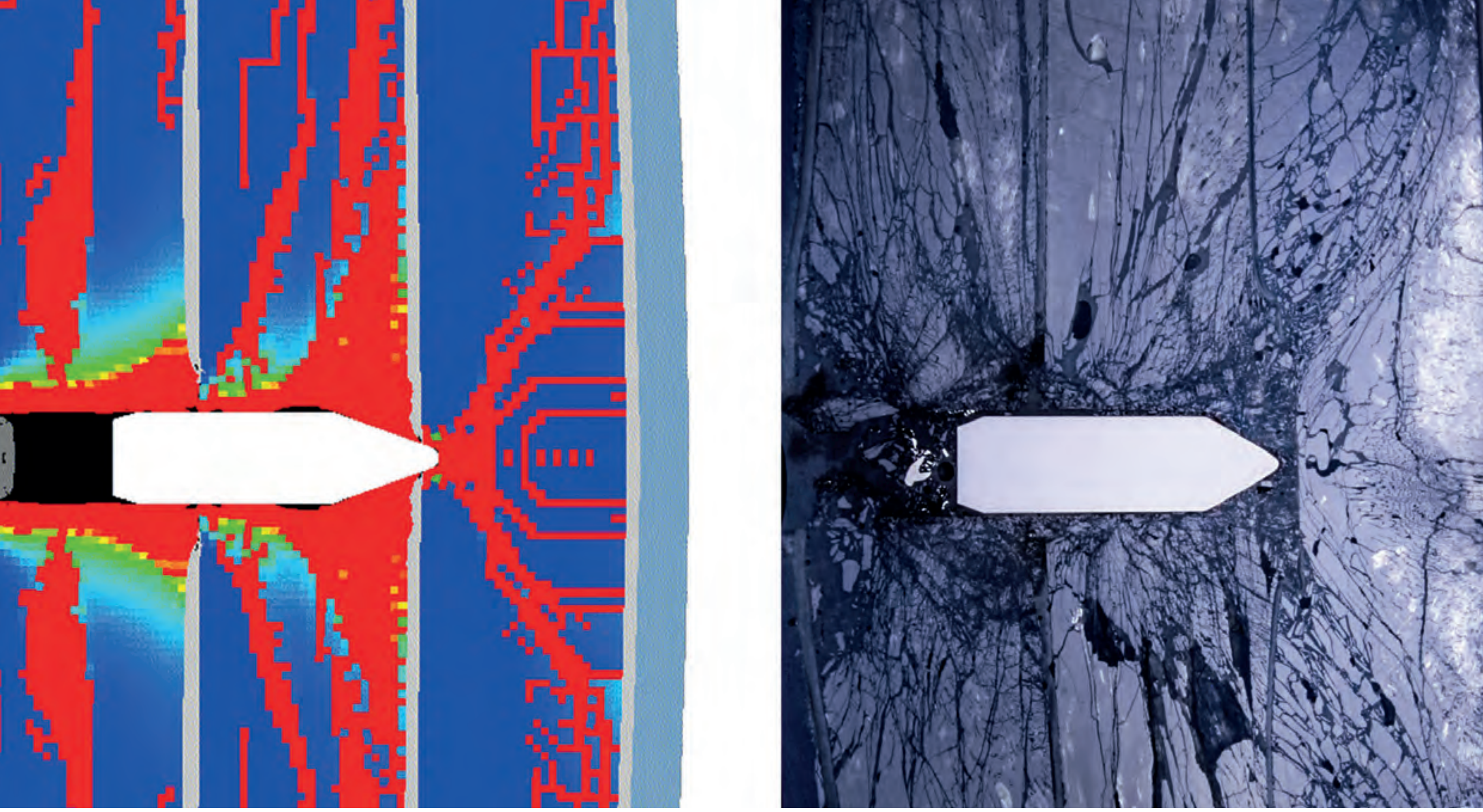
Terminal ballistic mechanics of transparent protective materials

A contribution by Dr. Steffen Bauer, steffen.bauer@emi.fraunhofer.de

The Ernst-Mach-Institut is investigating how the safety of the viewing window areas of armored vehicles can be improved against ballistic threats. A more in-depth analysis of the dynamic impact processes using numerical simulations enables the protective effectiveness of transparent protective elements to be increased. In order to improve the predictive power of the simulation calculations, new characterization methods were developed for the constitutive material models of the brittle materials used in the layered structure. For the first time, these methods enable an experimental determination of the necessary model parameters, which also take into account the preloads associated with a projectile impact.

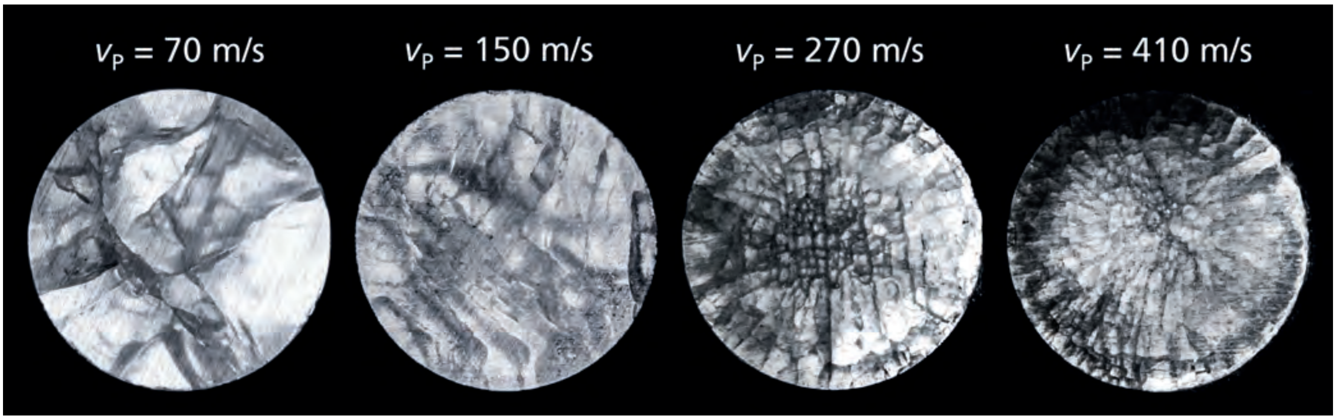
The increasing threat to armored vehicles from ballistic projectiles and blast leads to ever-increasing requirements on protective systems. In order to effectively protect the occupants, vehicle armor must be able to withstand, for example, multiple hits from infantry ammunition, fragments, explosively formed projectiles and improvised explosive devices (IEDs). The transparent areas are particularly targeted during attacks and are among the most critical components of armor for light armored vehicles. The aim of current work is therefore to increase the protective effectiveness of the transparent armor and thus protect the lives of the occupants as best as possible. The particular challenges in the design of the layered structure for transparent protective elements consist in determining suitable combinations of brittle and ductile materials (glasses, ceramics, adhesives, plastics) and the appropriate specification of the individual layer thicknesses. The complex structure of the transparent protective systems requires the use of numerical simulations for their design and in-depth analysis. The predictive power based on current constitutive material models, which describe the relationship between mechanical loads and change in material properties for any point in the material, was not yet sufficient because suitable model parameters for relevant materials were not yet available. For this reason, existing characterization methods for brittle and in particular for transparent protective materials were further developed at Fraunhofer EMI. The results for the protective effectiveness against small-caliber fire are presented below. The focus of current work is on impact scenarios against laminates made of soda-lime glass. The methods developed here can also be applied to other brittle materials in the future.



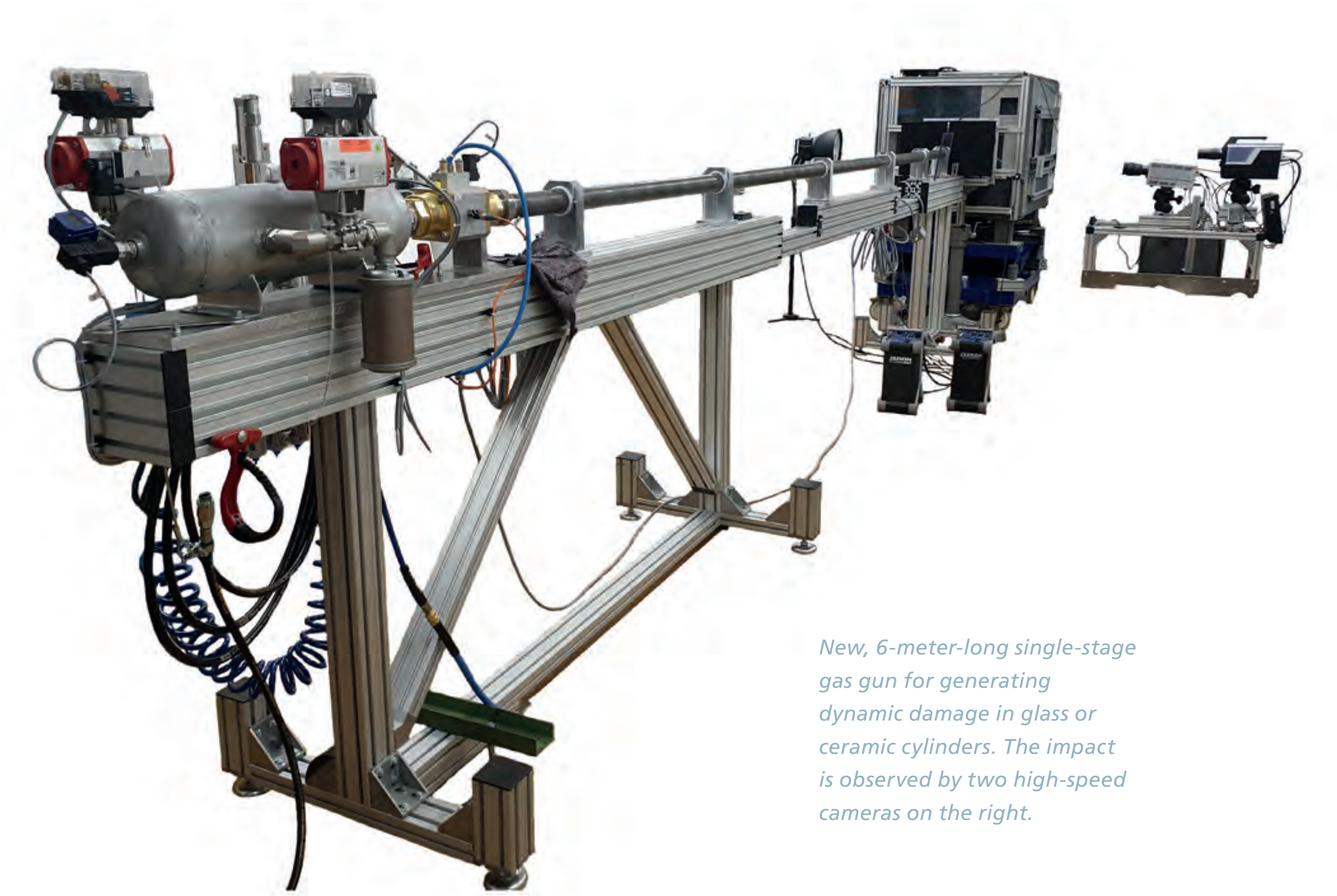
Crucial process: pre-damaging by shock waves

Upon the ballistic impact of a projectile, for example armor-piercing ammunition (AP), shock waves are induced in the glass in addition to the penetrating projectile, which propagate at very high velocities and lead to pre-damage of the glass in front of the projectile. Since the projectile consequently penetrates into previously damaged material, in the case of brittle protective materials, the strength of the pre-damaged material is governing the ballistic resistance of the protective arrangement. In order to characterize the shock wave propagation, an extensive, highly dynamic impact series with small glass specimens (glass plates with a thickness of 5 millimeters and a diameter of up to 50 millimeters) was carried out, and existing analysis methods have been improved. In these so-called planar plate impact tests (PPI), a defined, one-dimensional state of compressive strain is generated in the glass specimen by the planar impact of a metal disk. Stress waves are induced in the ▶

With the improved model (left), a high level of agreement with the experimental crack patterns (right) was achieved for the prediction of the failure behavior. The images show a vertical sectional plane through the center of the projectile and the layered transparent protective element.



Transmitted light images of cylindrical samples of a transparent protective material (here glass) that were dynamically damaged in the experiment: With increasing impact velocity v_P, the generated crack density increases significantly.



New, 6-meter-long single-stage gas gun for generating dynamic damage in glass or ceramic cylinders. The impact is observed by two high-speed cameras on the right.

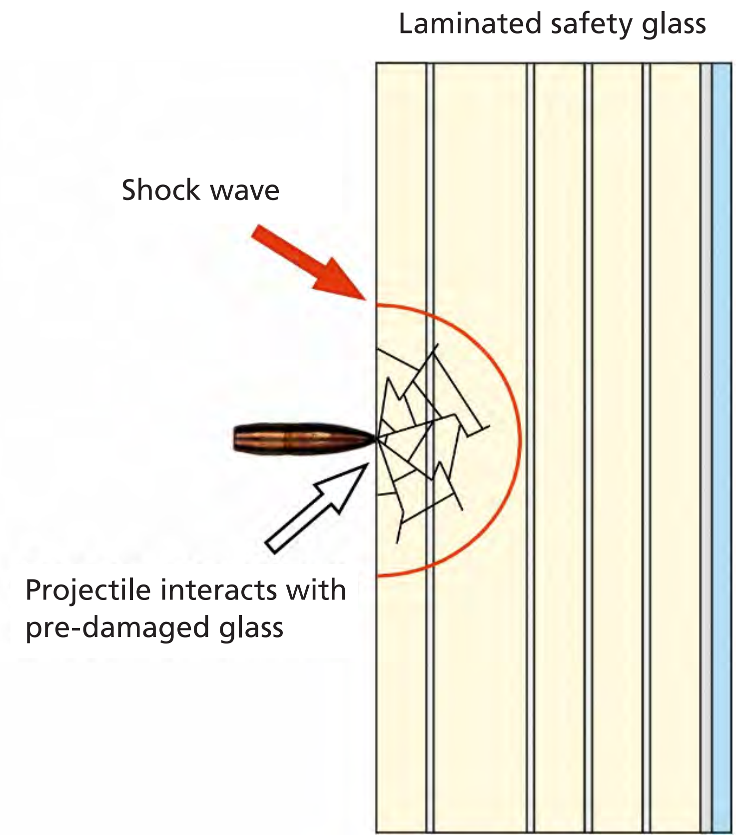
glass, which lead to compression. The relation between the applied pressure and the dynamic volumetric compression of the glass (compression curve) is determined based on a laser interferometric velocity measurement on the back of the glass specimen. The accuracy of the analysis was improved significantly compared to common evaluation methods through the development of an incremental evaluation method.

A newly developed characterization method also includes the use of two high-speed cameras that observe the impact process simultaneously from two directions. This allows the propagation of stress waves and damage fronts in the glass specimen to be visualized in an unprecedented quality. Since the glass is observed simultaneously from the side and the back, the wavefronts can be located more precisely, and new insights into the initiation conditions can be obtained.

First-time measurement of the strength of dynamically pre-damaged glass
The previously available literature data for the strength of pre-damaged glasses in impact scenarios were insufficient for the determination of constitutive model parameters. This is because previous strength measurements were carried out either on loose quartz sand or on thermally shocked glass samples. In both cases, the degree of damage is not representative for the pre-damaged material in front of a ballistic projectile. For this reason, a new method was developed at Fraunhofer EMI in which small glass cylinders (6 millimeters in height and diameter) are dynamically damaged, and the degree of damage is then determined using X-ray computed tomography (CT). The strength of the glass specimens can then be measured for different degrees of damage in a triaxial compression test.

Here, the current state of science was expanded in several points: First, the shear strength of dynamically pre-damaged glass samples could be measured for the first time. Second, the strength was determined as a function of the degree of damage for the first time as well. In addition, a model taken from the literature could be modified with the newly obtained material data and thus improved significantly. This was demonstrated for a representative ballistic scenario with rigid body penetration (AP ammunition) against a transparent protective element with a total thickness of 46 millimeters.

In the future, the predictive models can be used to efficiently examine the influence of various parameters (such as material, number or thicknesses of the individual laminate layers) in order to be able to design new protective arrangements in a polyvalent manner. For this purpose, various types of glass are characterized in further investigations using the newly developed methods and the concepts are also applied in an enhanced form to transparent ceramics. ■



Schematic sketch of a transparent protective element with layers of adjustable thickness of protective glass (yellow), adhesive layers (gray) and a backing layer (blue) to suppress the flying of broken glass.

MMC material development with innovative 3D-printing system technology

A contribution by Martin Jäcklein, martin.jaecklein@emi.fraunhofer.de

Metal matrix composites (MMCs) consist of a metallic matrix phase reinforced by particles or fibers. By combining the materials, MMCs can unify advantageous properties of the two components or, with regard to defense applications, even achieve better mechanical characteristic values than the individual materials alone.

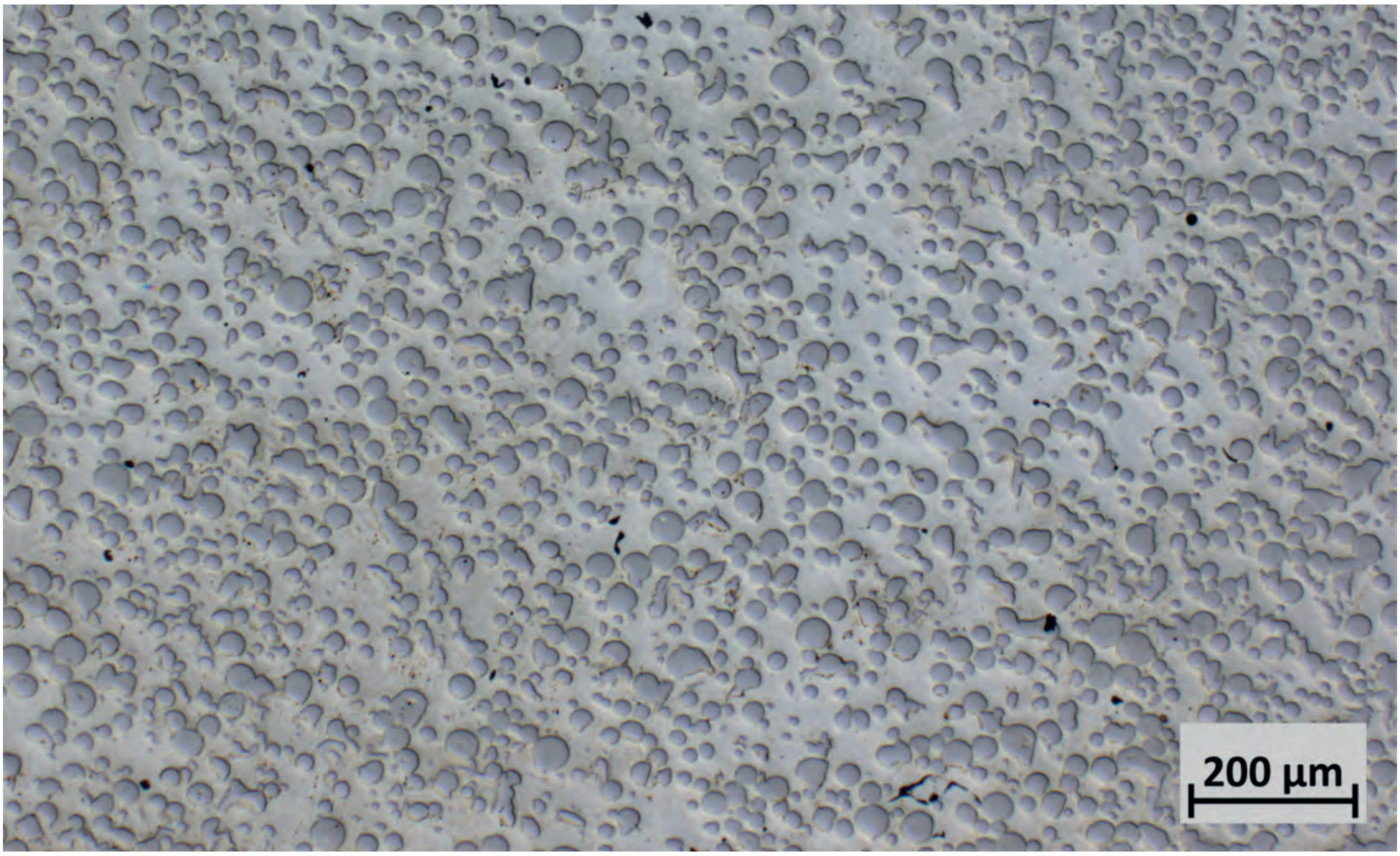
MMC potential and challenge

Additive manufacturing processes such as powder-bed-based laser beam melting (laser powder bed fusion, L-PBF) offer the potential to design new composite materials. Conventional manufacturing methods are often limited in terms of process control, mechanical properties or geometric complexity. This results in a limitation of the material selection for MMCs. Innovative material combinations in 3D printing could lead to composites with better properties in the future. The targeted setting of process parameters such as laser power and exposure speed enables the mechanical properties to be adapted to specific component requirements. Local variation of parameters can also influence the properties in defined areas to achieve different property profiles in different areas of a component.

However, the combination of different materials makes the manufacturing process more complex. For example, it must be avoided that undesirable phases, that is chemical compounds with unfavorable properties, form at the interfaces of the materials. For a controlled production of MMCs, a further development of the process technology is therefore desirable, as it is possible with special material development stations.

New 3D-printing system with new process and extensive measurement technology

With a newly installed material development station, Fraunhofer EMI has put into operation an L-PBF system for research purposes that is uniquely configurated in the world. The modular structure of the system enables a versatile use of the system. The four built-in lasers can work simultaneously or one after the other (in so-called master-slave operation). Build platform reductions can be used to work with smaller material batches in material development. Various construction platform heaters allow heating up to temperatures of 1200 degrees Celsius. The equipment also includes extensive measurement technology for process monitoring and support of special experimental setups, for example a high-speed camera that can be used to observe the melting behavior of the material in the process. Furthermore, two pyrometers offer the possibility to measure the temperature of the material in situ. Due to the availability of several free interfaces, further diagnostics



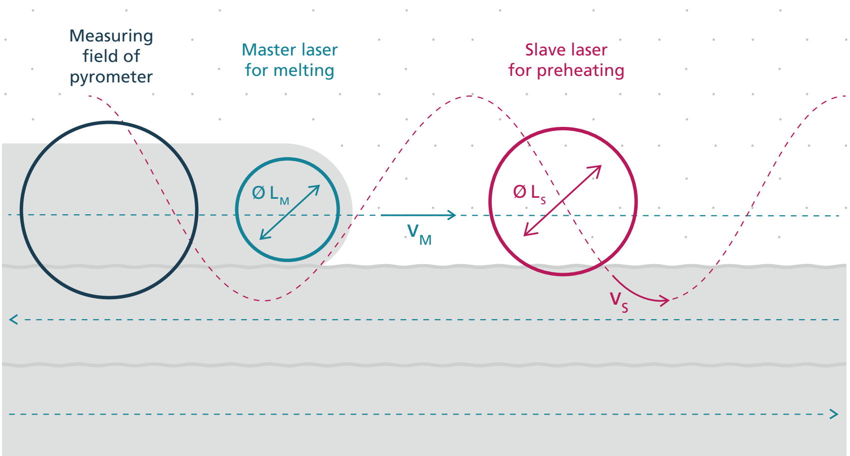
can easily be set up if required. In addition to other new process functions, such as the variable setting of the laser focus, there is also more freedom on the software side in terms of process control than with commercial systems.

Material development of new MMCs

Combinations of tungsten particles and steels or tantalum as a matrix have been the focus of investigations on metal matrix composites at Fraunhofer EMI so far. Special material combinations such as tantalum and tungsten with a small difference in the melting temperatures of the components require special strategies to melt the matrix material in the process while preserving the reinforcement particles as such. In initial tests, two lasers were used in master-slave operation to produce such a material system. One laser preheats the powder bed, the second laser follows at a defined distance and melts the powder. For this purpose, it was first necessary to determine in preliminary tests at which process parameter combinations of laser power and exposure speed, in other words at which energy input, the used powder is only heated but not melted. On this basis, possible process windows are currently being evaluated in master-slave experiments using diagnostic tools such as pyrometry.

The potential of the new system technology is to be able to select very many process settings by itself, but in doing so, it increases the complexity of the research tasks. The aim of the tests is to develop methods for efficient parameter development for new MMC material systems.

Microstructure of a steel-tungsten MMC.



The master-slave operation enables complex process control with up to four lasers following each other. A slave laser can be used to preheat the powder bed, another one to melt it and a third optic for temperature measurements using pyrometry.

EMI at the DWT forum

"Applied Research for Defense and Security in Germany — Future Technology for the Bundeswehr"

At the accompanying exhibition, the Fraunhofer Segment for Defense and Security VVS showed exhibits from its research.

The forum "Applied Research for Defense and Security in Germany — Future Technology for the Bundeswehr" by the German association for defense technology DWT was held in Bonn from March 8 to 10, 2022. It is the largest defense and security technology conference in Germany in the field of research and technology. Overriding issues were the preservation and expansion of technological sovereignty in the field of defense, the targeted use of research funds for the needs of the Bundeswehr, and a glance at technological trends and future challenges for the armed forces.

A wide range of topics was covered in 32 technical sessions and poster sessions, with EMI being present in different areas. Dr. Matthias Wickert chaired the session on protection and gave a presentation on the robustness of future combat aircraft to high-energy laser impact and hydraulic ram effects.

Marcin Jenerowicz spoke about injury prediction by simulation with human body models and experiments with biofidelic dummies for protection on deployment and occupational health and safety on duty, and Professor Frank Schäfer presented the EMI satellite ERNST and the demonstration mission for high-performance small satellites. Professor Werner Riedel and Dr. Robbert Rietkerk presented their poster titled "Machine learning for protection and effects: Modeling the dynamic behavior of materials and components under impact and contact detonation."

The event was organized by the Studiengesellschaft DWT mbH in coordination with the Fraunhofer Segment for Defense and Security VVS, the German Aerospace Center (DLR), the Federation of German Security and Defence Industries (BDSV) and the Federal Ministry of Defence (BMVg). The Studiengesellschaft der Deutschen Gesellschaft für Wehrtechnik (SGW) was responsible for the event, its organization and implementation.

The steel plate is ejected on top during the experiment due to the deflagration, and its velocity is determined via high-speed cameras.

Hazard range prediction for ammunition storages

A contribution by Dr. Johannes Schneider, johannes.schneider@emi.fraunhofer.de

Description of debris launch conditions under sub-detonative blast loading

During storage, ammunition is exposed to potential hazards such as fires or shelling, resulting in either a detonation or a less intense deflagration-type explosion.

The debris launch velocity (DLV) of ejected storage components due to internal explosions is, additionally to debris mass and launch angles, the essential parameter to describe the hazardous fragment trajectories. Therefore, it is the basis for hazard- and risk analyses for the safety domain of explosives. While Fraunhofer EMI derived the debris launch velocity (DLV) formulation for detonation-type explosions empirically in the past, the formulation for DLV in the sub-detonative domain (deflagration), which is characterized by the conversion of the explosive substance below the speed of sound, has not yet been adequately described. So, possible hazards originating from stored ammunitions capable of mass detonations (high-explosives) can already be assessed based on the existing DLV models. For the ammunition types not prone to mass detonation events, which are increasingly used by the German armed forces, these models are now of higher precision. It can be assumed that for this type of ammunitions lower risk areas are sufficient. The work aims to determine parameters for the DLV in deflagration-type events and to generate data points for the derivation of analytical equations. This makes an essential contribution to the safe storage of ammunition items by the German armed forces. To this end, extensive test series were carried out at Fraunhofer EMI, based on a test container filled with deflagrating explosives. Steel plates of different masses were used as cover and test specimens to determine the debris velocity. The launch velocity of the steel plates was determined using high-speed cameras and related to the energy content of the explosive, the combustion characteristics, and the resulting explosion pressure.

X-ray video analysis of dynamic failure events inside lithium-ion battery cells

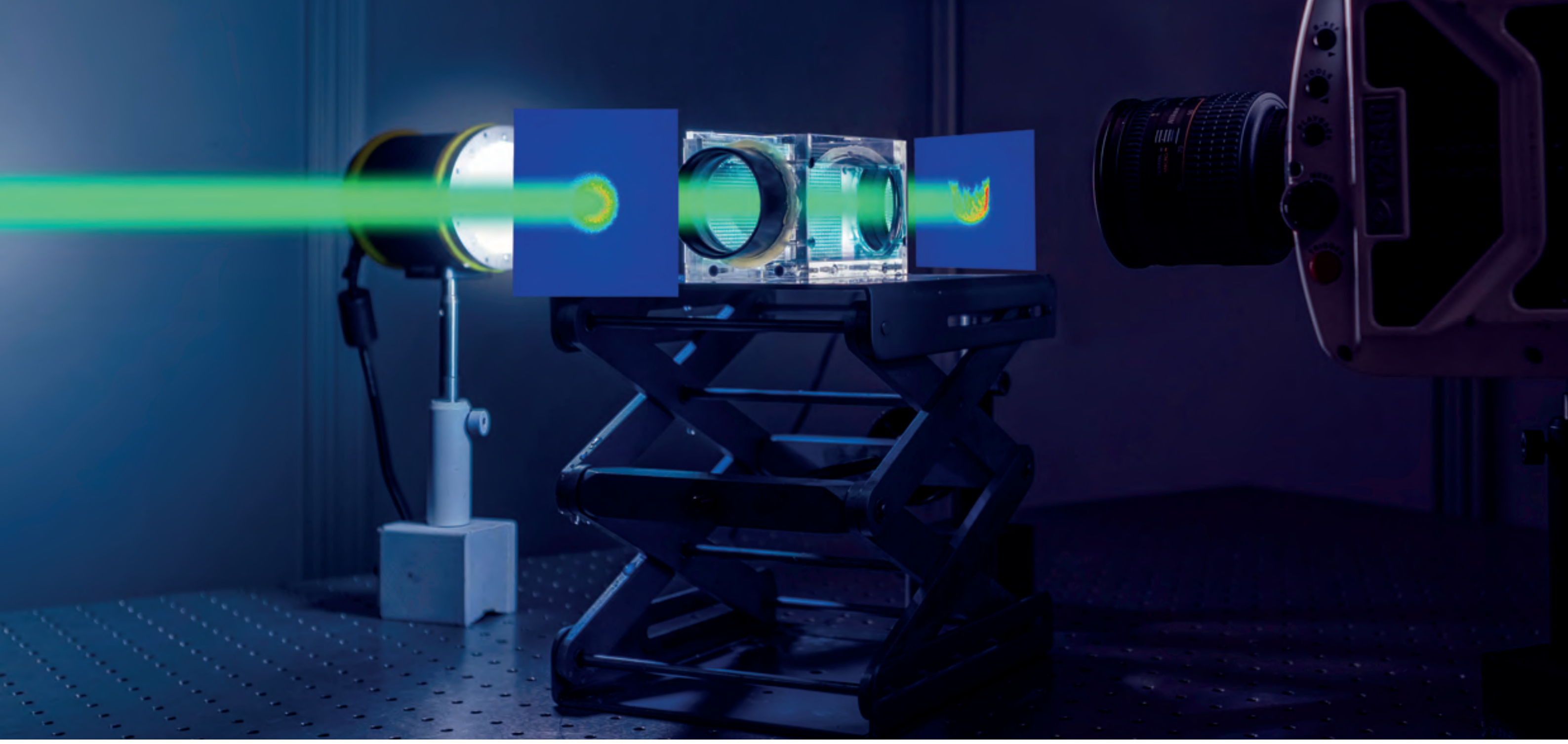
A contribution by Dr. Thomas Kisters, thomas.kisters@emi.fraunhofer.de

A detailed understanding of possible failure events inside lithium-ion battery cells is of central importance for improving the safety and robustness of electric energy storage systems. For this purpose, among others, dynamic X-ray technology is adopted, as for example at the synchrotron ESRF in Grenoble, a partner of EMI. This X-ray diagnostics represents an important insight for the analysis of battery failure as it enables the visualization of optically inaccessible internal processes. Unfortunately, due to the hazards related to battery failures, these types of investigations have been limited to small cells up to now. Yet, X-ray investigations of larger cells are relevant for defense applications.

