Fraunhofer
EMI

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

Annual report 2022/2023

Improved missile defense using nanosatellites

The ERNST nanosatellite is the first small-satellite platform for which the potential to support military tasks of the Bundeswehr is to be demonstrated. It was developed at Fraunhofer EMI with funding from the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw, Bundesamt für Ausrüstung, Informationstechnik und Nutzung der Bundeswehr).

With its high-resolution cryogenically cooled infrared camera, it will detect rocket launches and precisely measure the thermal radiation of the Earth's surface in the medium-wave infrared spectrum.

ERNST was selected for a fly-along opportunity as part of the Space Test Program (STP) of the United States Space Force (USSF) and is scheduled for launch in June 2024 aboard an RS1 launch vehicle from ABL Space Systems.

Cover photo: U.S. Army missile defense test at the Marshall Islands. The rocket was successfully captured and launched six minutes after lift-off. Crosshairs were drawn in to illustrate the satellite view.

Armor and anti-armor are the core topics of defense research at Fraunhofer EMI.

Dear reader,

With this annual report, we are spreading a spotlight on the Fraunhofer Institute for High-Speed Dynamics in extraordinarily challenging times. In the midst of the so-called "Zeitenwende", that is, the re-orientation towards higher priorities of defense endeavors, triggered by the Russian invasion of Ukraine, we are experiencing an unprecedented reduction in the research budget by the Federal Ministry of Defence. We all experience daily how existential the threat of a military aggressor in the middle of Europe can affect the people. At the same time, we observe the necessity, the effectiveness and the shortcomings of existing technologies on the battlefield. The safety and the military success of the defending Ukrainian soldiers depend directly on the quality and the reliability of their weapons. They can only succeed if their armor and weapon effectiveness are superior to those of the attackers.

Armor and anti-armor are the core topics of defense research at EMI. This research is vital in order to ensure that these capabilities of the Bundeswehr and our allies remain superior to those of potential attackers in the future. Unlike propaganda and threats of hypersonic and nuclear missions, real defense readiness deters and, thus, prevents wars. This knowledge gained from the Cold War must be cultivated anew today.

For a "Zeitenwende" to succeed in the long term, a sustainable financial approach that goes far beyond equally necessary short-term procurement measures is needed. The future viability of German defense efforts depends crucially on the quality of defense research and development.

We have proven since the founding of Fraunhofer EMI that our scientific potential contributes preeminently to the defense capability of the Bundeswehr. In this annual report, research currently in progress or recently completed in our business unit Defense is presented as well as the status of the research in our other