For this reason, a new method for the investigation of internal failure events of lithium-ion cells with larger dimensions has been established at EMI. It takes advantage of a rotating-anode tube that allows for video recordings of up to five seconds and frame rates of up to 2000 frames per second. In order to investigate penetration events, a nailing device was constructed wich allows to pearce cells of different formats (cylindrical, prismatic or pouch cells) and provke a thermal runaway. Video recordings of such a test permit observations at different times after the piercing, as shown exemplary in the picture. In the presented test, the nail (on the left lower side of the first picture, blue circle) enters the cell at time zero. Four seconds after the piercing, the whole jelly roll starts to move and pushes upwards out of the casing.

In addition to nail penetration tests, experiments utilizing overheating as a path for failure initiation were performed. In this case, heating foils attached to cell casings have been used to heat the cells above the critical temperature. Currently, we work on realizing the heating by way of a laser that allows for local heating at a single spot and, herewith, attain the critical temperature at a specific location much faster than via the more globally acting foils.

Video frames of failure events inside of a charged battery cell after its being pierced with a nail (blue circle on the lower left side of the first picture), recorded with 1000 frames per second.



When a high-power laser is transmitted through water, its beam shape changes. This was made visible with the help of multi-contrast imaging.

How does the beam of a high-power laser propagate in water?

A contribution by Dr. Stefan Reich, stefan.reich@emi.fraunhofer.de

Multi-contrast images make water movements that are invisible to the naked eye visible in the laser beam and can be used to calibrate simulations.

For applications of high-power laser radiation, the influence of the transport medium on the beam propagation can play an important role. Specifically for propagation in water, investigations were carried out at Fraunhofer EMI using a laser beam with a power of up to 7.5 kilowatts at a wavelength of 1070 nanometers. In this case, absorption processes lead to heating of the water in the area of the laser beam. In addition, turbulence occurs in the rising hot water. However, since hot water has different optical properties compared with cold water, the laser beam is also deformed. Measuring the temperature as well as the water flow locally in the laser beam is not possible, as any measuring device would be damaged by the laser.

For this reason, an indirect measurement method was implemented at Fraunhofer EMI. With the aid of multi-contrast imaging using a Hartmann mask, previously invisible contrasts can now be made visible. The mask generates a large number of small light points that are imaged onto a detector perpendicular to the direction of propagation of the laser beam. From the change in their position, the local changes in the optical properties can be made visible.

With the help of multiphysics simulations consisting of beam optics, heat flow and fluid mechanics, the experiments were simulated. Multi-contrast imaging data were used to validate the simulations. These simulations now allow the analysis of parameters not accessible in the experiment, such as the local temperature of the water in the laser beam, flow processes and the heat flow in the water.

Simulating fragmentation efficiently

A contribution by Dr. Pascal Matura, pascal.matura@emi.fraunhofer.de

Further development of methods for the efficient simulation of fragmentation processes

The description of the fragmentation of solids faces similar challenges to modeling and numerical simulation as turbulent fluid flows.

If a material is stressed far beyond its strength limit, cracks develop that can spread, branch and ultimately — under correspondingly high dynamic stress — also lead to complete fragmentation. As with a drinking glass that shatters on the floor at low velocities, the resulting fragments can cover many orders of magnitude: from a few larger fragments to the finest splinters that are barely visible to the eye.

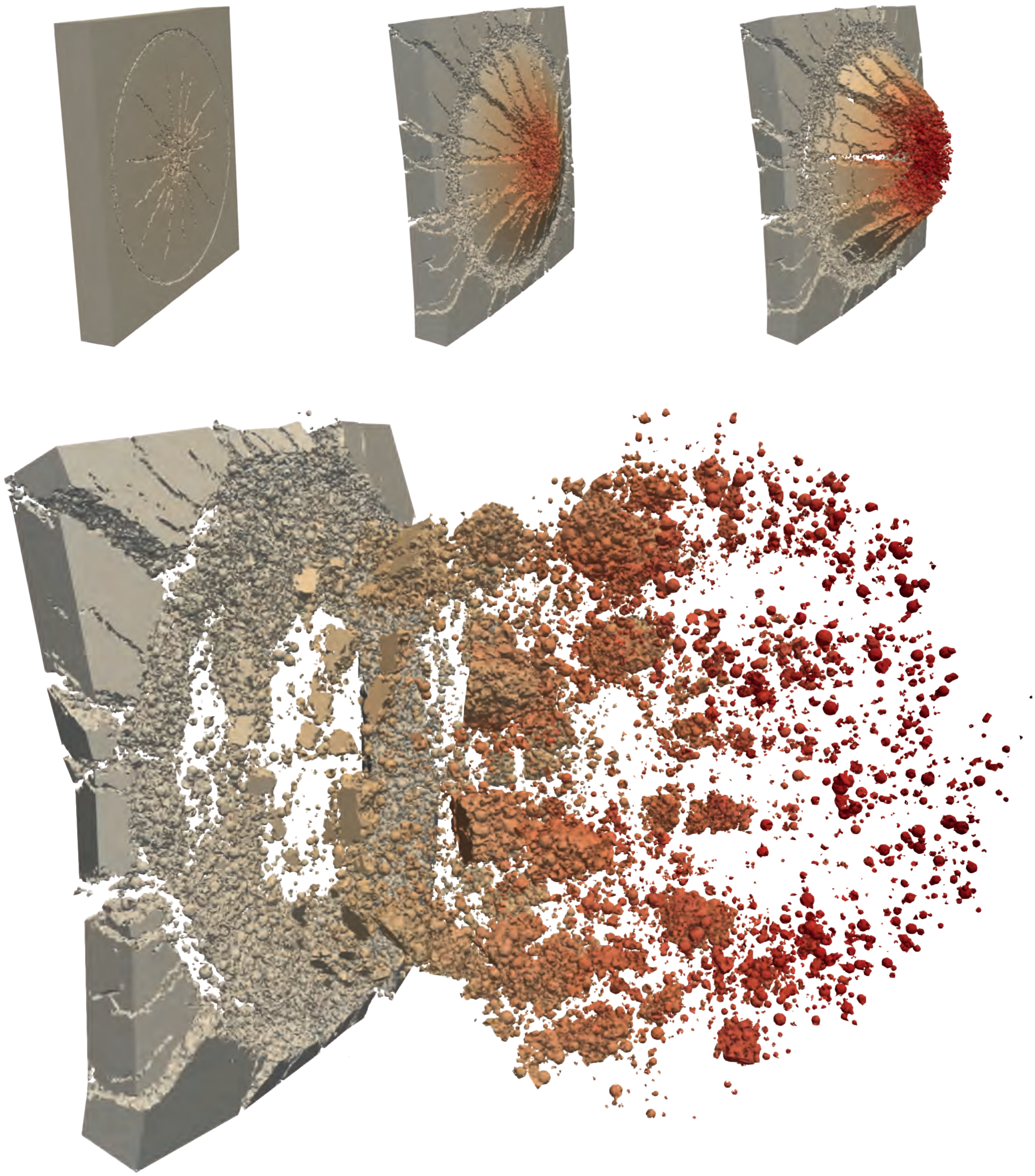
Fragmentation processes often occur during impact and explosion events. To simulate them numerically, the material behavior must be adequately modeled. In addition to that, special methods must also be used that can capture the creation of new surfaces as fracture surfaces that accompany crack propagation and fragmentation.

For this purpose, the structural dynamics code SOPHIA developed at EMI offers a method that describes the processes in the region of the fracture zone by means of so-called cohesive zone elements. These special elements capture the increasing material damage and allow the creation of new fracture surfaces in case of complete damage. The special feature here is that they are only inserted during the simulation at those positions in the material where the material strength is exceeded.

Particularly challenging is the fragmentation modeling in a homogeneous material, in which possible crack paths are not known a priori, but seem to emerge and fan out randomly. In this respect, the cohesive zone approach developed at EMI represents an innovative method to adequately and physically accurately model the crack formation in such a material. The efficiency and numerical stability of the method could be significantly improved by recent work.

Another, completely different approach to fragmentation simulation is taken with the code MD-Cube developed at EMI, which is based on the discrete element method. In simplified terms, the material to be simulated is represented by a large number of particles which are linked to each other by connecting elements and the interactions of which are described by material-specific laws. Fragmentation is thereby enabled in a natural way by the fact that these connecting elements can break. A highly parallelized implementation in MD-Cube allows models to be efficiently simulated even with many tens of millions of particles.

The complex and numerically demanding simulations also require a modern IT infrastructure on the hardware side, with the central component being the Scientific Linux high-performance computing cluster at EMI.



Fragmentation of a concrete plate under pressure impact loading over time. The color represents the velocity of the fragments perpendicular to the plate. In order to obtain a realistic fragmentation behavior, the aggregate grains, in this case a total of about 57,000, were explicitly considered in the model. Cohesive zone elements represent an ideal formulation to account for the weak bond between the cement matrix and the aggregate grains, while the cracks through the cement matrix are most effectively described by a so-called smeared-crack approach. The simulation was performed by Christoph Grunwald using the EMI software SOPHIA.

The floods in the Ahr valley have shown how vulnerable our networked infrastructures are. © Adobe Stock

Business unit Security and Resilience

Business unit Security and Resilience

Many companies still find it difficult to quantify their own resilience. In the face of increasingly complex challenges, however, it is in many cases no longer a question of whether, but rather when faults or failures will occur in one’s own system. You can prepare well for this with our tools: With the help of our resilience assessment tools, we support companies in taking the step towards quantifying their own resilience and thus being able to better evaluate investments in resilience.

In the following articles, you can explore selected topics of our current activities in the business unit Security and Resilience.

In Berlin, the newly founded Fraunhofer Center for the Security of Socio-Technical Systems SIRIOS has been working since January 2022 on making complex security scenarios for urban security tangible and controllable. The Multisafe project focuses on safety in urban road traffic. The need for resilient power grids for the energy transition is addressed in the RESIST project, and the security of other critical infrastructures such as Europe’s airports is at the core of the work of the SATIE project. Finally, the article on the Multischutz project discusses how impact- and blast-resistant elements made of fiber-reinforced composites protect people in vulnerable buildings and in public places.

Our customers have recognized that resilience as part of their strategy maintains their competitive advantage.”

Daniel Hiller

Daniel Hiller
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People in Security and Resilience research

Here, we present four individuals from Security and Resilience research — a small sample of the many employees who do excellent work at Fraunhofer EMI.

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Fraunhofer Center SIRIOS — EMI advances urban security and resilience in Germany's capital city

A contribution by Daniel Hiller, daniel.hiller@emi.fraunhofer.de

Fraunhofer Center for the Security of Socio-Technical Systems SIRIOS commences its operations in Berlin.

Public safety faces major challenges, be it climate-induced disaster, industrial accidents, terrorist attacks or riots at major events. Since January 2022, the newly-established Fraunhofer Center for the Security of Socio-Technical Systems SIRIOS has taken up its task to make complex security scenarios tangible and controllable.

The interdependencies of modern societies between people, technology and infrastructure make public safety and security complex and difficult to manage. Therefore, the scope of their impact depends on a multitude of direct or indirect influences, and existing security solutions often cover only partial aspects. Disruptions within such socio-technical systems can have severe and wide-scale effects, for example, on the supply of electricity, Internet, telecommunications, water and logistics. To be prepared in case of an emergency, researchers of Fraunhofer SIRIOS work on novel and comprehensive simulation systems with regard to such interdependencies.

Simulation — transfer — impact

Fraunhofer SIRIOS sees itself as an incubator for new public safety and security technologies. By applying interconnected simulations and new models it is possible to model the development and impact of complex socio-technical threats or disruptions and to derive scientifically sound measures. In various scenarios, relevant parameters and interdependencies of modern society are identified and exemplified in coupled simulations. The evaluations reveal existing vulnerabilities. This creates new room for new protection and resilience strategies, which are put into practice, working together with stakeholders. These new approaches to the problem of social hazards support the assessment and controllability of new technologies in the event of an emergency and also ensure the protection of data and personal rights and, in the final analysis, increase the citizens' subjective sense of security.

The vision of Fraunhofer SIRIOS for the coming years is to establish a testing, demonstration and training environment for the coupled simulation of complex security scenarios that is unique in Europe. The center focuses particularly on transferring the research into practice: Working with network partners in safety and security authorities, industry, research and politics, new models of technical systems and human behavior are integrated into complex scenarios, tested in simulations and evaluated within the transfer network. At the same time, regular exchange formats ensure that the needs which arise in practice are channeled back into research.

Extreme weather phenomena and man-made incidents at major events
Current research work concentrates on two special scenarios: the effects of extreme weather phenomena like storms or floods in a big city as well as man-made hazardous incidents at major events. Accordingly, the focus is on simulating damage to buildings, supply networks and infrastructures such as the power supply, as well as the resulting disruptions, for example, due to failure of the Internet, telecommunications or logistics chains. In order to be able to intervene ideally in panic situations at major events, it is of enormous importance to be able to anticipate the behavior of the crowd. SIRIOS aims to simulate this behavior and the involvement of helpers so that adequate responses can be made in the event of an emergency.

"Dangerous situations like these are a sad reality and will probably continue to affect us in the future. That is why it is so important to conduct even better research concerning the interaction between technology, infrastructure, emergency forces and the population, and to apply the findings to other or new threats," explains Daniel Hiller, managing director of Fraunhofer SIRIOS. ▶

The Fraunhofer Center for the Security of Socio-Technical Systems SIRIOS is located on the premises of Fraunhofer FOKUS in Berlin. © M. Zalewski, Fraunhofer FOKUS

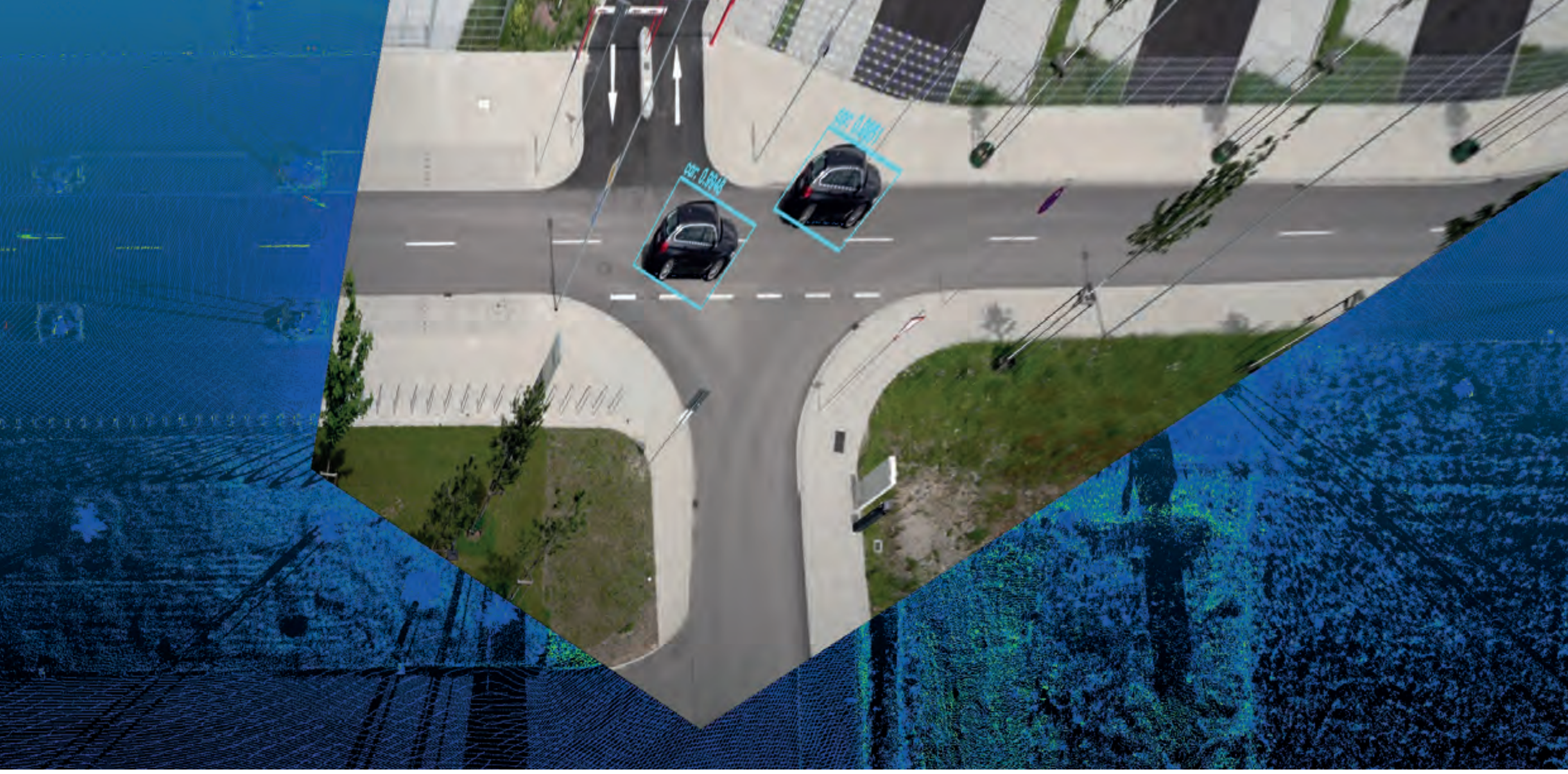
Extreme weather phenomena like heavy thunderstorms can pose significant challenges to municipalities. © Adobe Stock

A growing team of employees from the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, the Fraunhofer Institute for Open Communications Systems FOKUS, the Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB as well as the Fraunhofer Institute for Transportation and Infrastructure Systems IVI is going to research and work collaboratively on cross-institute projects to build up the center, located at the Berlin Fraunhofer FOKUS.

As managing director of the center, Daniel Hiller from Fraunhofer EMI is responsible for the scientific, financial and organizational

Rapid alerting and response time of rescue forces are decisive factors during operations. Both need to be optimized. © M. Heyde, Fraunhofer FOKUS management and coordinates all internal committees and teams. Daniel Hiller is head of the business unit Security and Resilience at Fraunhofer EMI. As spokesperson of the center, Professor Manfred Hauswirth represents Fraunhofer SIRIOS in all external matters. Professor Manfred Hauswirth is director of Fraunhofer FOKUS. Up to 2026, SIRIOS receives funding from the German federal government and the state of Berlin and is subsequently supposed to be consolidated as Fraunhofer Research Unit. ■

Large-scale events can become a danger in the event of attacks or accidents. © Adobe Stock



Overtaking and turning vehicles, braking maneuvers as well as pedestrian and bicycle traffic make street crossings dangerous.

Multisafe: safety in urban traffic

A contribution by Dr. Corinna Köpke, corinna.koepke@emi.fraunhofer.de

In the project Multisafe (Smart Multimodal Intersection for Traffic Safety), urban traffic situations were recorded and simulated.

The project Multisafe received funding over a duration of twelve months in 2021 through the project Smart Urban Road Safety (SURF) of the transfer initiative Austria of the Sustainability Center Freiburg. The Fraunhofer Institute for Physical Measurement Techniques IPM as well as Fraunhofer EMI were involved. As a first step, urban traffic scenarios at a T-junction were defined, which contained, for example, overtaking, turning and braking vehicles, but also pedestrians and bikes.

Recording of traffic situations

The scenarios were recorded from a diagonally-above view at Fraunhofer IPM using a Sony-Alpha-R7-camera. With the help of a laser scanner, the extracted pictures of the videos were projected to the street level. The traffic participants were detected and their centers of mass on the street were calculated using a neuronal network. Based on the positions of the centers of mass, the positions of the traffic participants on the street could be determined and their trajectories could be established.

Simulation of the scenarios

At Fraunhofer EMI, the scenarios were represented using the ASAM-standard OpenDRIVE and simulated in the simulation environment OpenPASS. The existing behavior models for traffic participants have been analyzed with respect to their suitability to represent the scenarios. A good agreement was achieved when comparing the recorded and simulated trajectories for certain scenarios. Furthermore, first traffic simulations involving the interaction of cars and pedestrians were successfully simulated. The focus of the project was primarily on the non-motorized, vulnerable road users, whose protection is to be increased in the future.

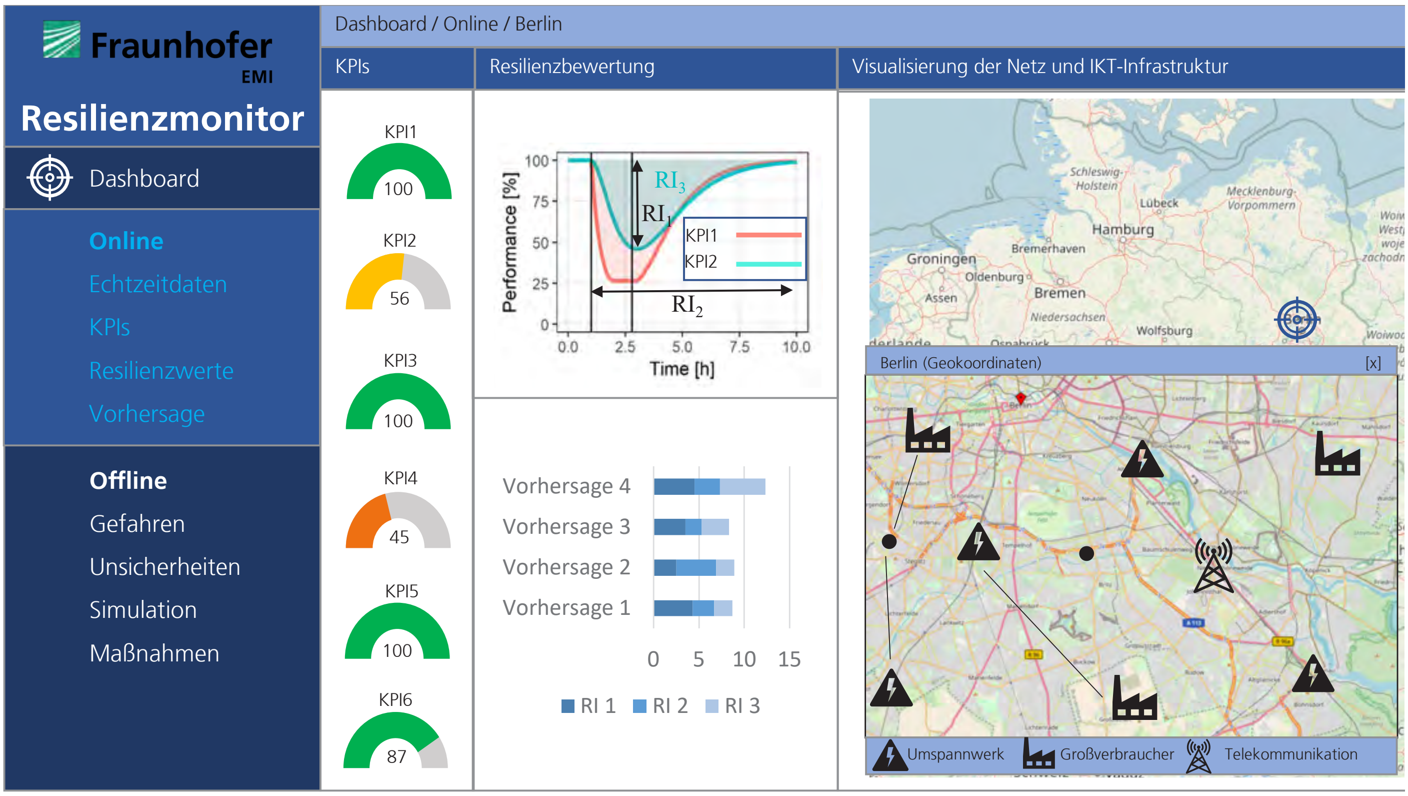
Resilient power grids for the energy transition — RESIST

A contribution by Prof. Dr. Alexander Stolz, alexander.stolz@emi.fraunhofer.de

The energy sector in Germany is facing serious upheavals. As a core element of the energy transition, a completely new structure of the power grid will emerge, characterized by new renewable and decentralized sources and the elimination of large power plants. In addition, the consequences of climate change in the form of increasing extreme weather events represent a stressor for reliable power supply. A future power supply will only be resilient, meaning maintaining its function during and after a disruption, if it remains continuously available across massive disruptions and unexpected events.

If an outage occurs, many people, companies and supply chains will be fundamentally affected. Given the expected changes throughout the system, the critical question is: How can resilience be quantified and operationalized, both technically and organizationally, to ensure a resilient-by-design power supply?

The overarching goal of the RESIST project is to increase the resilience of the power supply. The aspiration here is to develop a toolbox, based on the current structure and operation of the power supply in Germany, that integrates resilience in all phases of the upcoming transformation toward the energy transition and thus makes the resilience of the power supply system measurable, allows it to be displayed in real time, and identifies options for action to optimize system resilience across critical phases.



Possible representation of a resilience monitor.

SATIE: security for European airports

A contribution by Dr. Corinna Köpke, corinna.koepke@emi.fraunhofer.de

The project SATIE (Security of Air Transport Infrastructure of Europe) creates a new philosophy for airport security organizations.

SATIE toolkit

With a duration from May 2018 to October 2021, a total budget of almost 10 million euros and 19 project partners, a toolkit was created in SATIE to increase the security of airports. The results of the project were developed in collaboration with three European airports — Athens (AIA), Milan Malpensa and Zagreb. Threat scenarios were defined, and during corresponding simulations and demonstrations, the end-users were supported by the SATIE toolkit.

EMI contribution

From Fraunhofer EMI, 16 scientists and students were involved in the development of a software to estimate predictions based on alerts created by the SATIE toolkit: The impact of certain threats on the airport infrastructure is assessed and visualized in a graphical user interface. Furthermore, mitigation

At Zagreb airport, the baggage handling system was the focus of a threat scenario. © SATIE

Participants at the SATIE closing conference on Crete in October 2021. The event was held in combination with the 3S Clustering event. Both events focused on security research. © SATIE

measures are compared employing a resilience analysis. The software is based on a network model and an agent-based model. Finally, over the course of the project, four conference papers were published and two master students graduated successfully.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 832969. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein. For more information on the project, see: satie-h2020.eu


STRIKE FACE
This side towards the enemy


STRIKE FACE
This side towards the enemy

"Multischutz" — protection against the effects of terrorist attacks

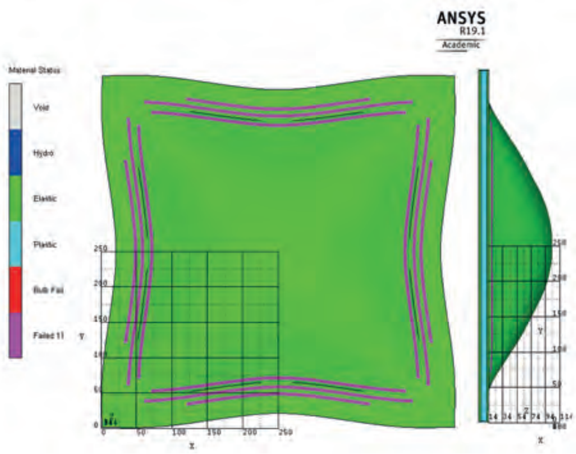
A contribution by Dr. Julia Rosin, julia.rosin@emi.fraunhofer.de

Impact- and blast-resistant fiber composite elements protect people in vulnerable buildings and public places.

Socio-political changes in recent years show: The risk of terrorist attacks in Europe is real. Anyone attending a concert or sports event, or using local or long-distance public transportation, is moving in a public space where an attack is at least conceivable. In the project "Multifunctional Component System for the Protection of Persons against Explosive Events", funded by the German Federal Ministry for Economic Affairs and Energy (BMWi), Fraunhofer EMI, in cooperation with Mehler Engineered Defence GmbH and the German Federal Office of Civil Protection and Disaster Assistance (BBK), has developed a variable protection system for the civil sector. The protection system is designed to retrofit sensitive components, but is also intended to protect public areas of larger crowds against blast and fragmentation effects in mobile applications. In cooperation with the project partners, systems made of fiber composite materials were developed, which were investigated experimentally and numerically at Fraunhofer EMI with regard to specific protection targets.

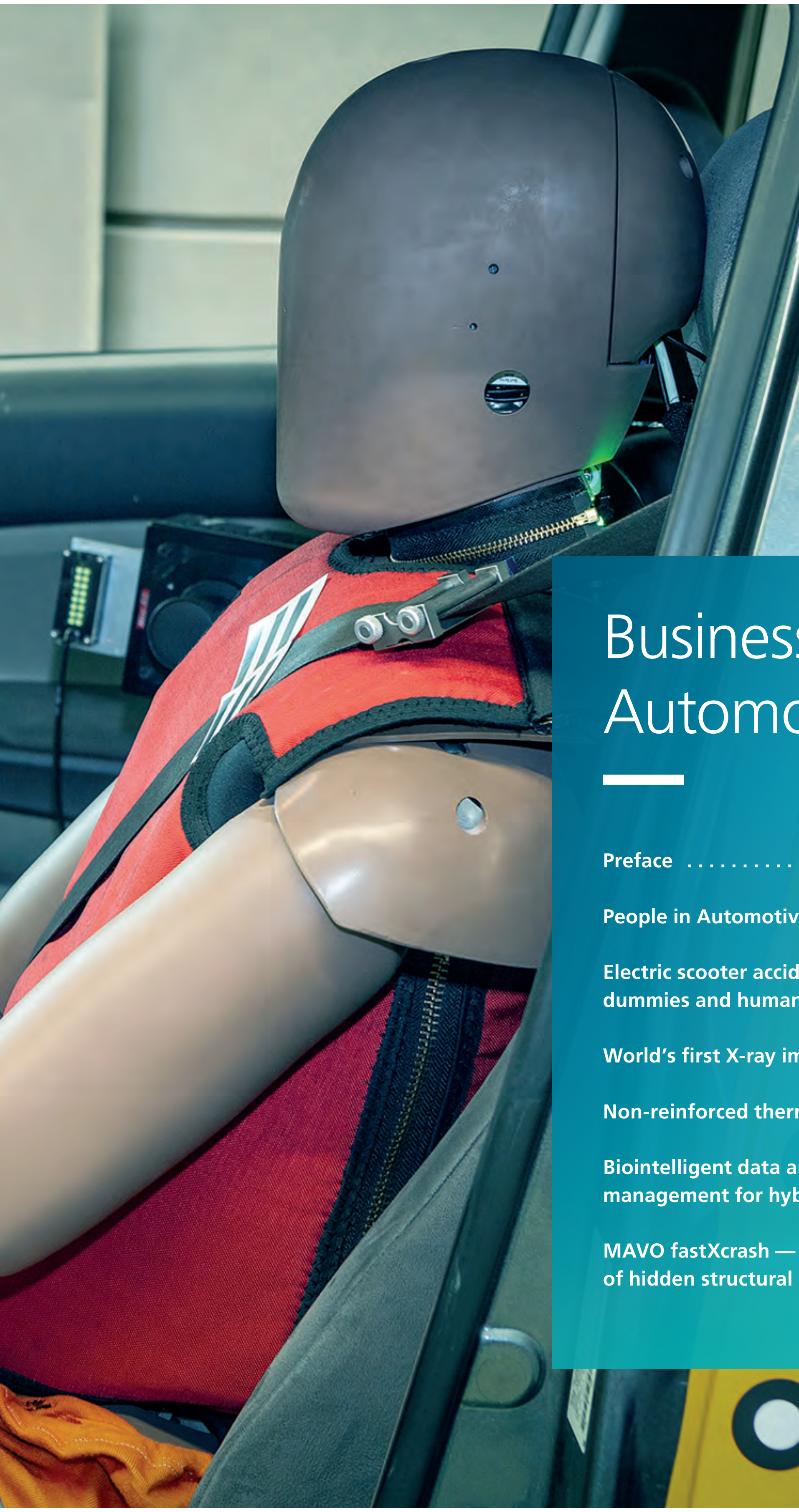
Due to their low weight and high energy-absorption capacity, fiber composite materials are ideally suited for applications to protect against highly dynamic impacts. The layer and ply structure can be adapted depending on the threat scenario. The effectiveness of the protection has been demonstrated in shock-tube and free-field explosion tests. The exact failure mechanism was determined by simulations accompanying the experiments. This enables the structural design for any load scenarios. Further design optimization potential was identified for the connection elements and manufacturing. A software tool was created for practical application. This allows the most efficient configuration of a protection system in the form of lightweight partition walls, pedestrian guidance systems, a new building façade or a retrofit of existing buildings to be determined..

Opposite picture: Free-field explosion tests with the protection structure at the Fraunhofer EMI test site in Efringen-Kirchen. Before (above) and after (below) the test.



Simulation result of the numerical calculations regarding the explosion test.


The risk of head, neck, chest and abdominal injuries is examined using the THOR-50M dummy in X-ray crash tests.



Business unit Automotive

Business unit Automotive

"New technology trends and the continuous shortening of develop-ment cycles lead to ever-increasing demands on vehicle development."

Dr. Jens Fritsch

Dr. Jens Fritsch
Head of business unit Automotive
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Mobility is an essential feature of a modern society. A decisive prerequisite for the approval as well as for the acceptance of new vehicles is still their safety. We are currently experiencing a significant expansion of this term from classic passive vehicle safety — that is crash safety — to active vehicle safety and the safety of autonomous driving functions. New technology trends such as alternative propulsion systems, the constant tightening of approval criteria and ratings and the continuous shortening of development cycles lead to ever-increasing demands on vehicle development. In order to meet these requirements, increasing digitization and virtualization are required to ensure the safety of all road users.

These challenges are being addressed in the business unit Automotive in the various working groups. In the Human Body Dynamics group, for example, the protection of vulnerable road users (VRU) being a critical aspect of road safety is addressed by focusing on the further development of human models in hardware and software. In combination with the possibilities of the crash center of the Fraunhofer-Gesellschaft at the EMI, new, relevant accident scenarios, arising in multimodal, urban traffic, can be examined and evaluated in detail.

People in Automotive research

Here, we present eight individuals from Automotive research — a small sample of the many employees who do excellent work at Fraunhofer EMI.

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Electric scooter accidents — dummies and human body models in action

A contribution by Dr. Matthias Boljen, matthias.boljen@emi.fraunhofer.de, and Patrick Matt, patrick.matt@emi.fraunhofer.de

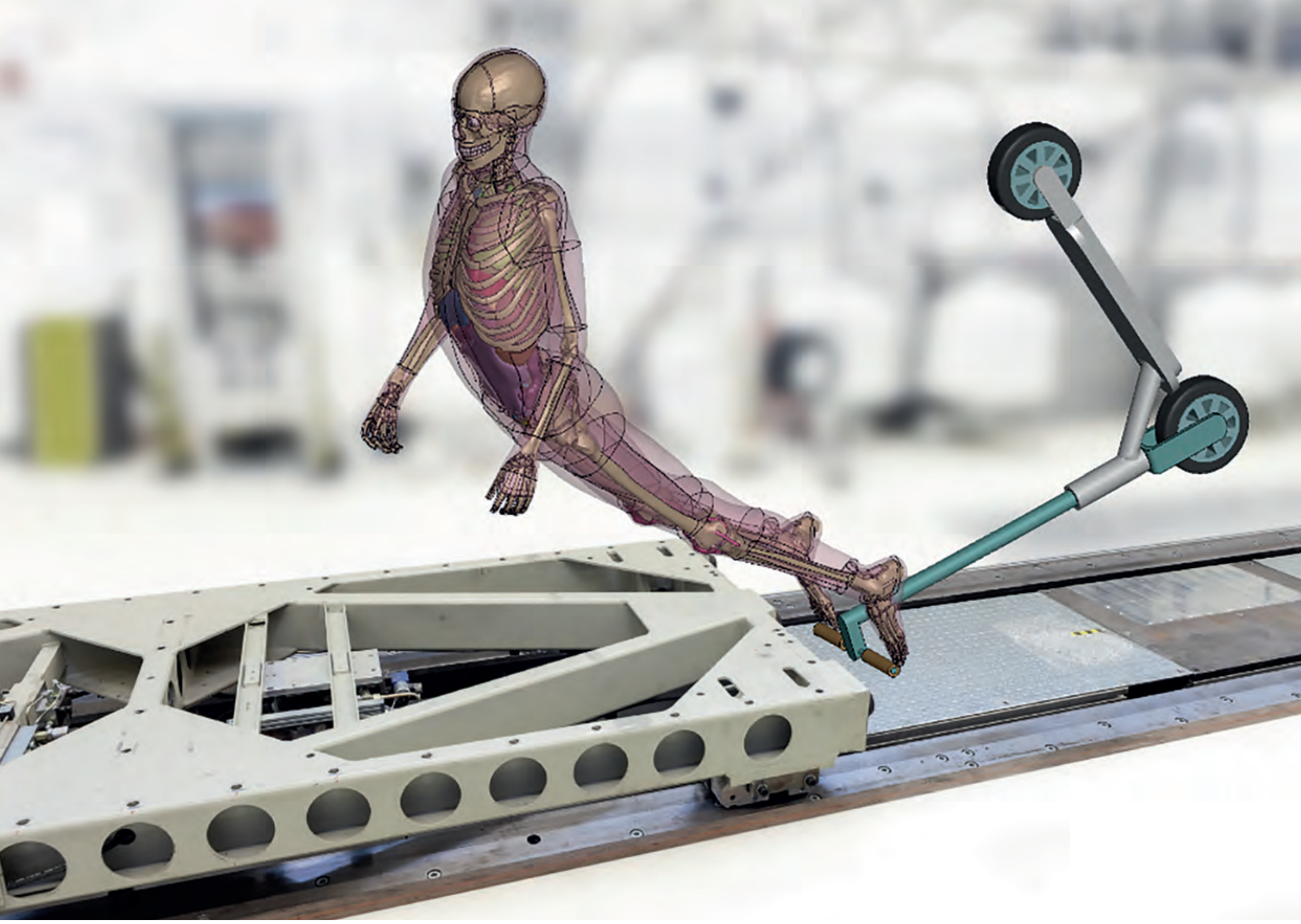
Investigation of accident parameters in single e-scooter accidents with partially surprising results

The ride with an e-scooter is not without danger. The accident statistics 2021 of the German Federal Statistical Office have shown that almost half of all accidents in Germany with personal injury are represented by single accidents. Reason enough to take a closer look at the accidents involving this still young group of vulnerable road users (VRU) in a specific scenario.

In a joint research project with the Fraunhofer Institute for Mechanics of Materials IWM, collisions of e-scooter riders with curbs were reconstructed experimentally and numerically at the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI. Of particular interest was the question if during falls caused in these special scenarios certain body regions are at risk and whether and to what extent protectors can be used to protect oneself in these cases. While the colleagues at IWM focused primarily on material scientific topics around the helmets and knee protectors examined in this study, the colleagues at EMI concentrated on the use of the pedestrian dummy PRIMUS in experiments at the Crash Center of the Fraunhofer-Gesellschaft and the use of the human body model THUMS in simulations in the Human Body Dynamics group. The common goal was to be able to recreate and evaluate the accident process itself both experimentally and numerically.

Test scope and simulation matrix

For the simulation of the accidents, partial models of the e-scooter, the helmet, the knee protectors and curb were created. However, the central component of the simulations was the human rider himself, whose body was also represented via a partial model. In preliminary simulations the human body model was equipped with protectors, moved into the correct body posture and was set with gravitational loading on the scooter so that the correct contact force was applied between the e-scooter and the rider at the time of impact. The crash study included collision simulations at different velocities (10, 20, 30 kilometers per hour) and different impact angles with the curb stone (60 degrees and 90 degrees in the direction of travel). As for the experiment, acceleration profiles were measured inside the head and inside the knees in the simulations, which were then evaluated using various injury criteria.



Kinematics of the fall

The fall itself followed a relatively similar pattern in all the scenarios investigated. At a collision angle of 90 degrees to the direction of travel, the front wheel of the e-scooter gets blocked between the curb and the vehicle. Due to its inertia, the e-scooter acts here like a lever in relation to the rider and catapults him upwards to varying heights depending on the configuration. This effect is less pronounced at an impact angle of 60 degrees. Here, the front wheel skids along the curb, the handlebars tilt sideways, and the scooter flips downwards, which only makes the fall marginally less serious for the rider. The duration of the fall is approximately between half a second and three quarters of a second, depending on the velocity, and the fall distance is between two and five meters.

Relation to test standards

The head impact velocity exceeded the velocity of the scooter for all investigated configurations. This is especially interesting because the head impact velocities predicted by the accident simulations start where the impactor velocities prescribed for the approval of bicycle helmets by the German test standard DIN EN 1078 stop, namely at about 5.4 meters per second. This is an important insight which helmet manufacturers can adopt when designing their products. In addition, the contact points on the helmet can be determined relatively precisely because the simulations can describe the trajectories of the rider prior to impact with the ground, which is also a significant advantage over standardized test regulations in terms of helmet dimensioning and design. ▶

Outline of the setup of an inverse crash test. Sled crashing into the pedestrian dummy standing on the e-scooter (here: visualized by a numerical model).

Limitations and discussion

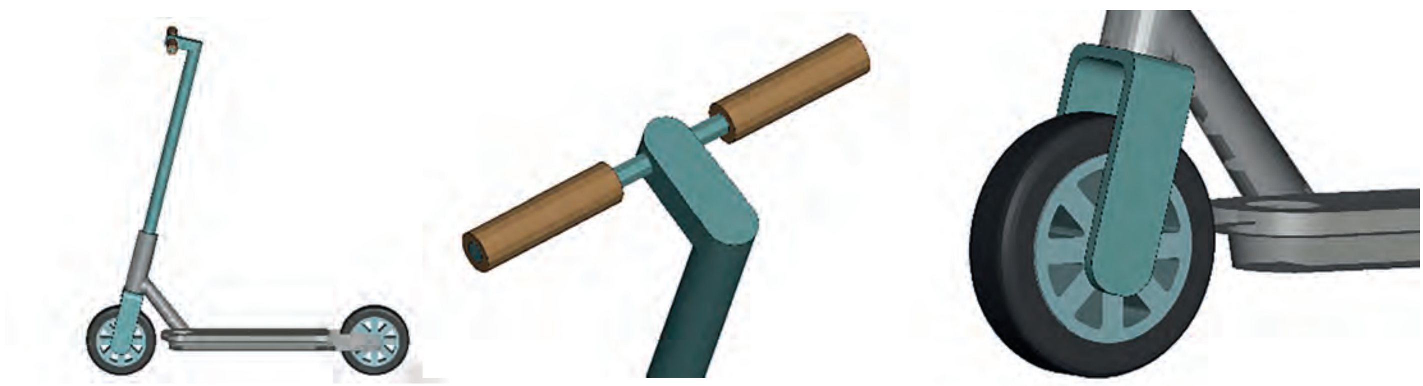
A limitation of the investigations was that both human body model and dummy as methodical tools fall absolutely without reaction during the crash. Reflex movements, as might be expected in reality and which would probably reduce injury severity, could not be modeled. Fortunately, it could be proven in all scenarios except for one that the maximal translational accelerations to the head could be reduced by significant 51 percent to 72 percent by the use of a helmet. However, the simulations also demonstrated that the investigated velocity and impact angle changes resulted in different loading conditions so that by using only one injury criteria no unrestricted universal conclusion can be made. In the bottom line, this can certainly lead to a dilemma: What is the use of the prognosis for the injured person that, on the one hand (according to head injury criterion, HIC), he or she is very unlikely to suffer a skull fracture because of wearing a helmet, but on the other (according to brain injury criterion, BrIC), is still exposed to considerable rotational acceleration loads on the head either way, which may result in permanent brain injuries?

Findings and possible follow-up project

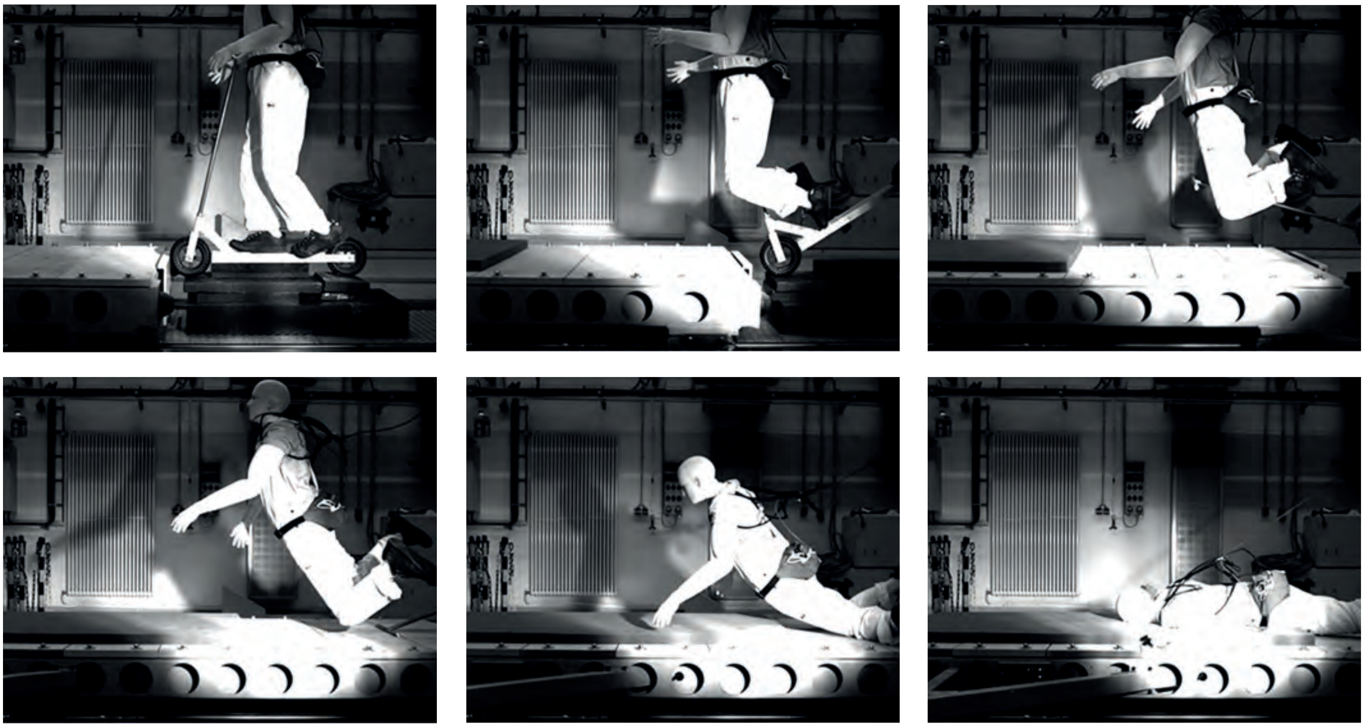
What is certain is that all investigated scenarios have pro-vided added value in that real accident scenarios can be used to examine currently valid test specifications for protectors closely, since the real loading boundary conditions und loading locations can be derived relatively accurately from the accident event itself and become statistically ascertainable. While the experimental test series in the Crash Center has not yet been completed at present, the test results already available so far have essentially confirmed the numerical predictions. The limitation of the still missing reflex movement of the upper extremities affects both experiment and simulation should therefore be the subject of a possible follow-up project.

Outlook and conclusion

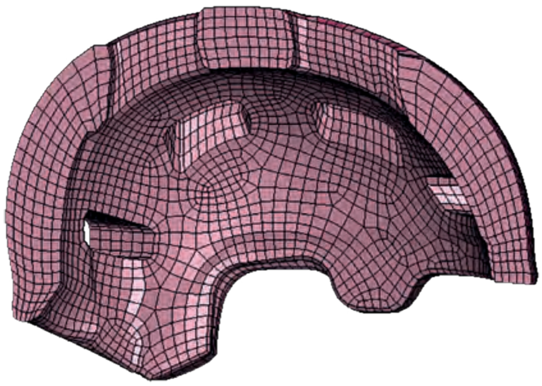
Until then, it is recommended that e-scooter riders should avoid the three most common mistakes made in accidents with personal injury according to the Federal Statistical Office, which, put positively, means: It is advisable to better use the right lane of the road, drive at a speed appropriate to the conditions and participate in road traffic only when sober! A helmet can also provide additional protection, but should not be misinterpreted as an all-round solution for full protection. ■



E-scooter model. E-scooter model resembling the Xiaomi M365 with validated mass distribution according to the original, rotatable wheels and turnable handlebar.



Crash test with the pedestrian dummy PRIMUS from CTS. Sequence of images visualizing the inverse crash at a collision velocity of 20 kilometers per hour against a curb angled at 90 degrees to the direction of travel (image interval about 100 milliseconds).



Longitudinal section through the helmet model. Using reverse engineering, the colleagues at Fraunhofer IWM modeled and characterized the geometry and material data of an up-to-date bicycle helmet. © Fraunhofer IWM

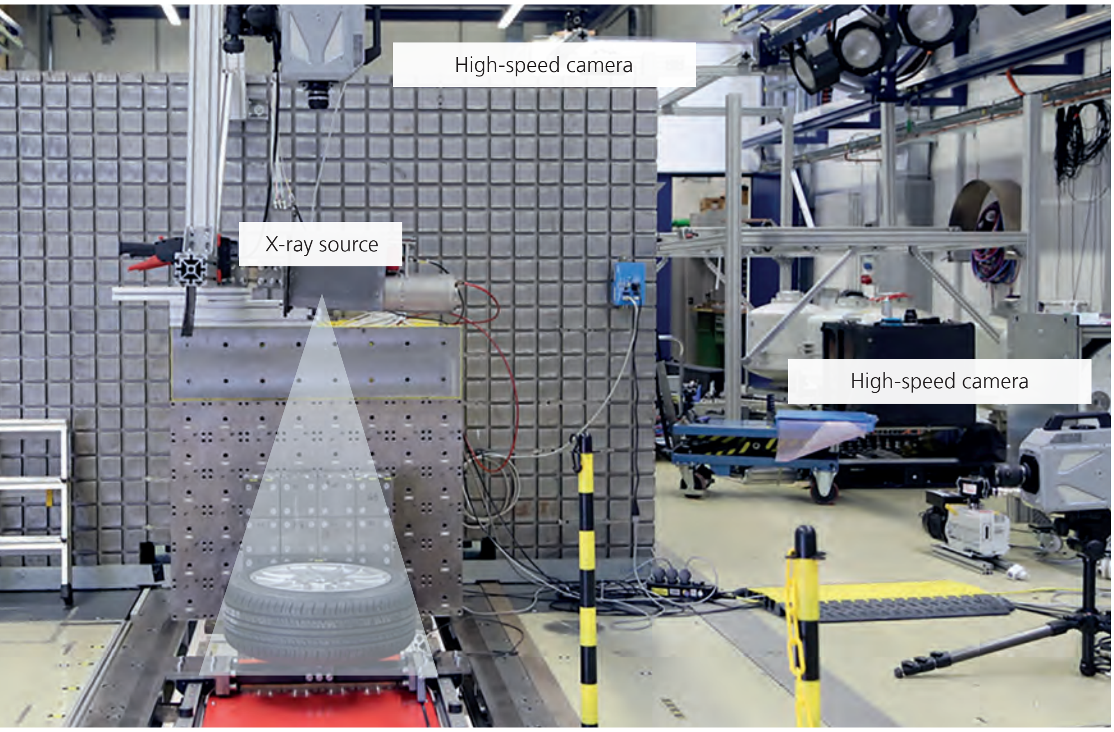
World's first X-ray images of wheel crash

A contribution by Dr. Malte Kurfiß, malte.kurfiss@emi.fraunhofer.de, and Yann Leost, yann.leost@emi.fraunhofer.de

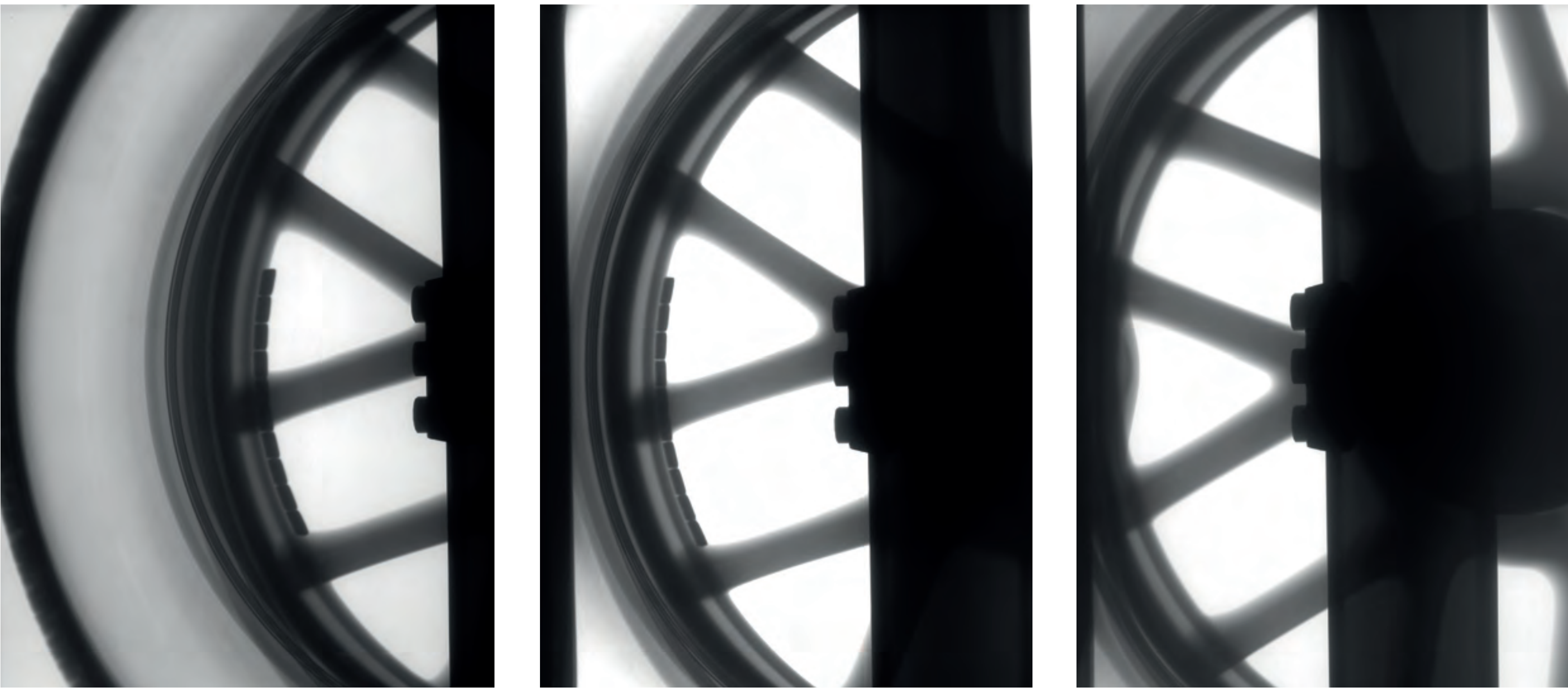
Car wheels might be subjected to severe loading and play an important role in safety, especially in frontal load case such as small-overlap. At Fraunhofer EMI, the world's first X-ray images of wheels during a crash have now been produced as part of a student research project. The experiments were carried out in a specially designed setup at the Crash Center of the Fraunhofer-Gesellschaft at the Efringen-Kirchen location of EMI. This way, spectacular images were created.

Within the scope of the student research project of Benjamin Schütz, a test setup for wheel tests was designed at the Crash Center of the Fraunhofer-Gesellschaft in Efringen-Kirchen for taking X-ray images. These recordings are the world's first X-ray images of car wheels at the moment of crash.

Dr. Malte Kurfiss, supervisor of the work, declares, "With such recordings we get a lot of attention in the professional community. The OEMs (original equipment manufacturers) have a strong interest in observing hidden structures during crash in order to further optimize vehicle safety. Some customers are already waiting in line for our new X-ray source, a linear accelerator, to go into operation."



The picture shows the experimental setup with he high-speed cameras, the X-ray source and the test object



Left: the wheel at rest before the test. Center: X-ray image of the non-destructive test. The tire is elastically deformed, the air in the tire is compressed; there is no so-called puncture, and the rim flange does not touch the impact plate. Right: X-ray image of the destructive test. For this purpose, the wheel was rotated by 90 degrees, so the spokes position is different. The picture shows how the rim flange is deformed and parts have broken off. The steel cables in the tire have been displaced and sheared off at some points.

For Benjamin Schütz, working with X-ray flash technology at the Crash Center was exciting new territory. "It was very exciting and satisfying for me to conceptualize such an experimental setup and then successfully implement the planned tests. This gave me the opportunity to gain many new insights and to grow from them personally."

The work builds upon existing know-how at Fraunhofer EMI. Simulations of vehicle wheels have already been carried out at Fraunhofer EMI by Yann Leost.

Based on these former simulations, the framework conditions of the test rig were defined in such a way that the results of the crash tests are comparable with the simulations. The new feature is the instrumentation with X-ray flash technology.

As shown in the photo, the experimental setup includes two high-speed cameras that take images from above and from the side, and an X-ray source that x-rays from top to bottom. At present, it is possible at EMI to take up to eight X-ray exposures during one test with the aid of the multi-anode tube. The linear accelerator Linac has been put into operation by now. In the new Linac laboratory LiLa (see page 114), as an extension of the Crash Center, the team can also observe and document such processes via X-ray video at one kilohertz.

Link to the video of the third, destructive, test. Here you can see how the tire and rim flange deform, how the air escapes from the tire and how two pieces of the rim break off.

s.fhg.de/video-wheel-crash

Non-reinforced thermoplastics under shear-loading

A contribution by Thomas Haase, thomas.haase@emi.fraunhofer.de

Biaxial shear-tests were used to characterize a non-reinforced thermoplastic up to shear failure.

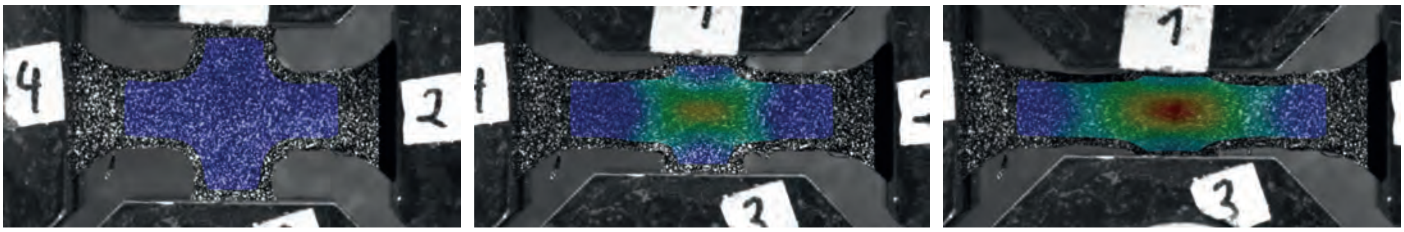
Ductile thermoplastics: an experimental challenge

Due to their very ductile behavior, non-reinforced thermoplastics are often used in automotive engineering. This ductility as well as the low tendency for shear failure of these materials make it hard to characterize their mechanical properties. Especially, the determination of the failure strain under shear-loading is challenging. Typical shear specimens undergo large deformations before eventually failure occurs, however, not under a shear state of stress. Instead, those specimens usually fail near notches under tensile loading. However, to calibrate failure models, the shear failure strain has to be measured.

Biaxial shear-tests as an alternative type of test

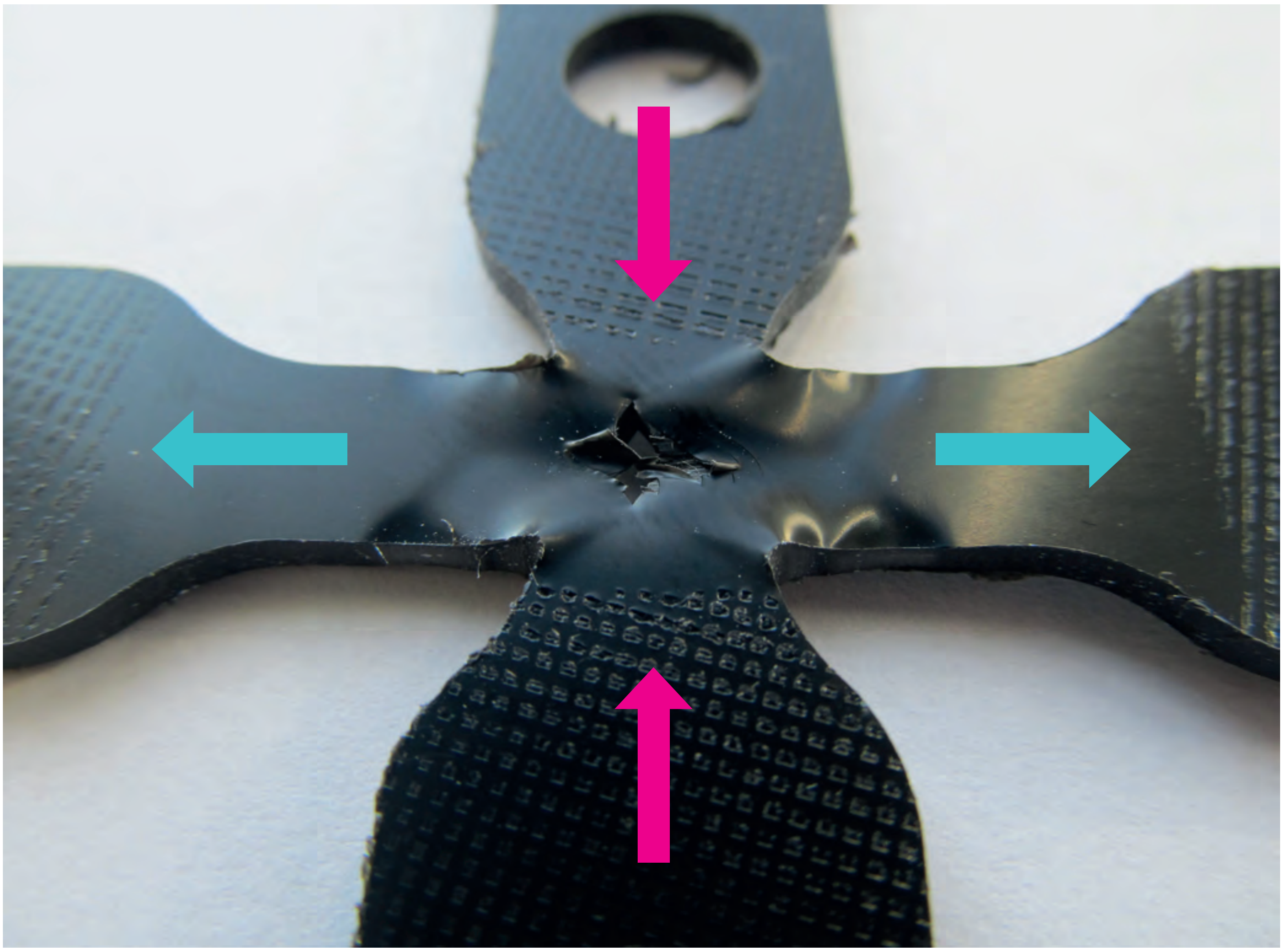
At Fraunhofer EMI, a shear test using a biaxial test facility was developed as an alternative to classical shear tensile tests. A cruciform specimen is stretched in one direction and compressed in the perpendicular direction. This leads to a shear state of stress in the specimen center. The specimen geometry and the displacements of the actuators of the test facility were optimized using finite-element simulations and optimization software such that the shear state of stress is maintained up to large deformations until eventually failure occurs in the specimen center. This biaxial shear test can therefore be used to determine the shear failure strain of ductile thermoplastics.

The complete research results are publicly available in the German report "FAT-Schriftenreihe 353".



t = 0 s *t = 50 s* *t = 112 s*

A biaxial shear-test from the beginning (left) to shear failure in the specimen center (right). The colors represent the shear strain on the surface of the specimen.



Biaxial shear specimen after the test. The specimen was stretched in horizontal direction and compressed in vertical direction. Shear failure occurred in the center.

Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

AiF Forschungsnetzwerk Mittelstand
iGF Industrielle Gemeinschaftsforschung
FAT Forschungsvereinigung Automobiltechnik

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Biointelligent data and knowledge management for hybrid AI

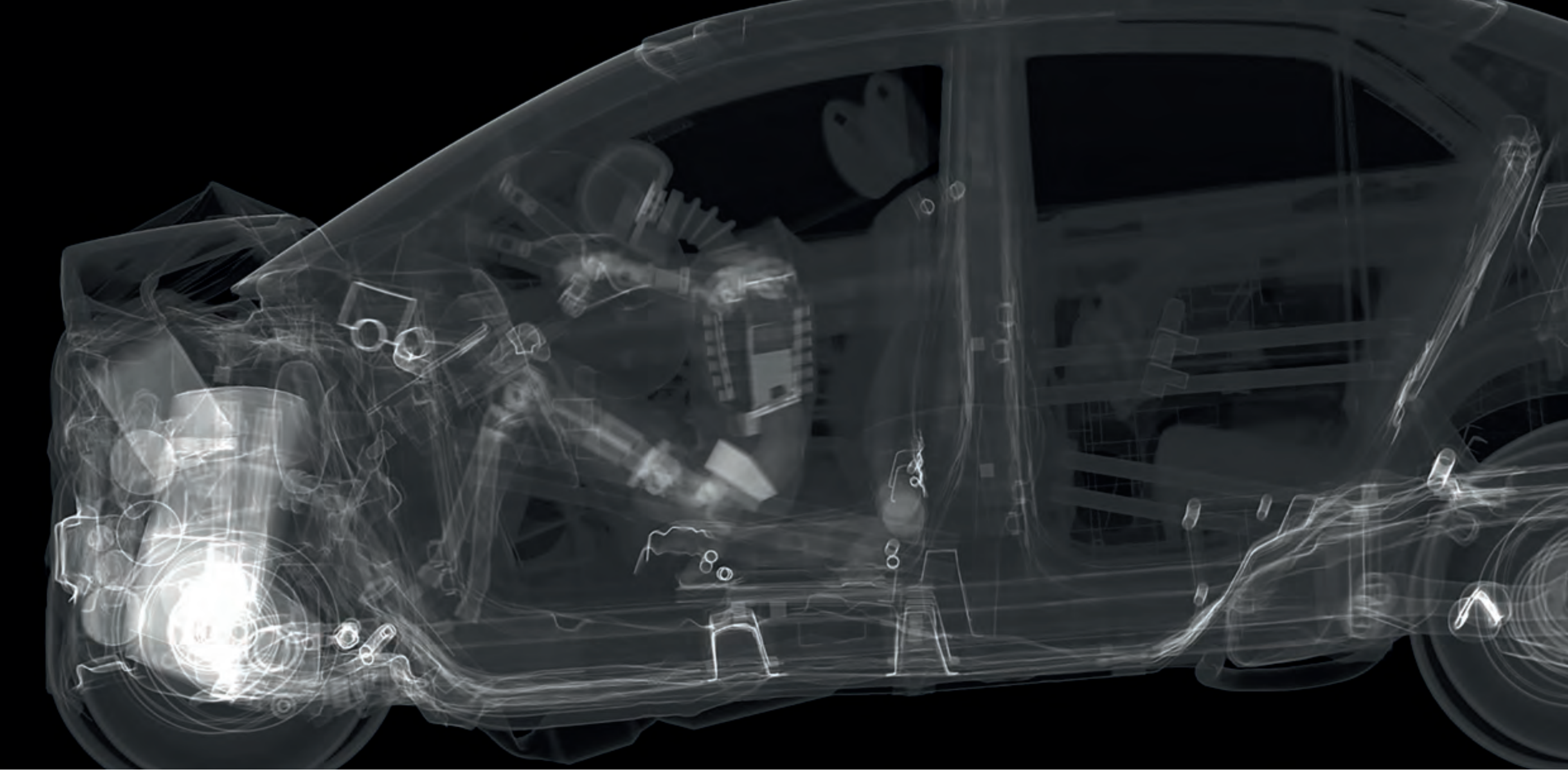
A contribution by Simon Bessler, and Martin Huschka, martin.huschka@emi.fraunhofer.de

Designing data and knowledge management efficiently — biological systems are far ahead of technology.

Biological concepts of data or knowledge management are identified, abstracted, and the feasibility of transferring them to the technical DKM system is examined. © Adobe Stock

Conventional artificial intelligence (AI) methods have significant shortcomings in terms of robustness, explainability, and dependence on available mass data. These disadvantages are to be resolved by a new generation of hybrid, meaning data- and knowledge-based AI. For this purpose, it is necessary to make data and associated expert knowledge accessible in digital form and to manage them jointly. In various projects, Fraunhofer EMI demonstrated that this is already possible in materials science and engineering. However, to take full advantage of hybrid AI, existing data and knowledge man-agement (DKM) technologies need to be further optimized for efficiency.

Biological systems utilize information in a particularly efficient way as the processes involved interact dynamically, adaptively and, above all, systemically linked as well as self-organized. The idea behind the DaWin project is to enable self-organized networking of data and knowledge and thus to establish a system-efficient DKM using biological transformation. In the process, biological regulatory patterns — for example regulation of gene expression — are abstracted and transferred to the DKM in a concrete application case in the field of additive manufacturing of lightweight aluminum components. It is the goal to obtain a biointelligent DKM to enable hybrid AI.



Visualization of dynamic X-ray diagnostics based on crash simulation of a Toyota Yaris with an occupant dummy (Hybrid-III-Dummy). The simulation was carried out with the software LS-DYNA (Livermore Software Technology Corp.) using the 2010 Toyota Yaris Finite Element Model (CCSA).

MAVO fastXcrash — X-ray view of hidden structural deformations

A contribution by Dr. Jens Fritsch, jens.fristch@emi.fraunhofer.de

New method of spatially and temporally high-resolution visualization of dynamic deformation processes of internal crash management structures.

Successful project completion of the Fraunhofer MAVO research project fastXcrash

As part of the Fraunhofer research project MAVO fastXcrash, a new measuring and evaluation method has been developed together with the Fraunhofer Development Center for X-ray Technology EZRT, which enables the observation of the dynamic behavior of hidden vehicle structures under crash loads using X-ray diagnostics. With the help of such a method, valuable information for the validation and optimization of numerical crash simulations can be recorded during the vehicle crash.

In cooperation with the partners at EZRT, the researchers were able to develop both the hardware and software components required to implement such a method into a crash test environment. In the field of measurement technology, an X-ray detector optimized for the specific area of application could be successfully developed and put into use.

A novel method for generating simulated X-ray images based on finite-element crash simulations was developed by the project team. It allows both for the optimization of the test setup as well as for the comparison of the numerical crash simulation with the experiment. The image data collected can be evaluated with the help of algorithms developed in the project for the automated detection and tracking of distinctive vehicle features.

In this way, the deformation behavior of selected crash structures can be reconstructed in the experiment and compared to the associated crash simulation.

At EMI, we develop our own nanosatellite ERNST.

Business unit Space

Business unit Space

"We apply unique methods for improving safety in space travel. We develop scientific payloads and resilient small satellite systems for innovative applications in Earth observation."

Prof. Dr. Frank Schäfer

Prof. Dr. Frank Schäfer
Head of business unit Space
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s.fhg.de/emi-space

The Longwave Infrared Sensing Demonstrator LisR was launched on February 19, 2022, from Wallops Flight Facility to the International Space Station. LisR is a novel scientific camera that images the Earth at two different wavelengths in the thermal infrared light spectrum. The information derived from these images will be used to optimize water consumption in agriculture. LisR has been developed by Fraunhofer EMI and its spin-off ConstellR, with significant contributions from Fraunhofer IOF and from SPACEOPTIX. The demonstration of the measuring principle of LisR lays the foundation for ConstellR's upcoming thermal infrared microsatellite constellation, which will monitor globally the land surface temperature (LST). LisR is also demonstrating EMI's capability to develop compact scientific payloads based on high performance commercial components.

The installation of the new clean room facility in spring 2021 was an important milestone for all research and technology development activities related to scientific optical payloads and small satellite systems. Currently, the flight model of ERNST is integrated there.

For the first time since Apollo 17, within its Artemis program, NASA aims at launching astronauts to the moon and installing a moonbase. For the long flight phase, the crew needs windows, primarily for taking pictures and for making the flight to the moon a pleasant event. EMI's contribution to this mission is to investigate the safety of the window design against hypervelocity impacts of meteoroids and space debris.

Collisions in space are of growing concern for the safety of spacecraft. This is especially true for spacecraft in low Earth orbits (LEO) because of the significantly increasing number of commercial spacecraft in constellations in these orbits leading to the creation of more space debris. With our experimental hypervelocity impact test capabilities and our quantitative risk assessment methods, we support our customers with quantifying impact risks and developing innovative protective solutions for their space systems. In our impact labs, we closely look at the progress of damage during impact of millimeter- to centimeter-sized projectiles. We use numerical simulation tools to investigate large and complex scenarios, such as the collision and fragmentation of two spacecraft.

People in Space research




Here, we present four individuals from Space research — a small sample of the many employees who do excellent work at Fraunhofer EMI.

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LisR successfully arrived on the International Space Station ISS

A contribution by Marius Bierdel, marius.bierdel@constellr.space

Since February 21, 2022, LisR, a newly developed instrument for measuring the water demand of agricultural crops, has been located outside the the International Space Station (ISS). What began in 2017 just as an idea has now become reality. With the LisR measuring device, Fraunhofer EMI and its spin-off ConstellR have laid the foundation for a future satellite constellation that will make it possible to measure the land surface temperature of our planet on a daily basis and thus optimize the use of water in agriculture.

Saving water in agriculture: "More crop per drop"

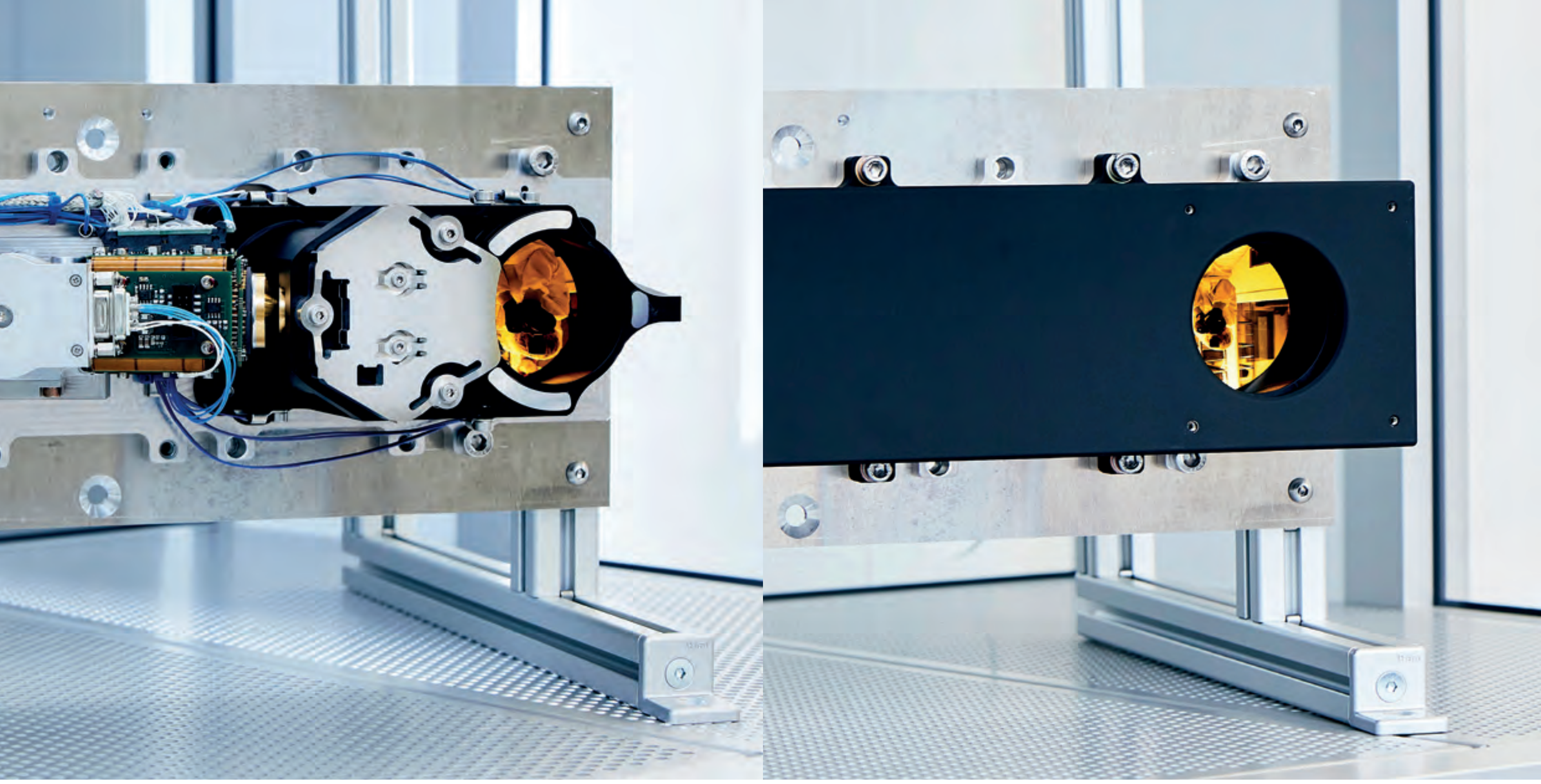
The goal of ConstellR is to set up a constellation of small satellites from 2023 onwards that can help make agriculture, and thereby food stability, more efficient. The measured land surface temperature of the Earth is an important factor for the health of agricultural land. The new measuring systems provide high-precision thermal infrared images that can be used to determine the health status and water demand of crops.

An impending drought can thus be detected at an early stage and prevented by targeted irrigation. This method reduces the amount of water used to irrigate fields while increasing the crop yield per liter of water used. "More crop per drop" is the motto. The data from the map recordings are accurate to within 50 meters and will be shared with smart farming companies, which can then provide information to those operating the farmland.

LisR mission on the ISS demonstrates newly developed technology for high-precision measurement of land surface temperature

The technology demonstration on the ISS represents an important step in the realization of the satellite constellation. With the help of this mission, the technological risk of building the satellite constellation will be drastically reduced. In doing so, the basic functionality of the later satellites is already demonstrated within the LisR mission, without having to develop, build and send an entire satellite into orbit.

The LisR measuring instrument essentially consists of three different core components, the data processing or power supply unit, the thermal infrared detector and the metal mirror optics. All these components are enclosed in a specially painted aluminum box, which guarantees efficient heat dissipation thanks to its black color.



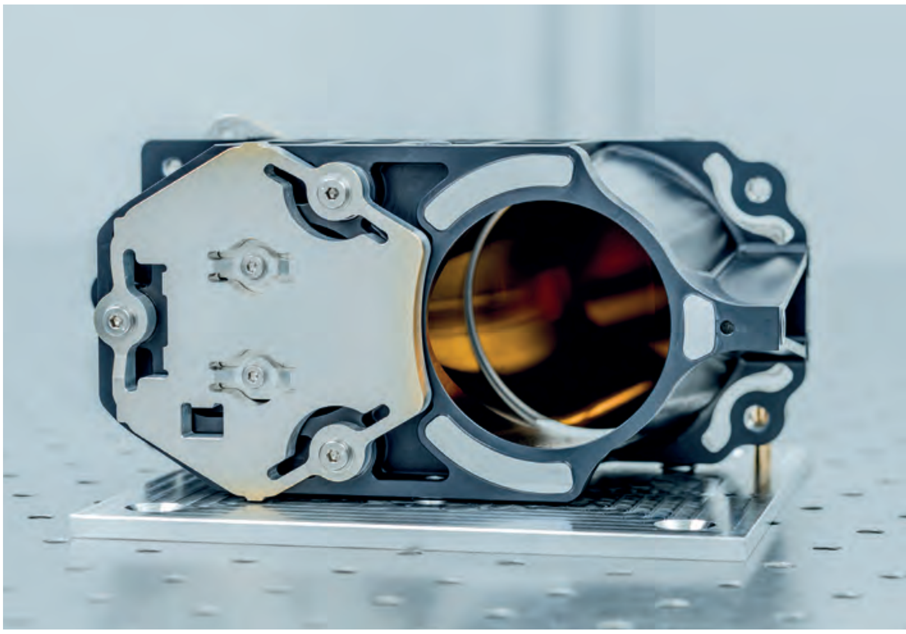
The instrument open (left) and in its box (right), where it was bolted to the ISS platform.

However, before LisR came to the ISS, the measuring instrument had to undergo extensive tests at Fraunhofer EMI, Airbus, NASA and Nanoracks.

The tests included the software, electronics and mechanics of the measuring instrument. Among other things, the loads that occur during launch due to vibrations of the rocket were simulated on a so-called shaker table, and the behavior of the measuring instrument was tested at low and high temperatures under vacuum conditions in a thermal vacuum chamber at Fraunhofer EMI. The final tests to characterize the electromagnetic properties were carried out from November 15, 2021, to December 1, 2021, at the Space Center in Houston, USA. After successful tests in Germany and the USA, LisR was officially handed over to NASA on December 17, 2021.

Successful launch to the ISS and commissioning of the LisR technology demonstrator

And then the time had come: On February 19, 2022, LisR was flown to the ISS aboard an Antares rocket from Wallops Island, Virginia, USA, with the supply flight NG-17. The team around the founders Max Gulde, Christian Mittermaier and Marius Bierdel were able to experience the launch on site and were pleased about a textbook launch of the rocket. ▶



The optics of the measuring instrument consists of specially formed metal mirrors, which have been machined with nanometer precision and coated with a layer of gold. © Fraunhofer IOF

After final quality control, the mirror optics is handed over to Marius Bierdel (center) by Henrik von Lukowicz (left) and Matthias Beier (right) in the Fraunhofer IOF clean room. © Fraunhofer IOF

LisR was installed on the Nanoracks External Platform (NREP) on March 9, 2022, by US astronaut Kayla Barron. For this purpose, the NREP platform was transported into the interior of the ISS with the help of a robotic arm in order to then install the new measuring instrument LisR on it. After the successful installation, LisR was activated for the first time on March 16, 2022, and has been recording the first data since then. After a four-week commissioning phase during which various system tests are carried out, LisR will continuously monitor the Earth's land surface temperature from mid-April 2022. This data is then regularly sent back to Earth for further processing and forms the basis for the various application goals of ConstellR: among other things, detecting changes in plant health, more efficiently irrigating agricultural land and ultimately a higher crop yield.

This ambitious project would not have been possible without the help of a broad network of supporters

The realization of the LisR project in less than twelve months was only possible due to a close cooperation of Fraunhofer EMI with its spin-off ConstellR. With the support of the Digital Innovation Hub Photonics (DIHP), part of the measuring instrument, namely the optics, was developed by the Fraunhofer IOF and manufactured by its spin-off SPACEOPTIX. The LisR project was supported by EXIST funding from the Federal Ministry for Economic Affairs and Energy (BMWi), now: Federal Ministry for Economic Affairs and Climate Protection (BWK).

ConstellR founding team: (left to right) Marius Bierdel (CTO), Dr. Max Gulde (CEO), Christian Mittermaier (CFO) celebrate after the successful launch of their first space mission on Wallops Island, Virginia, USA. © ConstellR

What's next? Big future plans with small satellites

A look into the future: LisR is a technical demonstrator. The next step will be to put two microsatellites into orbit at the end of 2023, followed by two more in 2024.

Scalable, commercial crop water monitoring and smart agriculture will help achieve the goal of greater food security for people.

By 2028, 16 satellites with ConstellR technology are to support the irrigation of agricultural land in Earth orbit. The ongoing miniaturization of the technology required for this purpose makes it possible to develop microsatellites the size of a shoebox, which are powerful and robust, in order to implement satellite constellations of this type at low costs. Previous satellite systems for monitoring the surface temperature of the Earth are often as big as a bus and sometimes cost more than a billion euros per mission. The ConstellR technology makes it possible to carry out such missions for a fraction of the cost. From 2026, 180 billion tons of water and 94 million tons of CO_2 could be saved annually, while global crop yields could increase by up to four percent without higher water consumption. This would be enough food for over 350 million people. ■

Facts about the measuring instrument LisR

- LisR — Longwave Infrared Sensing Demonstrator
- Weight no more than 6 kilograms
- Size approximately 40 centimeters by 10 centimeters by 10 centimeters
- Launch date February 19, 2022
- Installation on Nanoracks External Platform (NREP) March 9, 2022, by astronaut Kayla Barron
- Commissioning on March 16, 2022
- First land surface temperature data since mid-April 2022
- Nanoracks is the service provider that supplies the test platform outside the ISS

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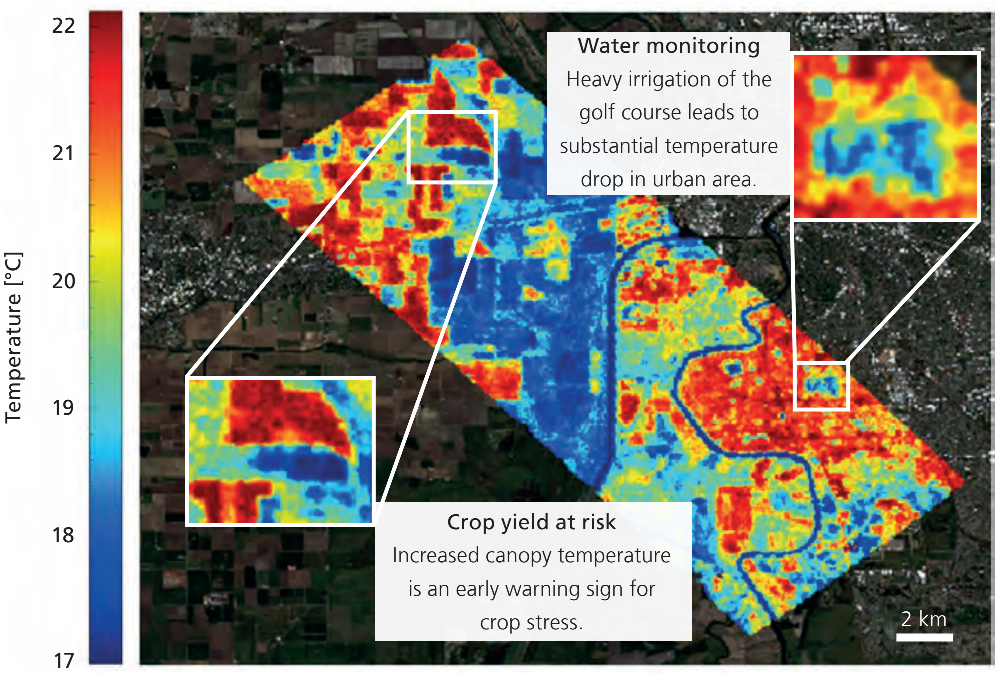


One of the first LisR images shows temperature data from Sacramento in California, USA. © ConstellR

A relaxed vista into space — thanks to our experiments

A contribution by Robin Putzar, robin.putzar@emi.fraunhofer.de

Illustration of the Lunar Gateway, the space station of the Artemis program. © A. Bertolin, NASA

Fraunhofer EMI has qualified window elements against micrometeoroid impacts for mankind's return to the moon.

Equipping modules for astronauts with window elements is a reasonable design choice. Since they are part of the outer wall, window elements are likewise endangered by impacts of micrometeoroids, close to Earth also by space-debris particles. Due to the high encounter velocities in the solar system, even small particles having a size of a few millimeters can cause significant damage. To assess crew safety, the protective capabilities of all outer wall elements, including the windows, needs to be known.

On behalf of Thales Alenia Space, Fraunhofer EMI has tested window elements for the Artemis program. The aim of this NASA-led program is to return humans to the moon. The window elements consist of three layers. The outermost layer is made of fused silica glass. Due to its small thermal expansion, this layer tolerates well the large temperature variations in space. Since fused silica glass is brittle, a second layer is required to absorb the high energies released during an impact event. This second layer is made of acrylic and is positioned with some distance to the fused silica glass. The third and innermost layer is also made of acrylic. This layer sustains the inner atmospheric pressure of the module. Therefore, no damage to this last layer is tolerated following an impact event.

In the experiments, the protective capabilities of the window elements were characterized accurately. This characterization allows our customer to precisely quantify the risk for the crew with respect to impacting particles.

Working in the clean room has to follow strict procedures to keep the concentration of airborne particles low.

New clean room for space-flight research

A contribution by Clemens Horch, clemens.horch@emi.fraunhofer.de

Since early 2021, a new clean room has been available in EMI's Satellite Lab for use in space-related projects. Currently, the EMI satellite ERNST is being integrated in this facility.

Since early 2021, Fraunhofer EMI has been equipped with its own clean room for space-flight research. Clean rooms are required in this field for fulfilling the cleanliness requirements of optics and mechanisms during the integration of flight hardware and for qualification and functional tests before launching items to space. Even the smallest dust particles can degrade the performance of sensitive space-grade instruments. The largest sources for dust in room air are generally humans and their clothing. Therefore, special work clothes and cleaning procedures are part of the operation of the clean room as well as air-filtering systems.

The EMI clean room is equivalent to the ISO 7 classification. Per cubic meter of air, no more than 3000 particles larger than 5 micrometers are allowed. This is a reasonable compromise for the projects of EMI. Even higher clean room classes, as they are common in, for example, semiconductor manufacturing, increase the cost for construction and operation significantly. For all relevant work, especially in the New Space segment, the chosen classification is appropriate and constitutes significant increase in the capabilities of EMI.

Currently, the integration of the EMI nano-satellite ERNST is in progress. Its main payload is an infrared imaging system for the detection of missile launches. Before that, the ISS payload LisR has been integrated and tested successfully in the clean room. LisR is a joint project of EMI and its spin-off ConstellR.

ERNST — integrating the flight model

A contribution by Dr. Martin Schimmerohn, martin.schimmerohn@emi.fraunhofer.de

The development of the ERNST nanosatellite is entering the final phase in 2022 with the integration, testing and delivery of the flight model.

The ERNST nanosatellite is pioneering in different fields: It is the first satellite developed by Fraunhofer, the first small satellite to support military tasks for the German armed forces, and the first CubeSat, the size of half a beer crate, which will use a cryogenically cooled infrared payload to perform tasks as complex as detecting rocket launches.

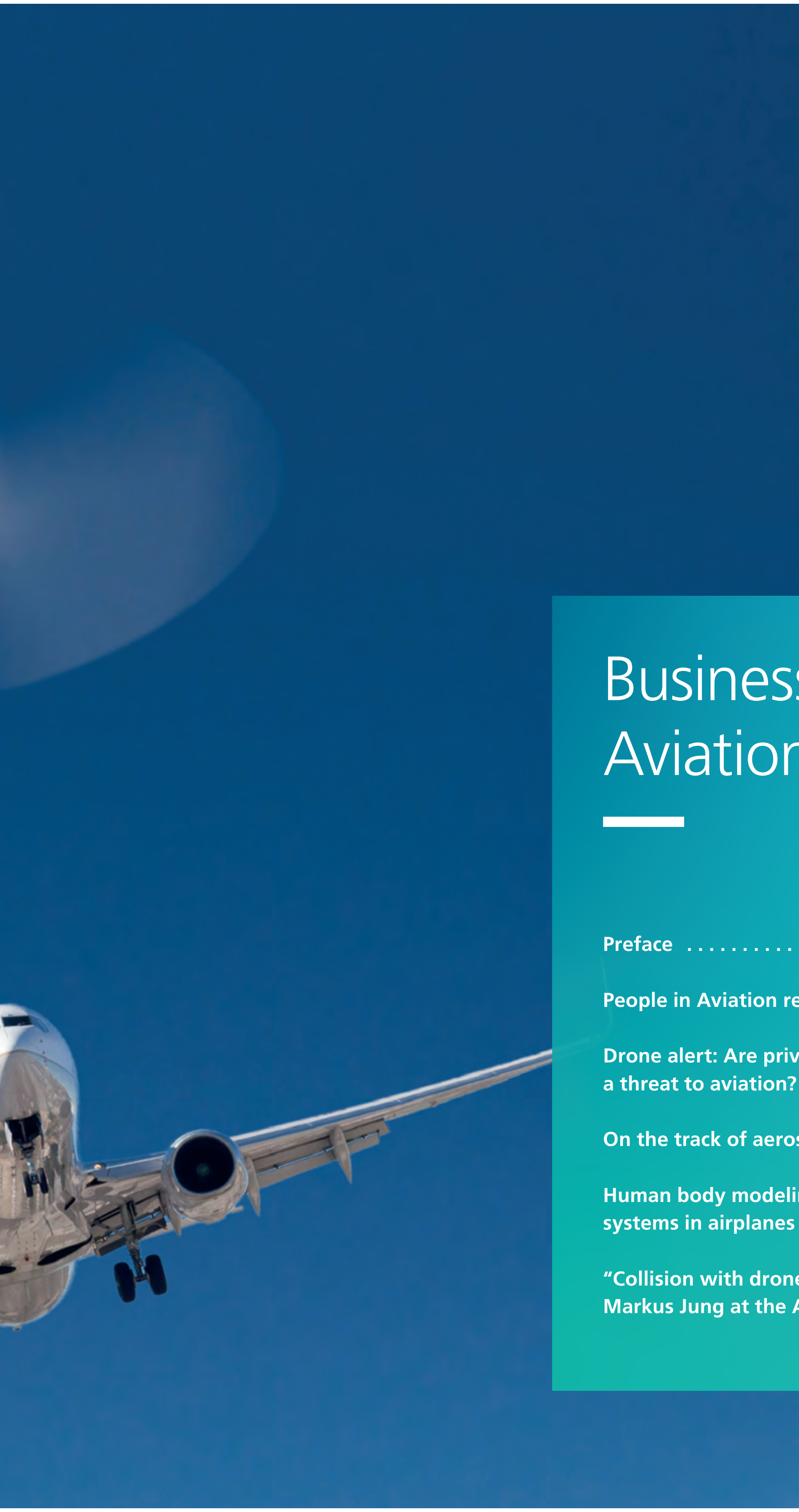
The ERNST satellite design and the implementation of its subsystems was successfully accomplished last year, despite the pandemic situation and resulting supply chain issues. The design freeze after the critical design review marked the transition to the integration phase starting at subsystems and payload level. Critical components such as the cooler-detector unit, the attitude control system and even

The filters of the filter wheel are inserted into the optical path between the optics and the detector module, to extend the field of view in different spectral ranges to be recorded.

ERNST infrared payload integrated with detector-cooler unit, filter wheel and optics in the additively manufactured optical bench.

a deployable braking sail were completed for the flight mission and subjected to functional tests. With the completion of a clean room and extended vibration and thermal-vacuum testing capacities in the integration laboratory, the way is paved for integrating the ERNST flight model that will be launched into orbit in 2023.

The increasing number of aerial drones in airspace poses a threat to aviation. © Adobe Stock



Business unit Aviation

Business unit Aviation

Each year, millions of people travel by plane — let it be for meeting business partners or reaching their holiday destination with the family. It is therefore no surprise, that the safety of passengers is of upmost importance for regulatory bodies, such as EASA, and the aviation industry. Researchers at Fraunhofer EMI also strive to contribute to the promotion of safety in civil aviation. The following two articles address novel, safety relevant scenarios for aviation. The first article describes analyses of potential threats imposed by privately piloted drones, which may cause damage to aircraft or rotorcraft in case of a collision. The results of these analyses were presented at an international conference and attracted quite some interest amongst the audience (see final article). The second article deals with a topic, which has kept the world in suspense since March 2020: spreading of aerosols in closed environments, such as a classroom or an aircraft cabin. The third article describes the development of a prototype belt system for increasing the safety of infants during an unplanned, hard landing.

Enjoy reading!

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People in Aviation research

Here, we present five individuals from Aviation research — a small sample of the many employees who do excellent work at Fraunhofer EMI.

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4 Dr. Matthias Boljen
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Drone alert: Are privately piloted drones a threat to aviation?

A contribution by Dr. Michael May, michael.may@emi.fraunhofer.de

Approximately 400,000 privately piloted drones are operated in German airspace. Accidental collisions with an aircraft or a rotorcraft are deemed inevitable.

Silence at Gatwick Airport

During December 2018, there is remarkable silence at Gatwick Airport, one of the ten largest airports in Europe. What had happened? After several sightings of drones near the airfield, air traffic was suspended for two days. How dangerous are privately piloted drones for aircraft and rotorcraft? Researchers at Fraunhofer EMI are trying to answer this question within the project RumTrain, which is funded by the Federal Ministry for Economics and Climate Action.

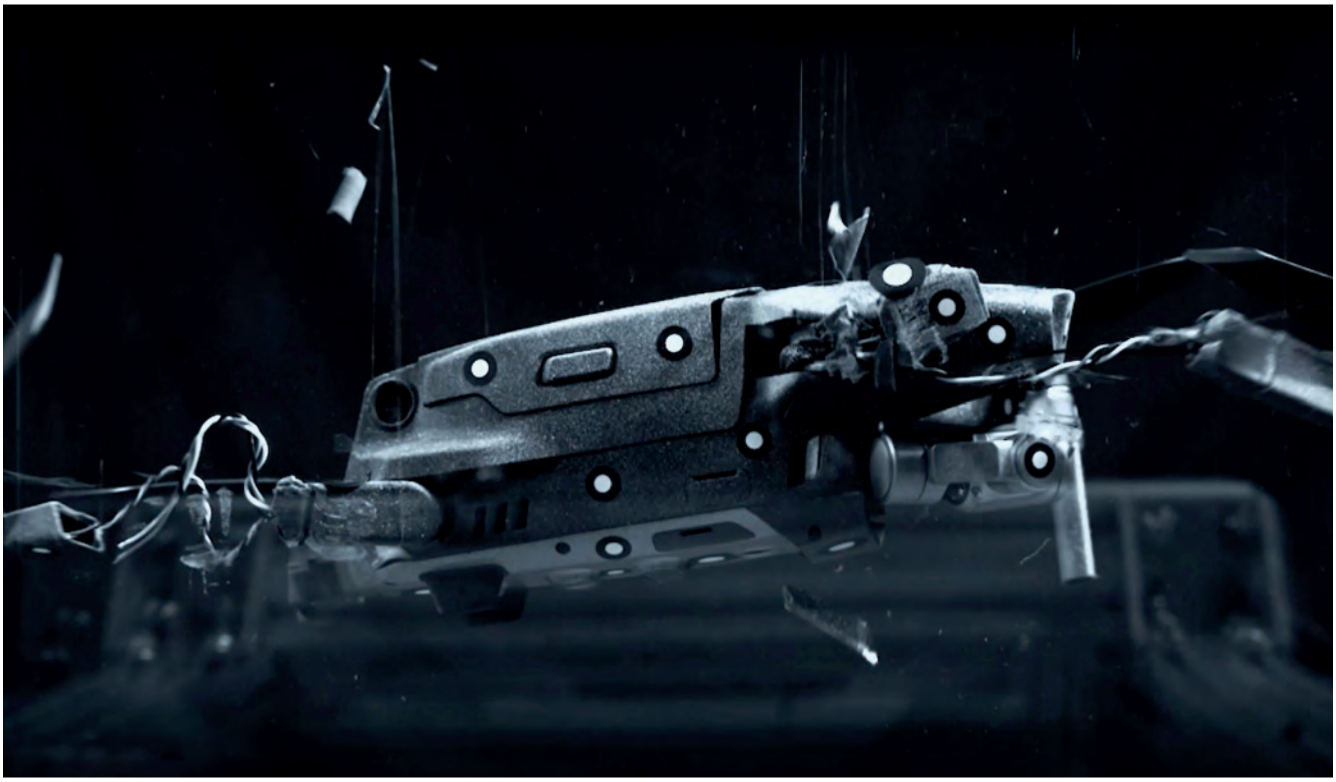
The DJI Mavic 2 Zoom — a representative privat-purpose drone weighing approximately one kilogram.

Initial results

In comparison to birds, for which the threat to airborne structures is well-known and considered during the design phase, drones are characterized by higher strength and stiffness due to the individual components (for example batteries, motor, cameras). Therefore, for a collision scenario, drones cause higher damage. In order to evaluate potential damage caused by drones, several components of the commercially available drone DJI Mavic 2 Zoom were characterized under quasi-static and dynamic loading conditions.

The first results indicate, that amongst the selected components of the drone (battery, motors, camera), the battery poses the highest threat for aviation due to the combination of high mass and stiffness. Future work is therefore going to focus on predictive modeling of the behavior of batteries in order to contribute to aviation safety.

Potential collision scenario involving a drone and an aircraft. © Adobe Stock



Collision of a drone with a windshield-type structure.

Classrooms are a prime example of indoor spaces where many people gather every day over a long period of time.
© Adobe Stock

On the track of aerosols — Fraunhofer vs. Corona

A contribution by Dr. Pascal Matura, pascal.matura@emi.fraunhofer.de

What role do respiratory aerosols play in the corona pandemic, how do they spread indoors, and what protective measures help effectively?

Transmission of the SARS-CoV-2 virus can occur not only via larger droplets emitted when sneezing or coughing, but also via very small aerosol particles produced primarily when speaking or breathing. This transmission route is of great importance because aerosol particles can spread over long distances due to their long residence time in the air and thus accumulate over time, especially in poorly ventilated indoor spaces.

In this context, the dispersion and distribution of aerosols depends on the typical flow conditions in the indoor spaces under consideration, which are very different in aircraft cabins, open-plan offices or classrooms. Therefore, effective and practicable protective measures are needed that consider the specifics of the corresponding indoor spaces. While air conditioning systems in aircraft cabins can make a valuable contribution to indoor hygiene by supplying fresh air and appropriately filtered recirculated air, only a very small number of schools in Germany have central ventilation systems. This raises the question of how to

effectively counteract the accumulation of aerosol particles and thus reduce the risk of infection.

Therefore, we used experimental methods, detailed literature studies on respiratory aerosols, and complex numerical flow simulations to shed more light on aerosol dispersion using a classroom as an example: This allowed us to systematically investigate the effectiveness of window ventilation options and, most importantly, the effect of a room air cleaner and the influence of its positioning on aerosol concentration.

Conclusion
The investigations show: Room air cleaners and proper ventilation can significantly reduce indoor aerosol concentrations and thus significantly reduce the risk of infection. Looking to the future, the topic of indoor air hygiene should be given appropriate priority in the planning and implementation of renovation and new construction projects — and not just for school buildings.

By the way, the methods developed can, in principle, also be applied to other indoor spaces, such as theaters, supermarkets and aircraft cabins.

Voluntary homework: Why not visit our German website to find out more about our work in the AVATOR project?

s.fhg.de/emi-avator

Human body modeling of infants — restraint systems in airplanes

A contribution by Dr. Mathieu Imbert, mathieu.imbert@emi.fraunhofer.de, and
Dr. Matthias Boljen, matthias.boljen@emi.fraunhofer.de

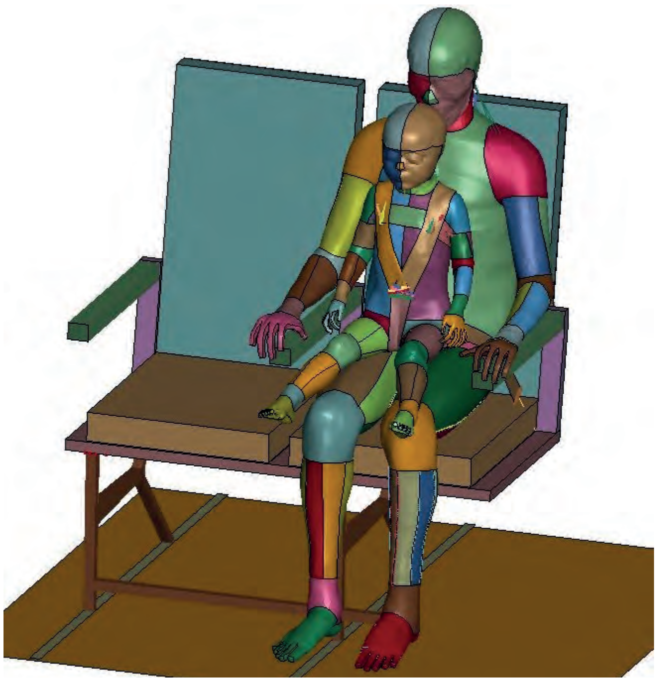
Human body modeling has been used to optimize the restraint system for babies currently in use in the European airspace.

Loop belts are currently required in European airspace as a minimum safety standard for buckling up children under 24 months of age. With this system, the infant is placed on the lap of the adult person and "secured" to that person's lap belt by an additional belt buckled around the abdomen. This double seat occupancy offers economic advantages for the travelers and ecological advantages due to the higher utilization of the aircraft. However, it is not optimal from a safety point of view, because in the event of an emergency landing, dangerous stresses can act in the abdominal area of the child. In this context, an alternative restraint system for dual seat occupancy was developed at Fraunhofer EMI with the aim of achieving a better distribution of forces on the child's body in the event of an emergency landing.

Human body modeling was used to investigate the kinematics and induced loads on the child and accompanying person during a normalized deceleration. For this purpose, THUMS virtual human body models were used for the child and adult person.

The simulation showed that although the new concept significantly reduced the loads on the child's abdominal region, a collision between the child's and adult's bodies could not be prevented due to the change in body kinematics. These results show that, for safety reasons, a separate seat with a dedicated restraint system is preferable to dual seat occupancy for children.

Physical prototype of the numerically investigated restraint system.



Positioned child and adult THUMS virtual human body models with restraint system before the deceleration.

The drone is prepared with tracking markers for the dynamic impact test.

"Collision with drones": presentation by Markus Jung at the AIAA SciTech Forum

A contribution by Markus Jung, markus.jung@emi.fraunhofer.de

The issue of vulnerability of aircraft structures in collision with drones is a concern for the aviation industry. Markus Jung of Fraunhofer EMI gave a digital presentation on this problem at the AIAA SciTech Forum of the American Institute of Aeronautics and Astronautics on January 4, 2022.

The greatest damage during drone impact is caused by its heavy and stiff components, namely camera system, battery and motor. Their effect on impact was investigated at Fraunhofer EMI in static and dynamic test campaigns at different impact velocities. Several tests with the identical test parameters showed the same results despite complex boundary conditions, so they show high reproducibility.

Markus Jung reported on the exciting results of this research in his presentation entitled "Vulnerability of aerostructures to drone impact — characterization of critical drone components".

The research project was funded by the German Federal Ministry of Economics and Climate Protection.

More information on the project can be found in the article "Drone alert: Are privately piloted drones a threat to aviation?" on page 78.

The video shows the high-speed recording of one of the tests:

s.fhg.de/AIAA-SciTech-Forum

Sustainability Center Freiburg

The Sustainability Center Freiburg develops solutions for a sustainable future. © Adobe Stock

Sustainability Center Freiburg

Sustainability Center Freiburg

> **"Through the continuation of the Fraunhofer high-performance centers, we can reliably plan strategically designed research projects and transfer activities of sustainability-oriented research at the Fraunhofer location Freiburg."**
>
> Dr. Juri Lienert

Dr. Juri Lienert
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The Sustainability Center Freiburg

The Sustainability Center Freiburg (LZN) is a cooperation of the Freiburg Fraunhofer Institutes EMI, IAF, IPM, ISE and IWM, the University of Freiburg (Albert-Ludwigs-Universität ALU) and other non-university research institutions and partners. Together, they pursue the goal of researching solutions for sustainable development and bringing them into practice. The institutes are supported by a central office, which is located at Fraunhofer EMI. Thus, the LZN offers an integrative transfer infrastructure with a precisely tailored range of services for its network.

The continuation of the Sustainability Center Freiburg

From 2022 to 2024, the funding of the LZN is secured and will be invested into a total of four research projects and an attractive transfer infrastructure. Together with 19 other Fraunhofer-Gesellschaft high-performance centers in Germany, the LZN will increase the visibility of Freiburg as a research location in the field of interdisciplinary sustainability research and will build transfer highlights by applying research to industry and society.

Internationalization of the LZN

Two international initiatives are also part of the LZN this year. As part of the transfer offensive "Internationalization of the Performance Centers", the transfer initiative Austria addresses the topic of road safety with the project SURF (Smart Urban Road Safety). The transfer initiative Finland FORESEE (Forest Resilience) highlights the topic of sustainable forest management. In addition to Fraunhofer EMI, IPM and IWM are involved.

People in the Sustainability Center Freiburg

Here, we present four individuals from the Sustainability Center — a small sample of the many employees who do excellent work at Fraunhofer EMI.

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Peeling-based recycling of thermoplastic composites

A contribution by Dr. Mathieu Imbert, mathieu.imbert@emi.fraunhofer.de

Towards closing the material cycle of thermo-plastic composites

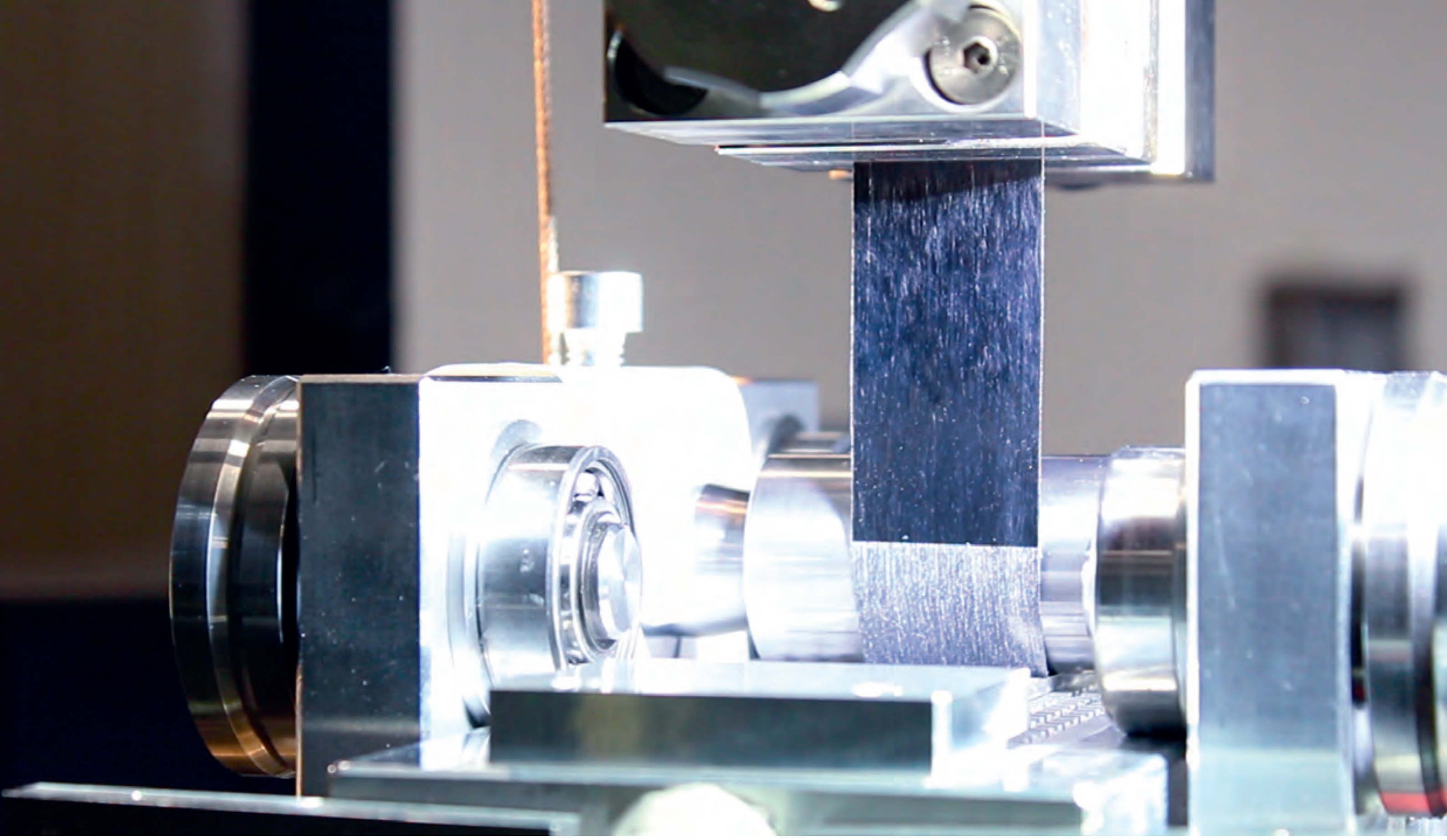
In contrast to most classical recycling processes for high-performance fiber composites, the peeling-based recycling process investigated at Fraunhofer EMI maintains the continuity of the fibers. This lays the foundations for recycling without downcycling and for closing the material cycle.

Context

High-performance fiber composites are lightweight materials and thus allow valuable weight savings in vehicle structures or in pressure vessels for the transport sector. The fiber-reinforced plastic (FRP) composite consists of two components of different natures: continuous fibers in the form of plies, the length and orientation of which ensure the stiffness and strength of the material, and a polymeric (thermoplastic or thermoset) matrix, in which the fibers are embedded. For recycling, however, this heterogeneous composition constitutes a major technical challenge: Which and how can reusable semi-finished products be generated from offcuts or end-of-life components? For thermoset fiber composites, fiber-matrix separation is a prerequisite because the matrix cannot be melted. For thermoplastic fiber composites, on the other hand, melting the matrix offers more potential in terms of recycling because fiber-matrix separation is not required. In this context, a pragmatic recycling route for the thermoplastic FRP is to shred the material. This results in fragments or in coarser or finer powders of polymer and short fibers. These materials can be readily reprocessed by compression molding or injection molding, but shredding the material results in the loss of fiber length and fiber orientation, leading to a very significant downcycling. Nevertheless, the FRP are valuable materials (typically the price is more than 15 euros per kilogram for carbon-fiber-reinforced plastics) and thus offer a greater economic potential for more elaborate recycling processes if these allow high quality for the recyclate.

Investigated concept

In this context, the recycling approach investigated at Fraunhofer EMI is to recover the individual layers of thermoplastic FRP in a controlled manner and as undamaged as possible. For this purpose, the Fraunhofer EMI expertise in the field of fracture mechanics of FRP is specifically deployed to apply the most effective loads that enable the separation of the individual layers of the FRP.



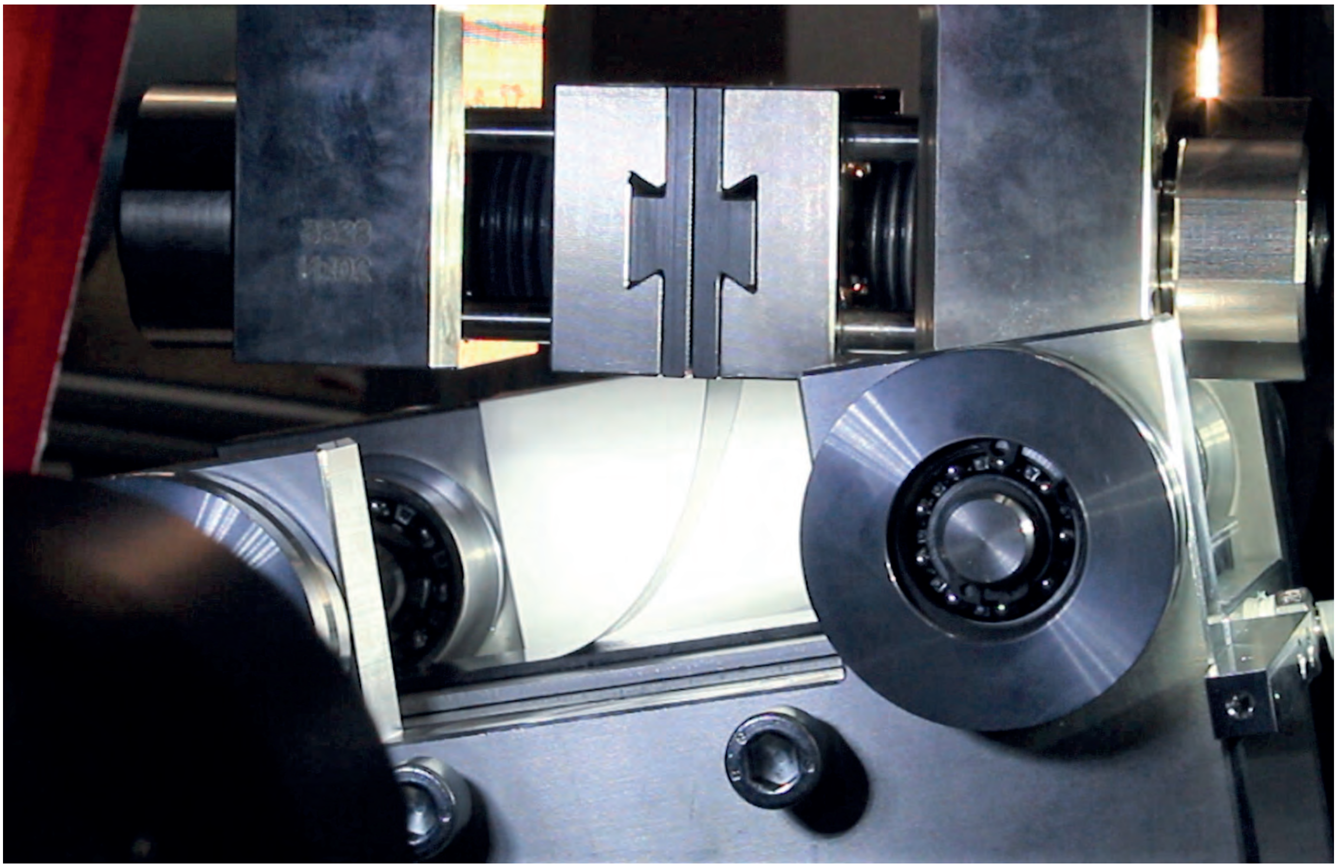
Peeling test setup with mandrel.

An initial proof of concept has demonstrated that single layers of thermoplastic fiber-reinforced composites featuring a woven reinforcement could be recovered without significant reduction in their properties. Based on this promising result, the focus of the further works was set on wound structures.

Filament winding is a continuous manufacturing process, in which a polymer-impregnated yarn (tape) is wound onto a mandrel, and has applications in pressure vessel construction. The continuity of the tape is particularly interesting in the context of a recovery because it allows to recover a continuous and reusable tape.

As part of the project “MultiTrace: Digital Traceability for Efficient Recycling of Composite Tapes” (funding: Sustainability Center Freiburg), this continuous recovery was investigated. The material under investigation consisted of several layers of unidirectional carbon-fiber PA6 tapes.

A peeling test setup was developed for the project, and tests were conducted under quasi-static conditions in an electromechanical testing machine. The test setup consists of a vacuum table, on which the specimen is placed and which is free to move horizontally. The layer to be separated is fixed in the upper jaw of the testing machine and peeled off upwards. Different peeling conditions were investigated (with and without mandrel, with different horizontal counter forces, with different angles of the vacuum table to the peeling direction). For energy efficiency reasons, peeling was first performed at room temperature and quasi-static test speed. Within these conditions, the most preserving peeling conditions were identified. Finally, the recovered layers were tested under tensile load to determine the mechanical properties. ▶



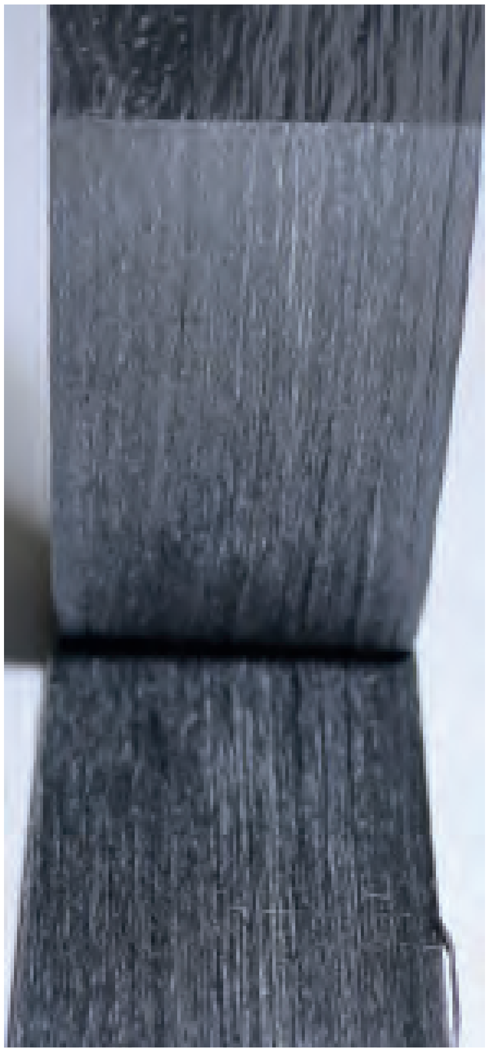
Peeling test setup without mandrel. The specimen features an angle of 80 degrees to the peeling direction.

Results

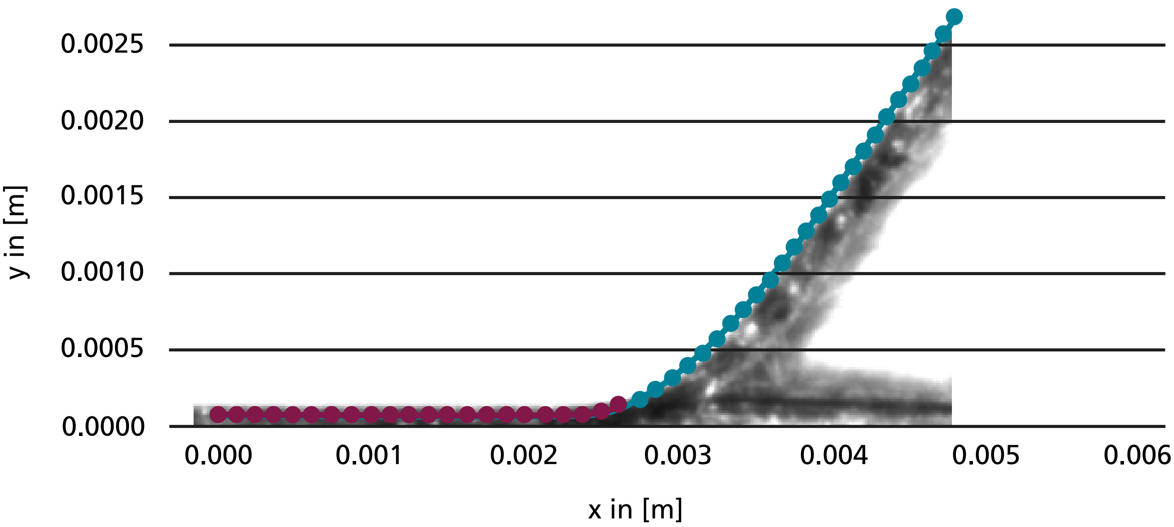
Comparison of the properties of the recovered tapes with the original tape showed that damage to the separated layers cannot be prevented under room temperature and quasi-static peeling conditions. Recycled tapes exhibited a reduced tensile strength of approximately 500 megapascals (approximately one third of initial strength) and a stiffness of approximately 45 gigapascals (approximately one-half of initial stiffness) after peeling and before any post-processing. Microscopic examination of the separated plies revealed two main damage mechanisms: First, fiber bridging: During peeling, some fibers of the separated ply remained on the surface of the remaining material. However, these lost fibers alone cannot explain the property reduction of the recyclate. Second, severe curvature of the ply during the process: Peeling caused local failure of fibers under tensile or compressive load due to the bending of the tape. This mechanism was identified as the major reason for the reduction in tape properties. Further optimization of the peeling conditions will be performed in the future to reduce the influence of these damage mechanisms. It should be noted that the residual properties of the material obtained are comparable to recyclates from optimized classical shredding-based recycling processes where fiber realignment is performed. However, the peeling-based recycling process offers much more potential for preserving the properties of the material and thus achieving a closed material circle. This process will therefore be further investigated and optimized at Fraunhofer EMI in the future.

Simulation of the process

Peeling, considered as a recycling process, is a new processing method for fiber composites. This process has many related parameters: peeling angle, temperature and speed. In this context, numerical simulation appears as a good solution to support the process parameter determination. For this purpose, an innovative modeling approach has been developed at Fraunhofer EMI. This approach allows both classical direct modeling (input values are the material properties and the boundary conditions, and the mechanical response of the material is calculated) and inverse modeling (the current or desired deformation of the material are input values, and the material properties or the boundary conditions — for example, the peeling force to be applied — are calculated). The goal of this model is to use process data to determine optimized process parameters, ideally in real time. With this model, comparisons were made between experiment and simulation. For example, based on the curvature of the peeling arm, the properties of the material were automatically calculated by the model, providing valuable information about the damage induced to the material. ■



Fracture surface between the peeled tape and the rest of the material.



Comparison of the simulation result obtained with the new modeling method with the results of the experimental peeling tests. In dark red: undamaged material. In dark turquoise: peeling arm with reduced mechanical properties.

The SWW supports the Fraunhofer institutes in Freiburg with regard to design, realization and evaluation of continuing education offerings.

Service Center Training and Knowledge Transfer — SWW

A contribution by Jeanette Kristin Weichler (Fraunhofer ISE), jeanette.weichler@ise.fraunhofer.de

As an integral part of the Sustainability Center Freiburg, the new Service Center Training and Knowledge Transfer (SWW) offers central services for the transfer of research into the economy and society.

Planning, implementation and realization of continuing education or in the context of knowledge transfer in R&D projects are repeatedly subject to delays and difficulties if essential aspects are not adequately addressed. For this purpose, the Service Center Training and Knowledge Transfer (SWW) was established to provide the five Fraunhofer institutes in Freiburg with advice and professional support.

Services and competencies of SWW

As the contact point for the Freiburg Fraunhofer institutes, SWW covers all areas of continuing education. The services include internal and external communication and consulting, the implementation of the legal framework for continuing education offerings, the assurance of qualitative and technical standards of the educational offerings as well as support in the didactic structure of continuing education and its implementation with digital media.

Support of R&D projects

In the course of strengthening science communication and knowledge transfer between research and society, SWW offers supervision of R&D projects. The expertise and references of the SWW make it possible to increase both the quality of project applications and the chances of project approval by taking into account the priorities and evaluation criteria of the ministries and the EU. In concrete terms, the offer ranges from clarification of the current requirements of the ministries and the EU for project applications with further training components, through the application and project processing, to project completion with a continuation of the results obtained in the form of a variety of further training concepts.

"For a sustainable continuation of training and education programs, the needs of customers must be taken into account and the content must meet high quality standards and be up to date with the latest research. The SWW team supports you in these challenges."

M. Sc. Jeanette Kristin Weichler, head of SWW and Fraunhofer Academy Freiburg Regional Office

Video series about the Sustainability Center Freiburg

A contribution by Dr. Juri Lienert, juri.lienert@emi.fraunhofer.de

Eleven videos showed the goals and past successes of the Sustainability Center Freiburg and its eight exciting demonstrator projects.

With the goal of promoting the terminated demonstrator projects of the LZN by presenting the scientific value and potential of the projects to the public, the LZN produced eleven professional image films, which were published in a two-week video series on social media. This also provided a nice alternative to a closing event in presence, which could not take place due to the corona pandemic.

Funding phases 1 to 3, demonstrator projects and start-up support

At the beginning, a video on funding phases 1 and 2 presented the basic idea, the goals and the main topics of the Sustainability Center. Afterwards, each of the eight demonstrator projects of funding phase 2 were portrayed in individual videos. In addition, the video on funding phase 3 dealt with the new international initiative of the LZN and the intended continuation of the research results as well as the involvement of industrial partners. Finally, a video on the initiative "Start-up Support" highlighted the services of the LZN to support the start-up scene around Freiburg with advice as well as financial means and to accompany prospective start-ups on their way to spin-off.

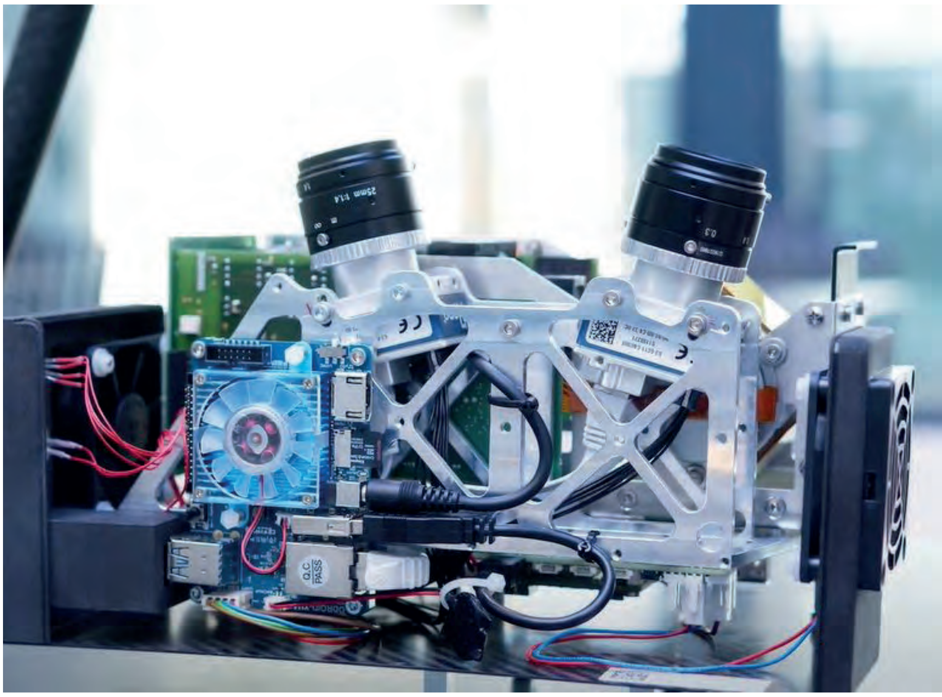
Response to the video series

By publishing the videos, the LZN could generate a high number of reactions and new followers on the social media channels used, LinkedIn and YouTube. In addition, the videos were viewed almost 1700 times on YouTube alone. The video series can thus be considered as a great success.

The videos can be viewed at the following link:

s.fhg.de/LZN-Videos

In the demonstrator project SwInG, a drone provides information on geo-risks such as forest damage with the aim of taking countermeasures in good time. © Fraunhofer IPM



Intelligence for cities in climate adaptation

A contribution by Christiane Felder, christiane.felder@emi.fraunhofer.de

In the I4C project, digital-ecological innovations in the form of artificial-intelligence(AI)-based methods are developed.
© A. Lipinski, Fraunhofer IPM

Using artificial intelligence (AI), locally precise weather forecast models will be possible for cities, which reflect the complexity of urban systems as well as can be used for future-oriented urban planning.

Urban spaces are particularly vulnerable to the effects of climate change, such as extreme weather events, heat waves, floods and storms. Future-oriented urban planning depends on locally precise weather forecast models on the one hand and on a good database for estimating effects of planning measures on the other. Artificial intelligence (AI) methods can support urban planning to improve the adaptability of cities to extreme events. In this research project funded by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), which runs until the end of 2023, the Fraunhofer Institutes for Physical Measurement Techniques IPM, Solar Energy Systems ISE and High-Speed Dynamics, Ernst-Mach-Institut, EMI, and the University of Freiburg are jointly developing various AI tools for climate adaptation for cities under the coordination of the Sustainability Center Freiburg.

Using artificial intelligence for the analysis and prediction of risks

By means of simulations, the data for environmental prediction are generated. First, abstract simulation data for temperature, water and wind for selected training areas are generated as time series on different spatial scales. The results subsequently serve as training data for the development of an efficient, fine-meshed AI prediction model: In a deep artificial neural network (ANN), measurement data and results of the simulations are used to learn with existing, numerical-physical models in order to be able to calculate approximate simulation results via the deep ANN much faster afterwards. Based on the simulation results of the training areas, AI can be used to create a fine-meshed prediction model for the entire city of Freiburg in a short time.

Further information (in German) can be found at s.fhg.de/verbundprojekt-I4C

The engineering sciences and research for a sustainable future attract many students. © K. Kreb, INATECH

Transfer via individuals — the INATECH

A contribution by Dr. Juri Lienert, juri.lienert@emi.fraunhofer.de

The Institute for Sustainable Systems Engineering (INATECH) with its focus on teaching and research in engineering science stands for the unique cooperation of the Fraunhofer Institutes with the University of Freiburg.

As the core of the Sustainability Center Freiburg in terms of its engineering science, the INATECH at the science and business location Freiburg continues to be a unique cooperation in Germany between Fraunhofer Institutes and the university in teaching and research. In doing so, the INATECH succeeds in addressing and linking the topics of sustainability and resilience in equal measure in a way that is exceptional throughout Germany. The long-term goal is to establish Freiburg as an internationally renowned location for sustainability and resilience research in the engineering sciences.

Against this background, the INATECH continued to play an important role in the training of specialists in the past year 2021. The German-language bachelor's degree program "Sustainable Systems Engineering" was again a popular choice among first-year students, with 75 students enrolled. The English-language master's program of the same name was also further expanded with 57 students in order to better meet the enormous demand. In addition, 15 excellent individuals from Fraunhofer EMI are involved in teaching at the INATECH. The "Sustainability Talks" organized by the INATECH together with the LZN also provide interested parties from the university as well as the Fraunhofer context with insights into the sustainability research of international and renowned lecturers — true to the motto "transfer via individuals".

Further information can be found at www.inatech.de/en

Administration and Infrastructure

The administrative processes create the general framework for research at EMI. © Adobe Stock

Administration

Administration

A crisis is an opportunity for new and better solutions that will benefit us in the future.”

Dr. Tobias Leismann

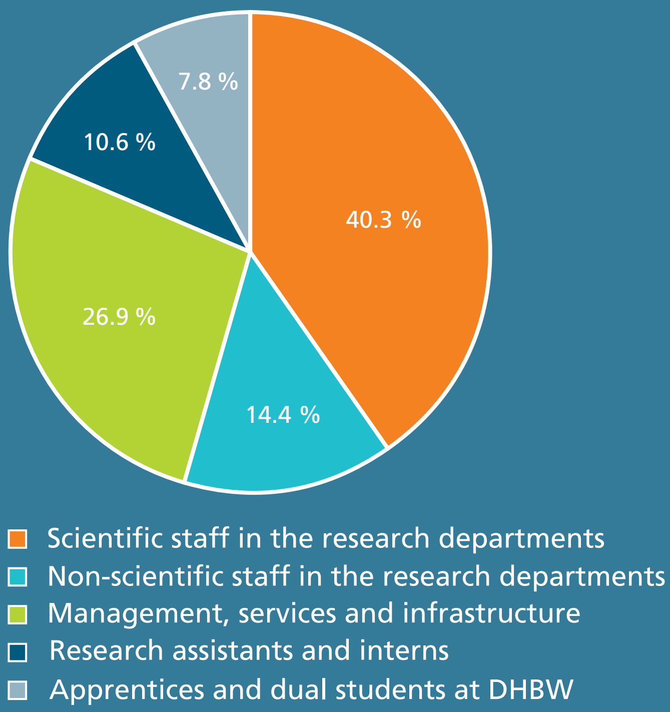
Dr. Tobias Leismann
Interim head of Administration
tobias.leismann@emi.fraunhofer.de

The new normal brought new challenges in the second year of the pandemic. And we would not be who we are if we did not also see this as an opportunity to develop new and better structures and processes.

Digital and hybrid collaboration makes many things easier, but it also poses new challenges, particularly when it comes to the onboarding of new colleagues. That is why, accompanied by the "New Work" working group, we have jointly developed new rules for mobile working that center on trust in our employees and combine their need for flexibility with the simultaneous preservation of team spirit and collaboration. In this way, we have managed to protect our employees in the best possible way during the pandemic and still enable them to work together in teams. We will benefit from these newly developed solutions in the long run.

One of our core competencies is to research how crises can be optimally overcome and how we can emerge even stronger from them afterwards. That is why we were a sought-after research partner during the pandemic: We are and were available to advise companies and institutions that want to improve their resilience in order to be well prepared for the next crisis.

The Fraunhofer-wide introduction of SAP is changing all processes in the administration. This has cost us a lot of energy and stamina so far. In some occasions, the process is a real test of endurance. The fact that we can successfully solve all the tasks together makes me optimistic about the future: We will continue to face crises with resilience and position ourselves for further change. I would like to express my sincere thanks to all administrative staff for their commitment.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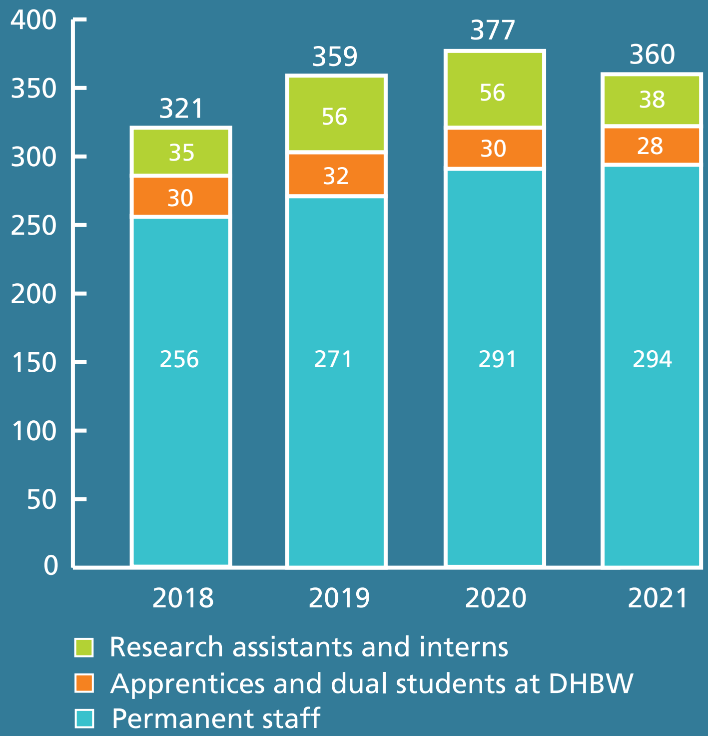
Scientific staff in the research departments
Non-scientific staff in the research departments
Management, services and infrastructure
Research assistants and interns
Apprentices and dual students at DHBW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2018
2019
2020
2021
Research assistants and interns
Apprentices and dual students at DHBW
Permanent staff

Staff structure

At the end of 2021, 360 people were employed at Fraunhofer EMI: 294 employees as permanent staff, 28 as apprentices and dual students, and 38 as research assistants and interns. 197 members of the permanent staff were directly involved in research and 97 worked in the fields of services, management and infrastructure. The proportion of female employees of the permanent staff was 25.2 percent.

20 of the 28 apprentices worked in the fields of precision mechanics, electronics, media design and administration. The remaining 8 worked at Fraunhofer EMI within the scope of their vocational training or university studies at the Baden-Württemberg Cooperative State University (DHBW).

Finances


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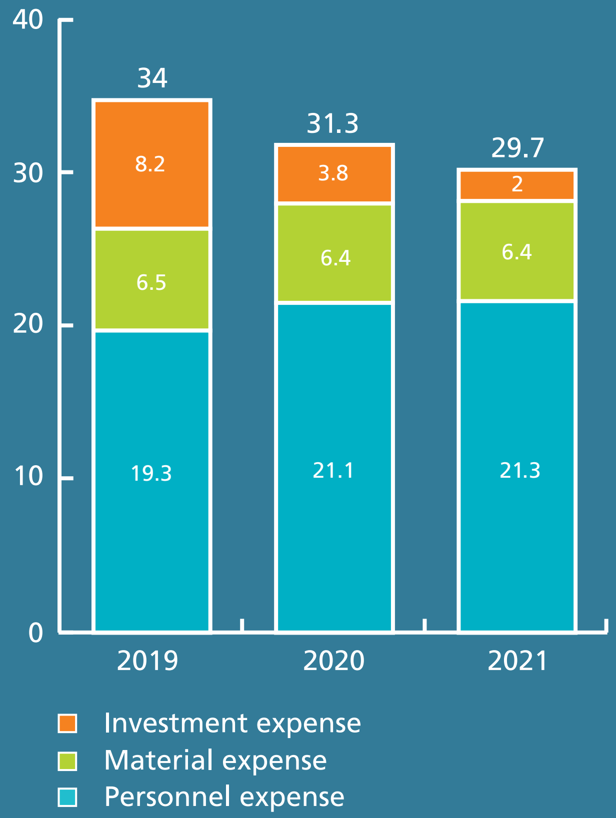
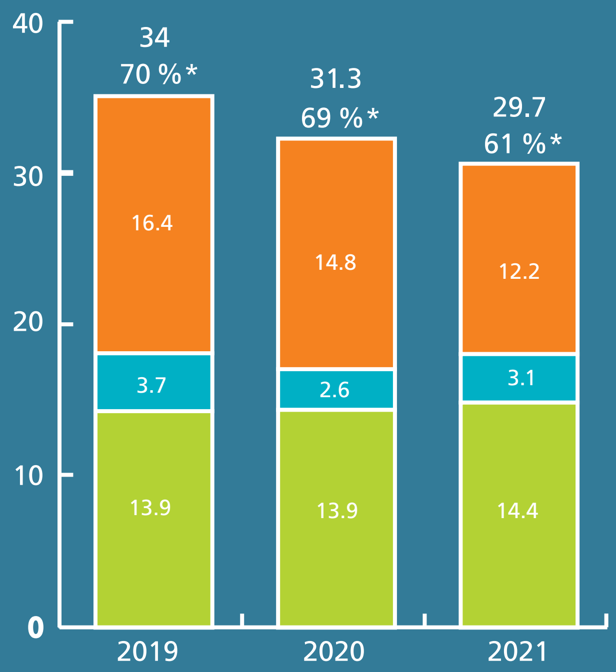
In comparison to the previous year, the total budget of Fraunhofer EMI has slightly decreased to just under 30 million euros. The operating budget (personnel and material expenses) has grown to 27.6 million euros, while the investment budget, at 2 million euros, was 40 percent lower. An important factor here is that the pandemic caused massive delays in almost all investment projects. Fraunhofer EMI is financed by external revenues from the industry and the public sector as well as by the institutional base funding of the German Federal Ministry of Defence (BMVg) and the Federal Ministry of Education and Research (BMBF). With the amount of 15.3 million euros of external revenues, a good value was achieved. In particular, the scope of orders from industrial customers has grown from 2.6 million euros (2020) to 3.1 million euros (2021) now. The decline in orders in the defense sector was counterbalanced by the strong growth in the security and resilience sector. Yet, in 2021, the biggest share of the operating and investment budget, namely 61 percent, was financed by the German Federal Ministry of Defence (2020: 69 percent).

Financing of the total budget in million euros



Total budget in million euros



*Federal Ministry of Defence share of total budget

The Infrastructure department is an internal, central service unit. © Adobe Stock

Infrastructure

Infrastructure

Working in the background to pave the way for others

The department combines the subject areas of workshops for mechanical manufacturing and processing of materials, the electronics laboratory, the maintenance and technical services, the construction department and health and safety at EMI. For all three locations, 47 employees provide (mostly) internal services and consulting expertise that meet the basic requirements of research colleagues at their workplaces and thus support the work at EMI. The two workshops as well as the electronics laboratory also provide continuous practical training in the operational needs of younger people seeking to enter the workforce. Central and higher-level tasks are performed and coordinated via the functions of the construction officer and the health-and-safety specialist.

> **If we knew what it was we were doing, it would not be called research, would it?"**

Albert Einstein (1879–1955),
Theoretical physicist

Christophe Weishar
Head of Infrastructure (until August 2022)

More transparency in crash tests

A contribution by Michael Drees, michael.drees@emi.fraunhofer.de

The expansion of the Fraunhofer Crash Center with the linear accelerator Linac significantly enhances research opportunities.

X-ray imaging is always limited by the capabilities of the radiation sources. Especially for time-resolved imaging of fast processes, the increase of photon energy by a factor of 20 with the help of the new linear accelerator system (Linac) helps the institute to advance into completely new areas.

High temporal and spatial resolution X-ray imaging has been one of EMI's central competencies from the very beginning of the history of the institute. The possibilities in this field are to be significantly expanded with the linear accelerator (Linac). In regular operation, the technology is expected to enable X-ray images at 1000 frames per second, in combination with all common materials used in the automotive sector. This is made possible by a continuous stream of X-ray pulses that provide a high contrast range to enable imaging despite the wide variety of materials. For special imaging, individual parts can be examined in the LiLa building (LiLa: short for Linac laboratory) even with long exposure times. In addition, this opens up the perspective for three- or even four-dimensional computed tomography in the LiLa.

A linear accelerator of this kind places great demands on the planners and the companies involved, both in terms of planning and construction. The complexity of the project is sometimes made clear by the fact that an eight-year project will now hopefully soon be completed. The development of the project is coordinated on-site, among others, by employees of the infrastructure department in the construction overview and coordination of the participants.

The project consists of the two parts LiLa and Linac, whereby the Linac is the linear accelerator device itself and the LiLa is the building, that is the premises with the entire infrastructure including the radiation protection measures. Within the context of an expert inspection of the LiLa building, the safety control system was tested and the Linac itself was briefly put into operation in order to be able to carry out radiation protection measurements. Fortunately, the Linac functioned directly within the expected parameters, so that the level of radiation exposure could be simulated in experimental operation. After completion of the final work, we expect the licensing authority to approve the operation of the Linac.

At the end of the project, one field of application will be X-ray imaging of crash-test scenarios in the crash hall of Fraunhofer EMI. In order to use the Linac, this building must also be adapted to the radiation protection requirements for this high-power radiation source. For this purpose, the complete hall wall facing the courtyard and the northern side wall will receive a full-surface facing

Exterior view of the new Linac laboratory LiLa, which houses the linear accelerator.

wall made of concrete, 30 centimeters thick. The windows and doors must be replaced with radiation-proof alternatives. For example, an additional gate weighing 85 tons was installed. Lead shielding is used to additionally protect certain areas against the radiation that occurs, so that operators are protected beyond the level required by the Radiation Protection Act. However, the structural measures must also be supplemented and flanked by organizational changes. For this purpose, additional areas will be closed during X-ray operation, which, in turn, will entail adjustments to the safety technology at doors and in the warning signals. Since there are a large number of rules and regulations from radiation protection to be observed here and a project of this magnitude is always characterized by diverse interactions, planning uncertainties and conflicting goals, it represents a great challenge for planners, companies and those involved at EMI. Thanks to regular coordination and intensive cooperation between all those involved, it has so far been possible to overcome all the challenges that have arisen.

Linear accelerator Linac in test operation during the technical expert inspection.

Profile of the institute

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The advisory board

The advisory boards of the various Fraunhofer institutes advise the directors of the institute and the executive board of the Fraunhofer-Gesellschaft. The advisory board also enhances the institute's contacts to organizations and to the industry.

Hanna Böhme
Managing Director Freiburg Wirtschaft Touristik und Messe GmbH & Co. KG, FWTM, Freiburg

Dipl.-Ing. Thomas Gottschild (Chairman)
Managing Director of MBDA Deutschland GmbH, Schrobenhausen

MinRin Sabine ten Hagen-Knauer
Head of Division 524: Civil Security Research, German Federal Ministry of Education and Research (BMBF), Bonn

Rainer Hoffmann
Chief Executive Officer carhs.training GmbH, Alzenau

MinR Dipl.-Phys. Claus Mayer
Head of Division 33: Automotive and Manufacturing Industries, Logistics, State Ministry of Economic Affairs, Labour and Tourism, Baden-Württemberg, Stuttgart

Prof. Dr. Merith Niehuss
President of the Universität der Bundeswehr München, Bundeswehr University Munich, Neubiberg

Michael Schätzle
Head of Product and Concept (EP), Porsche AG, Stuttgart

Oberst i. G. Jürgen Schmidt
Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support, BAAINBw, Head of Department Battle, Koblenz

Dr. Tobias Schmidt
Head of Department and Head of Development at location Unterluess, Rheinmetall Waffe und Munition, Unterluess

Prof. Dr.-Ing. Rodolfo Schöneburg
Road Safety Counselor, RSC Safety Engineering, Hechingen

Dr. Isabel Thielen
Management Thielen Business Coaching GmbH, Munich

MinR Dr. Dirk Tielbürger
Head of division A III 6, German Federal Ministry of Defence, Bonn

The Fraunhofer-Gesellschaft

Right: the headquarters of the Fraunhofer-Gesellschaft in Munich.

The Fraunhofer-Gesellschaft based in Germany is the world's leading applied research organization. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. It is a trailblazer and trendsetter in innovative developments and research excellence. The Fraunhofer-Gesellschaft supports research and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.

The Fraunhofer-Gesellschaft's interdisciplinary research teams turn original ideas into innovations together with contracting industry and public sector partners, coordinate and complete essential key research policy projects and strengthen the German and European economy with ethical value creation. International collaborative partnerships with outstanding research partners and businesses all over the world provide for direct dialogue with the most prominent scientific communities and most dominant economic regions.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany. Over 30,000 employees, predominantly scientists and engineers, work with an annual research budget of 2.9 billion euros. Fraunhofer generates 2.5 billion euros of this from contract research. Industry contracts and publicly funded research projects account for around two thirds of that. The federal and state governments contribute around another third as base funding, enabling institutes to develop solutions now to problems that will become crucial to industry and society in the near future.

The impact of applied research goes far beyond its direct benefits to clients: Fraunhofer institutes enhance businesses' performance, improve social acceptance of advanced technology and educate and train the urgently needed next generation of research scientists and engineers.

Highly motivated employees up on cutting-edge research constitute the most important success factor for us as a research organization. Fraunhofer consequently provides opportunities for independent, creative and goal-driven work and thus for professional and personal development, qualifying individuals for challenging positions at our institutes, at higher education institutions, in industry and in society. Practical training and early contacts with clients open outstanding opportunities for students to find jobs and experience growth in business and industry.

The prestigious nonprofit Fraunhofer-Gesellschaft's namesake is the Munich scholar Joseph von Fraunhofer (1787–1826). He enjoyed equal success as a researcher, inventor and entrepreneur.

Further information can be found at
www.fraunhofer.de/en

Publications, scientific exchange, lectures 2021/2022

Publications

Publications in books, specialist journals and proceedings with peer review

Bauer, S.; Bagusat, F.; Strassburger, E.; Sauer, M.; Hiermaier, S. (2021): New insights into the failure front phenomenon and the equation of state of soda-lime glass under planar plate impact. In: Journal of Dynamic Behavior of Materials 7 (1), S. 81–106. DOI: 10.1007/s40870-020-00268-2.

Becker, M.; Balle, F. (2021): Multi-spot ultrasonic welding of aluminum to steel sheets: process and fracture analysis. In: Metals 11 (5), S. 779. DOI: 10.3390/met11050779.

Bessler, S.; Hess, K.; Weigt, H.; Ramin, M. von (2021): Biological transformation-battery protection inspired by wound healing. In: Bioinspiration & biomimetics 16 (5). DOI: 10.1088/1748-3190/ac1249.

Blanke, F.; Boljen, M.; Lutter, C.; Oehler, N.; Tischer, T.; Vogt, S. (2021): Does the anterolateral ligament protect the anterior cruciate ligament in the most common injury mechanisms? A human knee model study. In: The Knee 29, S. 381–389. DOI: 10.1016/j.knee.2021.02.026.

Butz, I.; Moser, S.; Nau, S.; Hiermaier, S. (2021): Data assimilation of structural deformation using finite element simulations and single-perspective projection data based on the example of X-ray imaging. In: SN Applied Sciences 3 (5), S. 155. DOI: 10.1007/s42452-021-04522-7.

Contell Asins, C.; Landersheim, V.; Laveuve, D.; Adachi, S.; May, M.; Wacker, J.-D.; Decker, J. (2021): Analysis and design of a leading edge with morphing capabilities for the wing of a regional aircraft – gapless chord- and camber-increase for high-lift performance. In: Applied Sciences 11 (6), S. 2752. DOI: 10.3390/app11062752.

D'haen, J. J. A.; May, M.; Boegle, C.; Hiermaier, S. (2022): Damage evolution analysis on compression-loaded multidirectional carbon fiber laminates using ex-situ CT scans. In: Journal of Composites Science 6 (2), S. 63. DOI: 10.3390/jcs6020063.

D'haen, J. J. A.; May, M.; Knoll, O.; Kerscher, S.; Hiermaier, S. (2021): Strain acquisition framework and novel bending evaluation formulation for compression-loaded composites using digital image correlation. In: Materials 14 (20). DOI: 10.3390/ma14205931.

Del Linz, P.; Fung, T. C.; Lee, C. K.; Riedel, W. (2021): Response mechanisms of reinforced concrete panels to the combined effect of close-in blast and fragments: An integrated experimental and numerical analysis. In: International Journal of Protective Structures 12 (1), S. 49–72. DOI: 10.1177/2041419620923129.

Domaneschi, M.; Cimellaro, G. P.; Xie, L.; Bruneau, M.; Wu, Z.; Didier, M. et al. (2021): Present and future resilience research driven by science and technology. In: International Journal of Sustainable Materials and Structural Systems 5 (1/2), S. 50. DOI: 10.1504/IJSMSS.2021.115783.

Finger, J.; Ross, K.; Häring, I.; Restayn, E.-M.; Siebold, U. (2021): Open chance and risk management process supported by a software tool for improving urban security. In: European Journal for Security Research 6 (1), S. 39–71. DOI: 10.1007/s41125-021-00072-6.

Fischer, G.; Bordoy, J.; Schott, D. J.; Xiong, W.; Gabbrielli, A.; Höflinger, F. et al. (2022): Multimodal indoor localization: fusion possibilities of ultrasonic and Bluetooth low-energy data. In: IEEE Sensors Journal 22 (6), S. 5857–5868. DOI: 10.1109/JSEN.2022.3148529.

Fischer, G.; Zeqiri, F.; Gabbrielli, A.; Schott, J. D.; Bordoy, J.; Xiong, W. et al. (2021): Localization of acoustic gas leakage sources with a circular microphone array. In: Proceedings of the 2021 International Conference on Indoor Positioning and

Indoor Navigation (IPIN). Lloret de Mar, Spain, 29.11.–2.12.2021: IEEE, S. 1–7.

Fischer, K.; van der Woerd, J. D.; Harwick, W.; Stolz, A. (2021): Dynamic bearing capacity of point fixed corrugated metal profile sheets subjected to blast loading. In: International Journal of Protective Structures 48, S. 1–22. DOI: 10.1177/20414196211059201.

Gabbrielli, A.; Xiong, W.; Schott, D. J.; Fischer, G.; Wendeberg, J.; Höflinger, F. et al. (2021): An echo suppression delay estimator for angle-of-arrival ultrasonic indoor localization. In: IEEE Transactions on Instrumentation and Measurement 70, S. 1–12. DOI: 10.1109/TIM.2021.3083558.

Ganter, S.; Balbi, A.; Finger, J.; Schäffer, L.; Bolletta, F.; Fuggini, C. et al. (2021): Conceptual model and CONOPS for secure and resilient gas critical infrastructure. In: J. Soldatos, I. Praça und A. Jovanović (Hg.): Cyber-Physical Threat Intelligence for Critical Infrastructures Security: Now Publishers, S. 309–326.

Gärtner, M.; Ebert, M.; Schimmerohn, M.; Hergarten, S.; Schäfer, F.; Kenkmann, T.; Gulde, M. (2021): The first microseconds of a hypervelocity impact. In: W. U. Reimold und C. Koeberl (Hg.): Large Meteorite Impacts and Planetary Evolution VI, Bd. 10, S. 407–417.

Grunwald, C.; Durr, N.; Sauer, M.; Riedel, W.; Hiermaier, S. (2021): A concurrent two-scale coupling for wave propagation using direct solution schemes with explicit time integration. In: International Journal for Numerical Methods in Engineering 37 (1), S. 23. DOI: 10.1002/nme.6795.

Hahn, P.; Channammagari, H.; Imbert, M.; May, M. (2022): High-rate mode II fracture toughness testing of polymer matrix composites using the Transverse Crack Tension (TCT) test. In: Composites Part B: Engineering 233 (10–11), S. 109636. DOI: 10.1016/j.compositesb.2022.109636.

Häring, I. (2021): Technical Safety, Reliability and Resilience. Singapore: Springer Singapore.

Häring, I.; Fehling-Kaschek, M.; Miller, N.; Faist, K.; Ganter, S.; Srivastava, K. et al. (2021): A performance-based tabular approach for joint systematic improvement of risk control and resilience applied to telecommunication grid, gas network, and ultrasound localization system. In: Environment Systems and Decisions 117 (2), S. 286–329. DOI: 10.1007/s10669-021-09811-5.

Häring, I.; Lüttner, F.; Frorath, A.; Fehling-Kaschek, M.; Ross, K.; Schamm, T. et al. (2022): Framework for safety assessment of autonomous driving functions up to SAE level 5 by self-learning iteratively improving control loops between development, safety and field life cycle phases. In: Proceedings of the IEEE ICCP 2021, 17th International Conference on Intelligent Computer Communication and Processing. Cluj-Napoca, Romania, 28.–30.10.2021.

Häring, I.; Schäfer, J.; Vogelbacher, G.; Fischer, K.; Riedel, W.; Faist, K. et al. (2021): From event to performance function-based resilience analysis and improvement processes for more sustainable systems. In: International Journal of Sustainable Materials and Structural Systems 5 (1/2), S. 90. DOI: 10.1504/IJSMSS.2021.115784.

Häring, I.; Schäffer, L.; Restayn, E.-M.; Vogelbacher, G.; Stolz, A.; Finger, J. (2021): Formalization of questionnaire-based score card risk control and resilience assessment for critical infrastructure operators and companies countering Covid-19. In: Proceedings of the 31st European Safety and Reliability Conference (ESREL). Unter Mitarbeit von B. Castanier, M. Cepin, D. Bigaud und C. Berenguer (Hg.), S. 2862–2869.

Heilig, G.; May, M. (2021): Hydrodynamic ram effect driven by a hollow spherical hypervelocity projectile. In: Results in Engineering 11 (1), S. 100269. DOI: 10.1016/j.rineng.2021.100269.

Heine, A.; Wickert, M. (2021): Note on: “Ballistic model for the prediction of penetration depth and residual velocity in adobe: A new interpretation of the ballistic resistance of earthen masonry”. In: Defence Technology 14, S. 607. DOI: 10.1016/j.dt.2021.09.003.

Imbert, M.; Hahn, P.; Jung, M.; Balle, F.; May, M. (2022): Mechanical laminae separation at room temperature as a high-quality recycling process for laminated composites. In: Materials Letters 306, S. 130964. DOI: 10.1016/j.matlet.2021.130964.

Jain, A. K.; Schott, D. J.; Scheithauer, H.; Häring, I.; Höflinger, F.; Fischer, G. et al. (2021): Simulation-based resilience quantification of an indoor ultrasound localization system in the presence of disruptions. In: Sensors 21 (19). DOI: 10.3390/s21196332.

Jakkula, P.; Ganzenmüller, G. C.; Beisel, S.; Hiermaier, S. (2021): Investigating slow shock in low-impedance materials using a direct impact Hopkinson bar setup. In: EPJ Web of Conferences 250, S. 6009. DOI: 10.1051/epjconf/202125006009.

Jakkula, P.; Ganzenmüller, G. C.; Beisel, S.; Rüthnick, P.; Hiermaier, S. (2021): The Symmpact: A direct-impact Hopkinson bar setup suitable for investigating dynamic equilibrium in low-impedance materials. In: Experimental Mechanics 6 (2), S. 113. DOI: 10.1007/s11340-021-00785-8.

Jakkula, P.; Ganzenmüller, G. C.; Gutmann, F.; Pfaff, A.; Mermagen, J.; Hiermaier, S. (2021): Strain rate sensitivity of the additive manufacturing material Scalmalloy®. In: Journal of Dynamic Behavior of Materials. DOI: 10.1007/s40870-021-00298-4.

Kisters, T.; Gilaki, M.; Nau, S.; Sahraei, E. (2022): Modeling of dynamic mechanical response of Li-ion cells with homogenized electrolyte-solid interactions. In: Journal of Energy Storage 49, S. 104069. DOI: 10.1016/j.est.2022.104069.

Kisters, T.; Keshavarzi, M.; Kuder, J.; Sahraei, E. (2021): Effects of electrolyte, thickness, and casing stiffness on the dynamic response of lithium-ion battery cells. In: Energy Reports 7 (2020), S. 6451–6461. DOI: 10.1016/j.egyr.2021.09.107.

Kisters, T.; Kuder, J.; Töpel, A.; Langkemper, R.; Nau, S.; Schopferer, S. (2021): Strain-rate dependence of the failure behavior of Lithium-Ion pouch cells under impact loading. In: Journal of Energy Storage 41 (100550), S. 102901. DOI: 10.1016/j.est.2021.102901.

Köpke, C.; Eberhardt, D.; Fehling-Kaschek, M.; Papagiannopoulos, N.; Stolz, A. (2021): Impact of distance rules on infrastructure resilience. In: Proceedings of the 31st European Safety and Reliability Conference (ESREL). Unter Mitarbeit von B. Castanier, M. Cepin, D. Bigaud und C. Berenguer (Hg.), S. 3155–3162.

Köpke, C.; Srivastava, K.; König, L.; Miller, N.; Fehling-Kaschek, M.; Burke, K. et al.: Impact propagation in airport systems. In: H. Abie (Hg.): Cyber-Physical Security for Critical Infrastructures Protection. CPS4CIP 2020, Bd. 12618 (Lecture Notes in Computer Science 12618), S. 191–206.

Köpke, C.; Srivastava, K.; Miller, N.; Branchini, E. (2022): Resilience quantification for critical infrastructure: exemplified for airport operations. In: Computer Security. ESORICS 2021 International Workshops. ESORICS 2021. Lecture Notes in Computer Science, Bd. 13106: Springer, S. 451–460.

Langkemper, R.; Moser, S.; Büttner, M.; Rakus, D.; Sättler, A.; Nau, S. (2022): A priori information based time-resolved 3D analysis of the trajectory and spatial orientation of fast-moving objects using high-speed flash X-ray imaging. In: Journal of imaging 8 (2). DOI: 10.3390/jimaging8020028.

Ledford, N.; Imbert, M.; May, M. (2021): High-rate in-plane shear testing of CFRP using the Split Hopkinson Tension Bar. In: AIAA Journal. DOI: 10.2514/6.2021-0167.

Ledford, N.; Imbert, M.; May, M. (2021): High-rate in-plane shear testing of IM7/8552 using the Split Hopkinson Tension Bar. In: AIAA Journal 59 (10), S. 4257–4263. DOI: 10.2514/1.J060269.

May, M.; Arnold-Keifer, S.; Landersheim, V.; Laveuve, D.; Contell Asins, C.; Imbert, M. (2021): Bird strike resistance of a CFRP morphing leading edge. In: Composites Part C: Open Access 4 (1129), S. 100115. DOI: 10.1016/j.jcomc.2021.100115.

May, M.; Kilchert, S. (2021): The effect of loading rate on the in-plane shear strength of tri-axial braided composites. In: Journal of Composite Materials. DOI: 10.1177/00219983211047687.

May, M.; Kilchert, S.; Gerster, T. (2021): A modified compact tension test for characterization of the intralaminar fracture toughness of tri-axial braided composites. In: Materials 14 (17). DOI: 10.3390/ma14174890.

Mielniczek, J.; Köpke, C.; Srivastava, K.; Schröder, E. (2021): Cyber-physical security and resilience for offshore wind farms. In: Proceedings of the European Workshop on Maritime Systems Resilience and Security (MARESEC 2021). Bremerhaven.

Miller, N.; Satsrisakul, Y.; Faist, K.; Fehling-Kaschek, M.; Crabbe, S.; Poliotti, M. et al. (2021): A risk and resilience approach for railway networks. In: Proceedings of the 31st European Safety and Reliability Conference (ESREL). Unter Mitarbeit von B. Castanier, M. Cepin, D. Bigaud und C. Berenguer (Hg.), S. 2071–2078.

Mylo, M. D.; Hofmann, M.; Balle, F.; Beisel, S.; Speck, T.; Speck, O. (2022): Biomechanics of the parasite-host interaction of the European mistletoe. In: Journal of experimental botany 73 (4), S. 1204–1221. DOI: 10.1093/jxb/erab518.

Okafor, C. E.; Kebodi, L. C.; Kandasamy, J.; May, M.; Ekengwu, I. E. (2022): Properties and performance index of natural fiber reinforced cross-ply composites made from Dioscorea alata stem fibers. In: Composites Part C: Open Access 7 (4), S. 100213. DOI: 10.1016/j.jcomc.2021.100213.

Oliveira, P. R.; Kilchert, S.; May, M.; Panzera, T. H.; Scarpa, F.; Hiermaier, S. (2021): Environmental assessment of discarded plastic caps as a honeycomb core: An eco�mechanical perspective. In: Journal of Industrial Ecology 41 (2), S. 133. DOI: 10.1111/jiec.13211.

Oliveira, P.; Kilchert, S.; May, M.; Panzera, T.; Scarpa, F.; Hiermaier, S. (2021): Numerical and experimental investigations on sandwich panels made with eco-friendly components under low-velocity impact. In: Journal of Sandwich Structures & Materials. DOI: 10.1177/10996362211020428.

Oliveira, P.; May, M.; Kilchert, S.; Ávila de Oliveira, L.; Panzera, T. H.; Placet, V. et al. (2021): Eco-friendly panels made of autoclaved flax composites and upcycled bottle caps core: experimental and numerical analysis. In: Composites Part C: Open Access 4 (1–3), S. 100114. DOI: 10.1016/j.jcomc.2021.100114.

Rae, A. S. P.; Kenkmann, T.; Padmanabha, V.; Poelchau, M. H.; Schäfer, F.; Dörfler, M. A.; Müller, L. (2022): Dynamic compressive strength and fragmentation in sedimentary and metamorphic rocks. In: Tectonophysics 824, S. 229221. DOI: 10.1016/j.tecto.2022.229221.

Ramírez-Agudelo, O. H.; Köpke, C.; Guillouet, Y.; Schäfer-Frey, J.; Engler, E.; Mielniczek, J.; Sill Torres, F. (2021): An expert-driven probabilistic assessment of the safety and security of offshore wind farms. In: Energies 14 (17), S. 5465. DOI: 10.3390/en14175465.

Reich, S.; Schäffer, S.; Lück, M.; Wickert, M.; Osterholz, J. (2021): Continuous wave high-power laser propagation in water is affected by strong thermal lensing and thermal blooming already at short distances. In: Scientific reports 11 (1), S. 22619. DOI: 10.1038/s41598-021-02112-6.

Rey-de-Pedraza, V.; Ruiz Ripoll, M. L.; Roller, C.; Cendón, D. A.; Gálvez, F. (2022): Validation of two different analysis techniques to obtain dynamic mechanical properties of concrete using a modified Hopkinson Bar. In: International Journal of Impact Engineering 161 (1), S. 104107. DOI: 10.1016/j.ijimpeng.2021.104107.

Sauer, C.; Bagusat, F.; Ruiz Ripoll, M.-L.; Roller, C.; Sauer, M.; Heine, A.; Riedel, W. (2022): Hugoniot data and equation of state parameters for an ultra-high performance concrete. In: Journal of Dynamic Behavior of Materials 8 (1), S. 2–19. DOI: 10.1007/s40870-021-00315-6.

Schäfer, K.; Horch, C.; Busch, S.; Schäfer, F. (2021): A heterogenous, reliable onboard processing system for small satellites. In: 2021 IEEE International Symposium on Systems Engineering (ISSE). Wien, Österreich, 13.9.–13.10.2021: IEEE.

Schäffer, L.; Föhrenbacher, E.; Waseem, A.; Häring, I.; Finger, J.; Stolz, A. (2021): Large scale landslide and flooding hazard susceptibility assessment using semi-automated frequency ratio (FR) model. In: Proceedings of the 31st European Safety and Reliability Conference (ESREL). Unter Mitarbeit von B. Castanier, M. Cepin, D. Bigaud und C. Berenguer (Hg.), S. 896–903.

Scholz, J.-A.; Oertwig, N.; Delleske, C.; Fischer, K.; Knothe, T.; Stolz, A.; Kohl, H. (2021): Situation awareness monitor and liquidity assessment for enterprise resilience management. Unter Mitarbeit von My University, David Herberger und Marco Hübner. In: CONFERENCE ON PRODUCTION SYSTEMS AND LOGISTICS CPSL 2021; 2nd Conference on Production Systems and Logistics. Online verfügbar unter https://www.repo.uni-hannover.de/bitstream/handle/123456789/11359/Scholz%202021%20-%20Situation%20Awareness%20Monitor%20And%20Liquidity%20Assessment%20-%20CPSL%202021.pdf?sequence=1&isAllowed=y.

Schott, D. J.; Gabbrielli, A.; Xiong, W.; Fischer, G.; Höflinger, F.; Wendeberg, J. et al. (2021): Asynchronous chirp slope keying for underwater acoustic communication. In: Sensors 21 (9), Article No. 3282. DOI: 10.3390/s21093282.

Schott, D. J.; Saphala, A.; Fischer, G.; Xiong, W.; Gabbrielli, A.; Bordoy, J. et al. (2021): Comparison of direct intersection and sonogram methods for acoustic indoor localization of persons. In: Sensors 21 (13). DOI: 10.3390/s21134465.

Signetti, S.; Heine, A. (2021): Characterization of the transition regime between high-velocity and hypervelocity impact: thermal effects and energy partitioning in metals. In: International Journal of Impact Engineering 151 (2), S. 103774. DOI: 10.1016/j.ijimpeng.2020.103774.

Stilz, M.; Plappert, D.; Gutmann, F.; Hiermaier, S. (2021): A 3D extension of pantographic geometries to obtain metamaterial with semi-auxetic properties. In: Mathematics and Mechanics of Solids, 108128652110333. DOI: 10.1177/10812865211033322.

Suarez-Del Fueyo, R.; Junge, M.; Lopez-Valdes, F.; Gabler, H. C.; Woerner, L.; Hiermaier, S. (2021): Injury patterns within clusters of seriously injured occupants comparing real-world crashes in the United States and the European Union. In: Traffic injury prevention, S. 1–10. DOI: 10.1080/15389588.2020.1862805.

Sutherland, C.; Reynaert, E.; Sindall, R. C.; Riechmann, M. E.; Magwaza, F.; Lienert, J. et al. (2021): Innovation for improved hand hygiene: Field testing the Autarky handwashing station in collaboration with informal settlement residents in Durban, South Africa. In: The Science of the total environment 796, S. 149024. DOI: 10.1016/j.scitotenv.2021.149024.

Trippel, A.; Gutmann, F.; Ganzenmüller, G. C.; Hiermaier, S. (2021): 2D numerical simulation of auxetic metamaterials based on global DIC. In: EPJ Web of Conferences 250 (12), S. 2002. DOI: 10.1051/epjconf/202125002002.

Trube, N.; Riedel, W.; Boljen, M. (2021): How muscle stiffness affects human body model behavior. In: Biomedical engineering online 20 (1), S. 53. DOI: 10.1186/s12938-021-00876-6.

Tu, H.; Fung, T. C.; Tan, K. H.; Riedel, W. (2022): An analytical model to predict spalling and breaching of concrete plates under contact detonation. In: International Journal of Impact Engineering 160 (S1), S. 104075. DOI: 10.1016/j.ijimpeng.2021.104075.

Varga, M.; Herr, M.; Widder, L.; Campos, L. A. de; Mermagen, J. (2021): Ceramic-rubber hybrid materials – A knowledge-based design concept. In: Wear 267 (1), S. 203735. DOI: 10.1016/j.wear.2021.203735.

Wolfrum, J.; Eibl, S.; Oeltjen, E.; Osterholz, J.; Wickert, M. (2021): High-energy laser effects on carbon fiber reinforced polymer composites with a focus on perforation time. In: Journal of Composite Materials 55 (16), S. 2249–2262. DOI: 10.1177/0021998320988885.

Xiong, W.; Bordoy, J.; Gabbrielli, A.; Fischer, G.; Schott, D. J.; Höflinger, F. et al.: Two efficient and easy-to-use NLOS mitigation solutions to indoor 3-D AOA-based localization. In: Proceedings of the 2021 International Conference on Indoor Positioning and Indoor Navigation (IPIN), S. 1–8.

Xiong, W.; Bordoy, J.; Schindelhauer, C.; Gabbrielli, A.; Fischer, G.; Schott, D. J. et al. (2021): Data-selective least squares methods for elliptic localization with NLOS mitigation. In: IEEE Sensors Letters 5 (7), S. 1–4. DOI: 10.1109/LSENS.2021.3087422.

Zalitis, I.; Dolgicers, A.; Zemite, L.; Ganter, S.; Kopustinskas, V.; Vamanu, B. et al. (2021): A linearized numerical solution for steady-state simulations of gas networks. In: Latvian Journal of Physics and Technical Sciences 58 (3), S. 137–153. DOI: 10.2478/lpts-2021-0022.

Zehetner, J.; Häring, I.; Weber, U.; Riedel, W. (2021): Eye-tracking based quantification of the safety of human-machine interfaces of complementary protective system functions. In: International Journal of Occupational and Environmental Safety 5 (2), S. 1–13. DOI: 10.24840/2184-0954_005.002_0001.

Publications in books, specialist journals and proceedings without peer review

Altes, A.; Schaufelberger, B.; Matura, P. (2021): Modeling the mechanical behavior of a Li-ion pouch cell under three-pont bending. In: Proceedings of the 13th European LS-DYNA Conference 2021. Ulm.

Busch, S.; Horch, C.; Schäfer, K.; Schimmerohn, M.; Schäfer, F. (2021): A flexible test and operations automation framework for agile satellite engineering. In: Workshop on Simulation and EGSE for Space Programmes (SESP), 30.3.–1.4.2021.

Gutmann, F. (2021): Pantographische Struktur mit mikroskopischen Gelenken als programmierbares Metamaterial. In: Newsletter Fraunhofer Kompetenzfeld Additive Fertigung, Bd. 2.

Herr, M.; Varga, M.; Mermagen, J.; Rodinger, S.; Harwick, W. (2021): Ceramic-rubber hybrid materials – A way to sustain abrasive heavy impact applications. In: Proceedings of the 13th European LS-DYNA Conference 2021. Ulm.

Heß, S. (2021): Potenzial der Digitalisierung für die Gefechtsausbildung auf Truppenübungsplätzen mit scharfem Schuss. In: Wehrwissenschaftliche Forschung Jahresbericht 2020. Wehrwissenschaftliche Forschung für die deutschen Streitkräfte.

Jacka, C.; Peña, S.; Ordonez, R. C.; Lingard, D.; Neudegg, D.; Stamatescu, V. et al. (2021): Demonstration of a hybrid space architecture during RIMPAC 2020. In: Proceedings of the 35th Small Satellite Conference.

Kappe, K. (2021): Sustainable design with topology optimization for laser powder bed fusion of metals. In: Newsletter Fraunhofer Kompetenzfeld Additive Fertigung, Bd. 1.

Kappe, K.; Bihler, M.; Morawietz, K.; Pfaff, A.; Bierdel, M.; Huber, J. et al. (2021): Investigation of additively manufactured structurally integrated heat pipes for CubeSats. In: Proceedings of the 72nd International Astronautical Congress (IAC). Dubai, 25.–29.10.2021.

Kappert, H.; Schopferer, S.; Döring, R.; Ziesche, S.; Olowinsky, A.; Naumann, F. et al. (2021): Smart sensor systems for extremely harsh environments. In: Proceedings of the SMSI 2021, Sensor and Measurement Science International. Digital Conference, 3–6 May, 2021. Wunstorf, 3.–6.5.2021: AMA Service, S. 81–82.

Labusch, C.; Matura, P.; Schaufelberger, B. (2022): Strömungssimulationen eines Klassenzimmers – Aerosolausbreitung und Lüftungskonzepte im Kontext der Corona-Pandemie. In: 15. Anwendertreffen der FDS Usergroup – Tagungsband. Berlin, 4.–5.11.2021, S. 99–110.

n. a. (2021): Lego-Auto-Crash mit Highspeed-Röntgendiagnostik. In: c't (1). Online verfügbar unter https://www.heise.de/select/ct/2021/1/2031410504421478307.

Putzar, R.; Schäfer, F. (2021): Vulnerability of spacecraft nickel-cadmium batteries to hypervelocity impacts. In: Proceedings of the 8th European Conference on Space Debris.

Reich, S.: Application Note des Herstellers: Messung der Oberflächenveränderungen durch Laser-Bestrahlung (700 °C). In: Micro-Epsilon 2021.

Sauer, C.; Heine, A.; Riedel, W. (2022): Development of numerical models for the ballistic response of building materials. In: Periodic Bulletin of the International Ballistics Society (11), S. 8–9.

Schaufelberger, B.; Matura, P. (2021): Ausbreitung exhalierter Aerosole in Innenräumen – Strömungssimulationen im Hinblick auf SARS-CoV-2. In: 14. Anwendertreffen der FDS Usergroup – Tagungsband, S. 77–87.

Schimmerohn, M.; Ledford, N.; Putzar, R.; Horch, C.; Busch, S.; Millinger, M.; Schäfer, F. (2021): LArID: Concept of a large area low resource integrated impact detector. In: Proceedings of the 72nd International Astronautical Congress (IAC). Dubai, 25.–29.10.2021.

Zakharova, M.; Mikhaylov, A.; Reich, S.; Plech, A.; Kunka, D. (2021): Bulk morphology of porous materials at submicrometer scale studied by multi-modal X-ray imaging with Hartmann masks. Online verfügbar unter https://arxiv.org/pdf/2110.07475.pdf.

Scientific exchange, lectures

Lectures at congresses, symposia, colloquia, external seminars and important working conferences

Altes, A.; Schaufelberger, B.; Matura, P. (05.2021): Modeling the Mechanical Behavior of a Li-Ion Pouch Cell under Three-Point Bending. 13th European LS-DYNA Conference. Ulm, 5.–7.10.2021.

Arnold-Keifer, S.; Imbert, M.; Groß, N.; May, M. (2021): Towards controlled peeling as a process to recover reusable organosheet laminae. 8th ECCOMAS Thematic Conference on the Mechanical Response of Composites: COMPOISTES 2021. Online, 22.9.2021.

Aurich, H.; Strobl, M.; Denefeld, V. (2021): Sprengphysik am Ernst-Mach-Institut (EMI) am Beispiel Munitionssicherheit. Explosivstoffgespräch 2021 (EXG21). Online, 26.4.2021.

Boljen, M.; Klein, H.; Jenerowicz, M.; Trube, N. (2021): How to Combine 3D Textile Modeling with Latest FE-HBM. ECCOMAS Congress & 14th WCCM, 11.1.2021.

Boljen, M.; Lienhard, J. (2021): Untersuchungen zur Crashsicherheit von E-Scooter-Fahrern – das Projekt HUMAD. *crash*MAT-Workshop, 29.9.2021.

Busch, S. (2021): A flexible test and operations automation framework for agile satellite engineering. Workshop on Simulation and EGSE for Space Programmes (SESP), 30.3.2021.

Crabbe, S. (2021): Präsentation von SAFETY4RAILS. 9. Sitzung der EU rail and passenger security platform (RAILSEC). Online, 16.2.2021.

Crabbe, S. (2021): Präsentation von SAFETY4RAILS unter der Schirmherrschaft der Community of European Research and Innovation for Security (CERIS). Online, 5.5.2021.

Crabbe, S. (2021): Präsentation von SAFETY4RAILS unter der Schirmherrschaft der Community of European Research and Innovation for Security (CERIS). Online, 14.6.2021.

Crabbe, S. (2021): Präsentation von SAFETY4RAILS bei einem virtuellen Treffen zwischen der DG MOVE SECURITY und European Organisation for Security (EOS) (Integrated Border Security and Soft Target and Critical Infrastructure Protection Working Groups. Online, 10.9.2021.

Denefeld, V.; Aurich, H. (2021): Einbettung einer skalierten Ladung im Quarzsand. WTD 91. Meppen, 9.6.2021.

Finger, J.: Stadtsicherheit 3D. Vierteilige Prävinarreihe März bis Mai 2021. Deutscher Präventionstag.

Finger, J.; Schilling, A. (2021): Bewertung der urbanen Sicherheit mit 3D-Stadtmodellen. 26. Deutscher Präventionstag. Deutscher Präventionstag gemeinnützige GmbH. Online, 5.10.2021. Online verfügbar unter https://www.praeventionstag.de/nano.cms/vortraege/id/5329.

Gutmann, F. (2021): Additive manufacturing of non-assembly systems. SCHARF Kolloquium. Carl-Zeiss-Stiftung, 28.7.2021.

Gutmann, F. (2021): Promotion Florian Gutmann. CPM-Vernetzungstag, Fraunhofer Forschungscluster Programmierbare Materialien, 26.10.2021.

Heldt, C.; Nau, S. (2021): Future Combat Training System, Sicheres Üben in realitätsnahen, komplexen Szenarien im scharfen und simulierten Schuss. DWT, SGW-Forum: Wirkung und Schutz #neu, Klassische und künftige Aspekte, Wechselwirkungen und Resilienz. Bonn, 20.9.2021.

Heunoske, D.; Lück, M.; Wickert, M.; Osterholz, J. (2021): Spectroscopic and interferometric investigation of plasma dynamics in high-power cw laser-matter interaction. Global Summit and Expo on Laser Optics and Photonics (GSELOP). Paris, 2021.

Heusinger, V. (2021): Interview mit der Wissenschaftlerin und Gruppenleiterin am EMI Dr. Victoria Heusinger »Traut Euch!« Über eine Karriere in der Forschung, 2021. Online verfügbar unter https://www.emi.fraunhofer.de/de/karriere/-traut-euch---interview-mit-dr--victoria-heusinger.html.

Hoschke, K. (2021): Sustainable design for structural components, Process-specific topology optimization with SLM resource modeling. Rapid.Tech, Fraunhofer-Fachforum »Nachhaltigkeit durch additive Fertigung«, 22.6.2021.

Jenerowicz, M. (2021): Aktuelle Forschungsarbeiten am EMI – Blastbelastungen, Knochensurrogate, Wheelcharity, dynamisches Röntgen. CTS Dummy-Crashtest-Konferenz, 30.9.2021.

Kappe, K. (2021): Additive manufacturing of structurally integrated heat pipes for cubesats. 5th ESA CubeSat Industry Days Industry CubeSat Subsystems, Products and Technologies, 1.6.2021.

Kappe, K. (2021): Investigation of additively manufactured structurally integrated heat pipes for cubeSats. 72nd International Astronautical Congress (IAC). Dubai/Online, 25.10.2021.

Köpke, C. (2021): Impact of Distance Rules on Infrastructure Resilience. ESREL 2021. Online, 19.9.2021.

Köpke, C. (2021): Resilience Quantification for Critical Infrastructure: Exemplified for Airport Operations. ESORICS 2021 CPS4CIP 2021. Online, 4.10.2021.

Leost, Y.; Bösl, P.; Butz, I.; Kurfiß, M.; Heilmaier, J.; Griesemann, J.; Salamon, M. (2021): The Gap Between Experiment And Simulation Thanks To X-Ray Car Crash: Example Of A MPDB Based Scenario. Cahrs CAE Grand Challenge 2021. Hanau, 1.10.2021.

Matura, P. (2021): Aerosolen auf der Spur! Von der Forschung zum effizienten Infektionsschutz. Lunch-&-Learn-Veranstaltung der Simulationsfirma HTCO GmbH, 19.10.2021.

Mert, D. (2021): Test stand for combined temperature and vibration loads. eHarsh-Seminar. Online, 30.11.2021.

Miller, N. (2021): A Risk and Resilience Approach for Railway Networks. ESREL 2021. Online, 19.9.2021.

Nau, S.; Pilous, N. (2021): Zünder für moderne Schutz- und Munitionskonzepte, Fragen zur Technik und zu normativen Randbedingungen. 8. Nationaler Workshop für Zündertechnologie: Schwerpunkt »Alternative Zündkette«. Unterlüß, 21.9.2021.

Patil, S. (2021): Towards programming the strain rate dependency into mechanical metamaterials. 13th International Conference on Mechanical and Physical Behaviour of Materials under Dynamic Loading: DYMAT 2021. Madrid, 20.9.2021.

Pfaff, A. (2021): Metal additive manufacturing: application concepts for effectors and protection. European Military Additive Manufacturing Symposium. Bonn, 12.10.2021.

Ramin, M. von (2021): Methodology for classifying building damage in dynamically loaded structures. Seismic Design of Industrial Facilities, SeDIF. Online, 1.–2.3.2021.

Riedel, W. (2021): Persönliche Schutzausrüstung für zukünftige Anforderungen: besondere ballistische Bedrohungen, neue Materialien und ihre Projektilinteraktion. Symposium System Soldat. WIWeB Erding. Online, 9.11.2021.

Riedel, W.; Boljen, M.; Straßburger, E.; Lahm, K. U. (2021): Virtuelle Methoden zur Auslegung von Körperschutz – von individueller Anpassung bis zum Response Design mit einem Human Body Model. DWT-Tagung Wirkung und Schutz #neu. Bonn, 20.9.2021.

Schaufelberger, B.; Matura, P. (2021): Ausbreitung exhalierter Aerosole in Innenräumen – Strömungssimulationen im Hinblick auf SARS-CoV-2. 14. Anwendertreffen der FDS Usergroup. Online, 6.5.2021.

Schaufelberger, B.; Matura, P.; Labusch, C. (2021): Strömungssimulationen eines Klassenzimmers – Aerosolausbreitung und Lüftungskonzepte im Kontext der Corona-Pandemie. 15. Anwendertreffen der FDS Usergroup. Berlin, 4.11.2021.

Schaufelberger, B.; Trondl, A.; Kisters, T.; Altes, A.; Fehrenbach, C.; Sun, D.-Z. et al. (2021): BATTmobil und Battmobil-2, Projektübersicht. Workshop zur Kooperation im Rahmen der Transferinitiative SURF (Smart Urban Road Safety). Freiburg, 21.10.2021.

Schimmerohn, M. (2021): Numerical simulations of collisional fragmentations. 1st European Hypervelocity Impact Risk Assessment Forum, 24.11.2021.

Schneider, J.; Ramin, M. von (2021): Derivation of a debris launch velocity equation for deflagration type explosions. MSIAC Technical Meeting – 1.3 issues. Online, 7.12.2021.

Schneider, J. et al. (2021): Physics based injury model for blast overpressure effects to the thorax. Blast Injury Conference 2021. Online, 9.7.2021.

Schopferer, S. (2021): Dynamic pressure sensor characterization by shock tube tests. eHarsh-Seminar. Online, 30.11.2021.

Shrivastava, K. (2021): Impact Propagation Simulation. 3S Clustering Event, Satie and SecureGas final conference. Fodele, Kreta, Greece, 12.10.2021.

Stolz, A. (2021): Sicherer in unsicheren Zeiten mittels effizienter Resilienz. Fachtagung Sicherheit und Gesundheit in der Warenlogistik. Dresden, 13.9.2021.

Stolz, A. (2021): Aufbruch in eine resiliente Gesellschaft. Local Lounge Gesellschaftliche Resilienz im Spiegel wirtschaftlicher, digitaler und soziologischer Veränderungen. Tax Excellence Network München, 28.9.2021.

Stolz, A. (2.2021): Impulsreferat Resilience Engineering – mehr Sicherheit bei großer Unsicherheit ermöglichen. ETG-CIRED-Workshop 2021 (D-A-CH) Innovationen im Verteilernetz. München, 2.–3.11.2021.

Straßburger, E. (2021): Transparent Armor – Proposal of test configurations for the assessment of new materials. Israel-German Collaboration Meeting. Fraunhofer IKTS. Dresden, 27.10.2021.

Seminar lectures at EMI

Günther, S. (2021): Das neue europäische Forschungsrahmenprogramm Horizon Europe. EMI-Hausseminar, 20.5.2021.

Hoschke, K. (2021): Nachhaltiges Design für die additive Fertigung. Ein methodischer Rahmen und Modelle für die Automatisierung. EMI-Doktorandenseminar, 26.2.2021.

Hoschke, K. (2021): Probevortrag zur Disputation »Nachhaltiges Design für die additive Fertigung. Ein methodischer Rahmen und Modelle für die Automatisierung«. EMI-Doktorandenseminar, 15.10.2021.

Jäcklein, M. (2021): Entwicklung von Metall-Matrix-Verbundwerkstoffen im LPBF-Verfahren. EMI-Doktorandenseminar, 17.9.2021.

Langkemper, R. (2021): Die V|tome|x beschert uns tiefe und detaillierte Einblicke oder: Rund um die neue CT-Anlage. EMI-Hausseminar, 15.7.2021.

Pfaff, A. (2021): Probevortrag zur Disputation »Bestimmung von Abkühlraten zur Realisierung gradierter L-PBF Werkstoffe (+Metallografie)«. EMI-Doktorandenseminar, 17.12.2021.

Reich, S. (2021): 2D-Triangulation als Messtechnik für in-situ Oberflächenmessung bei Laserbeschuss möglich. EMI-Hausseminar, 25.11.2021.

Courses of the Carl-Cranz-Gesellschaft

Busch, S. (2021): Introduction to Machine Learning and Visual Pattern Recognition. 21IN-5.18, 5.10.2021.

Häring, I. (2021): Bestimmung von SIL-Anforderungen im Vergleich. Funktionaler Sicherheitsnachweis für wehrtechnische Systeme. Online, 9.2.2021.

Courses at the Federal Academy of Education and Training in the Bundeswehr, Mannheim, Germany

Nau, S. (2021): Messtechnik. Laufbahnlehrgang Fachgebietsbezogene Wehrtechnik, Systembewaffnung und Effektoren (SBE), A/HAT-WT: FWT/SBE 01-21 123./124. htD, LG-Nr. 904435. Mannheim, 20.1.2021.

Nau, S. (2021): Messtechnik. Laufbahnlehrgang Fachgebietsbezogene Wehrtechnik, Systembewaffnung und Effektoren (SBE), A/GT-WT: FWT/SBE 01-21, LG-Nr. 902356. Online, 5.5.2021.

Lectures

Balle, F. (Sommersemester 2021): Lab Course Engineering Materials and Testing Methods. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Balle, F. (Sommersemester 2021): Nachhaltige Materialien. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Balle, F. (Sommersemester 2021): Ringvorlesung Methoden der Materialwissenschaften. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Balle, F. (Sommersemester 2021): Sustainable Systems Engineering. Studienprojekt. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Balle, F. (Sommersemester 2021): Technische Funktionswerkstoffe. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Ganzenmüller, G. C. (Sommersemester 2021): Angewandte FEM für die Strukturmechanik. Vorlesung und Seminar. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Häring, I. (Sommersemester 2021): Functional Safety: Active Resilience. Vorlesung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Häring, I. (Wintersemester 2021/2022): Quantification of Resilience. Vorlesung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Häring, I. (Wintersemester 2021/2022): Resilience and Risk Analysis and Management. Vorlesung. Furtwangen University, Wintersemester 2021/2022.

Hiermaier, S. (Sommersemester 2021): Climate Change. Vorlesung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Hiermaier, S. (Sommersemester 2021): Grundlagen resilienter Systeme. Vorlesung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Hiermaier, S.; Ganzenmüller, G. C. (Sommersemester 2021): Werkstoffdynamik: Werkstoffcharakterisierung / Dynamics of Materials: Material Characterization. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Hiermaier, S.; Kilchert, S. (Wintersemester 2021/2022): Life Cycle Analysis. Vorlesung und Übung, Wintersemester 2021/2022.

Hiermaier, S.; Kilchert, S. (Sommersemester 2021): Material Flow Analysis. Vorlesung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Hiermaier, S.; Kilchert, S. (Wintersemester 2021/2022): Material Life Cycles. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Imbert, M. (2021): Vorlesung zur dynamischen Prüfung von Faserverbundwerkstoffen. Lehrveranstaltungsprogramm zur Weiterbildung zum Composite Engineer, Modul »Material- und Bauteilcharakterisierung«, Fraunhofer IFAM.

Matura, P. (Wintersemester 2021/2022): Numerische Methoden in der Mathematik. Vorlesung. DHBW Lörrach, Wintersemester 2021/2022.

Matura, P.; Hiermaier, S. (Wintersemester 2021/2022): Kontinuumsmechanik. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

May, M. (Sommersemester 2021): Adhesive Bonding. Vorlesung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

May, M. (Sommersemester 2021): Dynamics of Materials. Vorlesung. Universitat de Girona, Sommersemester 2021.

May, M.; Imbert, M. (Wintersemester 2021/2022): Composite Materials. Vorlesung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Osterholz, J. (Sommersemester 2021): High-Energy-Density Physics. Vorlesung. Heinrich-Heine-Universität Düsseldorf, Sommersemester 2021.

Ramin, M. von (Sommersemester 2021): Lehrbeauftrager im Masterstudiengang »Katastrophenvorsorge und -Management«, Unterrichtseeinheit »Bauliche Prävention im Bevölkerungsschutz« im Modul »Ausgewählte Konzepte und Maßnahmen der Katastrophenvorsorge«. Rheinische Friedrich-Wilhelms-Universität Bonn, Sommersemester 2021.

Riedel, W. (Wintersemester 2021/2022): Schutz kritischer Infrastrukturen. Vorlesung. Furtwangen University, Wintersemester 2021/2022.

Sauer, M. (Wintertrimester 2021): Laborpraktikum. Universität der Bundeswehr München, Wintertrimester 2021.

Sauer, M. (Wintertrimester 2021): Numerische Simulationsverfahren. Vorlesung. Universität der Bundeswehr München, Wintertrimester 2021.

Sauer, M. (Wintertrimester 2021): Werkstoffcharakterisierung. Vorlesung. Universität der Bundeswehr München, Wintertrimester 2021.

Schäfer, F. (Wintersemester 2021): Charakterisierung von Geomaterialien unter Stoßbelastung I, Characterization of Geomaterials under Shock Loads I. Vorlesung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021.

Schäfer, F. (Sommersemester 2021): Charakterisierung von Geomaterialien unter Stoßbelastung II, Characterization of Geomaterials under Shock Loads II. Vorlesung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Schimmerohn, M. (Wintersemester 2021/2022): Satellite Technology – Micrometeoroids and Space Debris. Vorlesung in der Lehrveranstaltung Spacecraft System Analysis im Masterstudiengang Space Science and Technology. Julius-Maximilians-Universität Würzburg, Wintersemester 2021/2022.

Stolz, A. (Sommersemester 2021): Design and Monitoring of large Infrastructures. Vorlesung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Stolz, A. (Sommersemester 2021): Resilience of Supply Networks. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2021.

Stolz, A. (Wintersemester 2021/2022): Robustness of Structures. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

van der Woerd, J. D. (Wintersemester 2021/2022): Spezielle Kapitel aus dem Massivbau. Hochschule Augsburg, Wintersemester 2021/2022.

Visiting scientists at EMI

Amlung, Elena 21.6.2021–13.9.2021.

Ballal, Niranjan 1.8.2021–31.12.2021.

Fransson, Matilda, European Synchrotron Radiation Facility (ESRF), Grenoble, 20.9.2021–1.10.2021.

Hofmann, Julia 21.6.2021–13.9.2021.

Jain, Atin 16.11.2020–31.8.2022.

Nasr, Engy 1.3.2021–28.2.2022.

Oliveira, Pablo Resende 1.6.2018–31.5.2022.

Padmanabha, Vivek 15.4.2019–14.12.2021.

Plappert, David 15.5.2021–30.4.2023.

Schalm, Tobias 1.1.2022–31.7.2022.

Schmidt, Steffen 21.6.2021–13.9.2021.

Song, Billy 7.7.–9.7.2021.

Trippel, Antonina 16.1.2019–31.12.2022.

Vattem, Lalita Yamini 1.12.2021–31.3.2022.

Yu-Sheng, Tang 15.3.2021–14.9.2021.

PhD

Bauer, S. (2021): Novel Experimental and Analytical Concepts for the Characterization and Modeling of Soda-Lime Glass under Impact Conditions. Dissertation. Universität der Bundeswehr, München.

Hoschke, K. (2021): Sustainable Design with Topology Optimization for Laser Powder Bed Fusion of Metals. Dissertation. Albert-Ludwigs-Universität Freiburg.

Bachelor, master and diploma theses

Altas, C. (2021): Implications of COVID-19 Spread for Critical Infrastructure Implications of COVID-19 Spread for Critical Infrastructure - Identifying Change Points and Inferring Relations to COVID-19 Interventions. Master Thesis. EMI Report A 03/21. Universität Basel.

Amlung, E. (2021): Numerische Simulationen der Wechselwirkung von Hartkern-Projektilen mit geneigten Zielstrukturen. Bachelorarbeit. EMI-Bericht A 44/21. DHBW Mannheim.

Arunagiri, H. H. P. (2021): Multi-Objective Optimization of Crash-Box Filled with Functionally Graded Cellular Lattice Structures. Master Thesis. EMI Report A 15/21. Universität Duisburg Essen.

Bhatnagar, M. (2021): Discrete-event Simulation of Border Control Points using Monte-Carlo Methods. Master Thesis. EMI Report A 22/21. Hochschule Heidelberg.

Bihler, M. (2021): Investigation of wick structures of 3D-printed heat pipes for CubeSat applications. Master Thesis. EMI Report A 16/21. Universität Stuttgart.

Bruneau, A. (2021): Innovative recycling method for Organosheets. Master Thesis. EMI Report A 45/21. École Centrale de Nantes.

Elaprolu, S. (2021): Reliability and safety analysis of ground and aerial chemical plant inspection robots. Master Thesis. EMI Report A 53/21. Hochschule Heidelberg.

Elgazzar, R. (2021): Spray pyrolysis of novel material system for cost-effective production processes in photovoltaics. Master Thesis. Albert-Ludwigs-Universität Freiburg.

Feix, W. (2021): Smart Coating – Materialcharakterisierung von Polyurea als Beschichtung zum Explosionsschutz. Masterarbeit. EMI-Bericht A 54/21. Technische Hochschule Mittelhessen.

Felde, R. (2021): Numerische Simulation und Optimierung stationärer Gasflüsse. Masterarbeit. EMI-Bericht A 56/21. Albert-Ludwigs-Universität Freiburg.

Groß, N. (2021): Methodenuntersuchung des Peeling-Tests zur Risspropagation an Faserverbundwerkstoff. Bachelorarbeit. EMI-Bericht A 33/21. DHBW Lörrach.

Hagner, N. (2021): Calculating Radiative Exchange Factors for Spacecraft with Monte Carlo Raytracing. Bachelorarbeit. EMI Report A 09/21. Albert-Ludwigs-Universität Freiburg.

Hofmann, A. (2021): Charakterisierung und Modellierung der Charakterisierung und Modellierung der mechanischen Eigenschaften thermisch vorbelasteter POM-Zugproben. Masterarbeit. EMI-Bericht A 04/21. Technische Hochschule Mittelhessen.

Hofmann, J. A. (2021): Auslegung und Charakterisierung von Infrarot-Messtechnik für Untersuchungen zur Wirkung hochenergetischer Laserstrahlung. Bachelorarbeit. EMI-Bericht A 43/21. DHBW Mannheim.

Hörnle, O. (2021): Thermo-hydraulische Simulationen zum Vergleich von Trinkwarmwasser-Systemvarianten für Mehrfamilien-Bestandsgebäude. Masterarbeit. Albert-Ludwigs-Universität Freiburg.

Huang, T.-T. (2021): Enhancing Safety and Performance of State-of-the-Art Mixed Transition Metal Oxide battery by incorporating a novel additive with boron-nitrogen-oxygen alkyl group in electrolyte. Masterarbeit. EMI-Bericht A 23/21. Albert-Ludwigs-Universität Freiburg.

König, L. (2021): Weiterentwicklung und Inbetriebnahme einer Webanwendung zur Bestimmung der Resilienz von Unternehmen. Bachelorarbeit. EMI-Bericht A 58/21. DHBW Lörrach.

Kretschmann, D. (2021): Analytical-empirical determination of the fragmentation process for rectangular im-provised explosive devices Using Autodyn with user subroutines to create fragment data within the project SUSQRA. Bachelor Thesis. EMI Report A 41/21. Hochschule Stralsund.

Lamsairhi, R. (2021): The impact of photovoltaic module building process on the interconnection joint properties for shingled cells. Master Thesis. Albert-Ludwigs-Universität Freiburg.

Linnenberg, M.: Manufacturing and characterization of functionally graded steel microstructures. Master Thesis. Karlsruher Institut für Technologie.

Manam, B. U. (2021): Measuring the Mixed-Mode-I/II Fracture Toughness in Composite Materials Using Wedge Loaded Asymmetric DCB Specimen. Master Thesis. EMI Report A 01/21. Albert-Ludwigs-Universität Freiburg.

Marx, N. (2021): Konstruktion einer Vorrichtung zur aktiven Beeinflussung des Abgangszustands von Geschossen. Bachelorarbeit. DHBW Mannheim.

Mauler, N. (2021): Untersuchung des Peeling-Prozesses als innovatives Recycling-Verfahren für Faserverbundwerkstoffe – Investigation of the peeling process as an innovative recycling process for composites. Bachelorarbeit. EMI-Bericht A 57/21. Universität Stuttgart.

Mert, D. (2021): Kombination von Schlierentechnik und Licht-schnittverfahren zur Strömungssimulation für die Untersuchung von Aerosol-Ausbreitung. Masterarbeit. EMI-Bericht A 48/21. Wilhelm Büchner Hochschule.

Molina, P. (2021): Separation of aluminum bonded joints by thermo-mechanical loadings. Master Thesis. EMI Report A 55/21. Albert-Ludwigs-Universität Freiburg.

Montague, W. (2021): The State of the Art of Modeling and Simulating Urban Climate Resilience. Master Thesis. EMI Report A 21/21. Albert-Ludwigs-Universität Freiburg.

Mues, J. B. (2021): Umsetzung einer Krisenmanagement-Funktion in einer bestehenden Geoinformations-Software. Bachelorarbeit. EMI-Bericht A 47/21. DHBW Lörrach.

Murali, K. (2021): Development of a 2D-triangulation setup for in-situ sample surface measurement during high power laser penetration. Master Thesis. EMI Report A 32/21. Leibniz Universität Hannover.

Pulaparthi, V. P. K. (2021): Experimental Characterization and Numerical Simulation of Heat Transfer when measuring Surface Temperatures with Thermocouples. Master Thesis. EMI Report A 18/21. Universität Duisburg Essen.

Rajendran, R. S. (2021): Local micro analysis of the mechanical PCB performance under shock and impact loading. Master Thesis. Albert-Ludwigs-Universität Freiburg.

Sangam, R. (2021): Effects of tool geometry on ultrasonic welding of Al-Cu dissimilar metals – a FEM studies. Master Thesis. Albert-Ludwigs-Universität Freiburg.

Savin, E. (2021): Strukturauslegung einer optischen Nutzlast für den Einsatz auf der Internationalen Raumstation. Masterarbeit. EMI-Bericht A 20/21. Hochschule München.

Sayed, B. (2021): Detektion und Bewertung von Explosionsereignissen mittels Beschleunigungssensoren. Bachelorarbeit. EMI-Bericht A 34/21. Hochschule Düsseldorf.

Schlager, M. (2021): Additiv gefertigter 17-4PH-Stahl – L-PBF-Prozessparameterentwicklung und Werkstoffbewertung. Bachelorarbeit. EMI-Bericht A 35/21. DHBW Lörrach.

Schmidt, S. (2021): Erprobung neuer Ansätze zur Verarbeitung von reinem Kupfer mittels SLM-Verfahren. Bachelorarbeit. EMI-Bericht A 42/21. DHBW Mannheim.

Shrivastava, S. (2021): Agent-Based Modelling with Group Behaviour and Social Distancing. Master Thesis. EMI Report A 14/21. TU Chemnitz.

Siewert, T. (2021): Entwicklung eines Kinderrückhaltesystems für Flugzeuge mit doppelter Sitzplatzbelegung. Bachelorarbeit. EMI-Bericht A 40/21. DHBW Lörrach.

Tang, Y.-S. (2021): Modeling of the failure of a single-lap hybrid joint under tensile loading. Master Thesis. EMI Report A 50/20. Albert-Ludwigs-Universität Freiburg.

Tritschler, F. (2021): Nutzerorientierte Gestaltung eines Nutzerorientierte Gestaltung eines Livestreams für ein hybrides Webinar am Fraunhofer EMI. Bachelorarbeit. EMI-Bericht A 10/21. DHBW Mannheim.

Turhan, E. (2021): The Effect of Technical Risks on the Achievement of Goals for Distributed Energy Supply Concepts in Residential Neighbourhoods. Master Thesis. Albert-Ludwigs-Universität Freiburg.

Völkl, F. (2021): Optimierung eines Solargenerators für 12U-Nanosatelliten. Masterarbeit. EMI-Bericht A 51/21. Universität Bayreuth.

Wagenfeldt, A. (2021): Evaluation zur Beschichtung von Perowskitschichten für die Anwendung von Tandemsolarzellen. Masterarbeit. Albert-Ludwigs-Universität Freiburg.

Weiland, P. (2021): Auslegung einer optischen Nutzlast für den Einsatz auf der Internationalen Raumstation (ISS) – Design of an optical payload for operation on the International Space Station (ISS). Master Thesis. EMI Report A 39/21. Universität Stuttgart.

Patents

Imbert, M.; Hahn, P.: Verfahren und Vorrichtung zum Recyclen eines mehrere Lagen umfassenden Verbundwerkstoffes. Angemeldet durch Fraunhofer-Gesellschaft. Veröffentlichungsnummer: EP 20 206 012.5, 5.

Patil, S.; Ganzenmüller, G. C.: A deformable structure. Angemeldet durch Fraunhofer-Gesellschaft. Anmeldenummer: EP21196326.9.

Straßburger, E. (2021): Transparente Verbundscheibe mit erhöhter Wirkung gegen Projektile mit Hartmetallkern. Angemeldet durch Fraunhofer-Gesellschaft am 26.10.2021. Veröffentlichungsnummer: 2021102610305900DE.

Workshops and events

EMI-Inhouseseminar zur EU-Forschungsförderung: Das neue EU-Forschungsrahmenprogramm Horizon Europe 19.5.2021.

Imbert, M. (2021): Laborbesichtigung und Präsentation der letzten Aktivitäten zum Thema Recycling. KMU@science. EMI Freiburg, 29.6.2021.

Participation in professional boards, associations and program committees

Günther, S.: Mitglied im Technischen Rat der Fraunhofer-Gesellschaft für Clean Sky 2.

Günther, S.: Mitglied in WG 4 Safety and Security in ACARE (Advisory Council for Aeronautics Research in Europe).

Günther, S.: Repräsentanz der Fraunhofer-Gesellschaft im Steering Committee des JTI Clean Sky 2 Airframe ITD.

Günther, S.: Vertretung des Institutsleiters Prof. Dr.-Ing. S. Hiermaier im Institutsleitungsrat (ILR) der Fraunhofer-Gesellschaft für Clean Sky 2.

Heine, A.: LWAG Lightweight Armour Group.

Jenerowicz, M.: WTD 52 GF 320 »Nichtletale Wirkmittel«: Arbeitsgruppe »Surrogat zur technischen Untersuchung von Letalitätsgrenzen«.

Köpke, C.: Mitgliedschaft in der »Young academy for sustainability research« des FRIAS der Albert-Ludwigs-Universität Freiburg.

Leismann, T.: Vorsitz des Expertenkreises Sicherheitsforschung des Bundesministeriums für Bildung und Forschung (BMBF).

May, M.: American Institute of Aeronautics and Astronautics – International Activities Advisory Committee.

May, M.: American Institute of Aeronautics and Astronautics – International Honors and Awards Development Committee.

May, M.: Scientific Committee VIII Conference on Mechanical Response of Composites ECCOMAS 2021, 22.–24.9.2021.

May, M.: Stellvertretender Vertreter der Fraunhofer-Gesellschaft im Steering Committee Clean Sky 2 AIRFRAME.

May, M.: Stellvertretender Vertreter Fraunhofer VVS im FCAS Masterplan.

May, M.: Vertreter der Fraunhofer-Gesellschaft im Programme Management Clean Sky 2 AIRFRAME.

Putzar, R.: Past Chairman der Aeroballistic Range Association (ARA).

Putzar, R.: Repräsentant des Ernst-Mach-Instituts in der Aeroballistic Range Association (ARA).

Ramin, M. von: Mitarbeit in der Klotz Group.

Ramin, M. von: Mitarbeit in der NATO PFP(AC/326-SG/C) AASTP-4 Custodian Working Group.

Ramin, M. von: Mitglied im Editorial Board »International Journal of Protective Structures«.

Ruiz Ripoll, M. L.: Mitglied der European Structural Integrity Society (ESIS).

Ruiz Ripoll, M. L.: Mitglied der Grupo Español de Fractura (GEF).

Schimmerohn, M.: Chairman of Working Group 3 of the Inter-Agency Space Debris Coordination Committee (IADC), external DLR Delegate.

Schopferer, S.: EDA CnGE (CapTech non-Governmental Expert) for CapTech Components.

Stolz, A.: Appointed International Member im Standing Committee on Critical Transportation Infrastructure Protection, AMR10 im Transportation Research Board USA.

Evaluated excellent research — projects funded by the German Research Foundation (DFG), the German Federal Ministry of Education and Research (BMBF) or the European Research Council

DFG-Projekt »Synergien zum thermomechanischen Ermüdungsverhalten von Polymer-Verbundwerkstoffen im Bereich sehr hoher Lastzyklen«.

DFG-Projekt »Verformungsratenabhängige Spröddeformation von Gestein während der Impaktkraterbildung: Verknüpfung mechanischer Daten mit Mikrostrukturen (DFG SCHA 1612/2-1 Verformungsraten)«.

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DFG-Projekt in der Linie »Neue Geräte für die Forschung«, Förderzeitraum 2021–2023.

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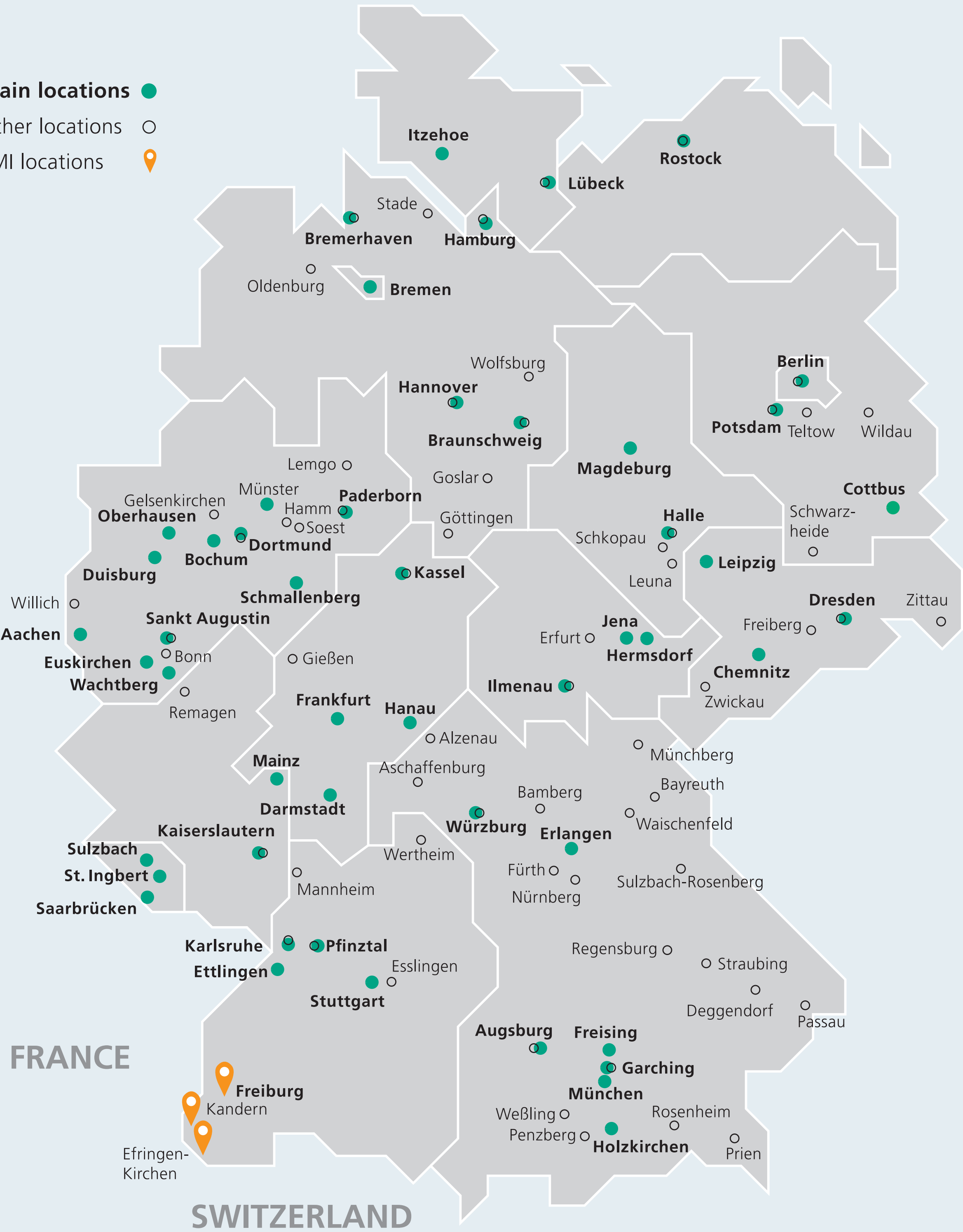

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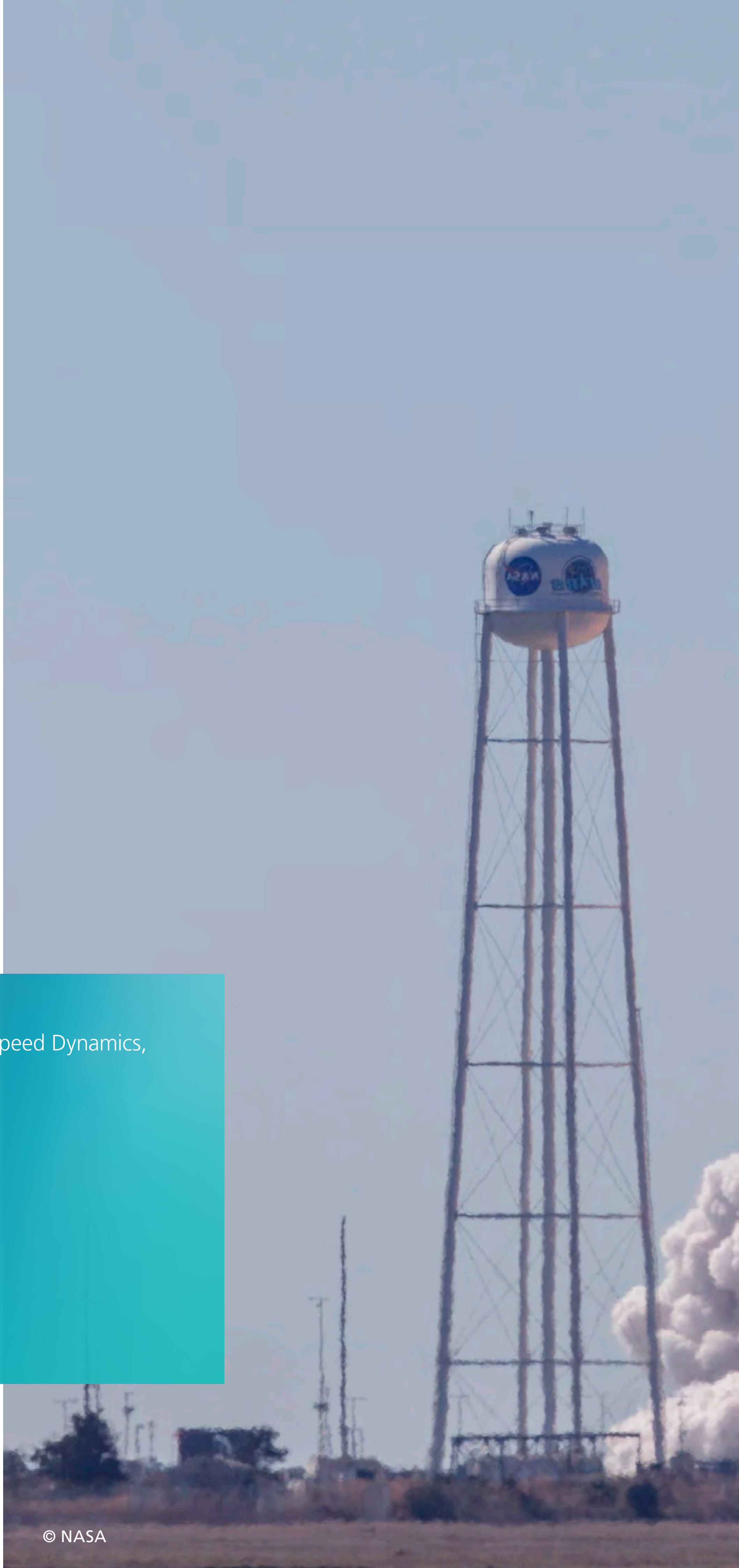

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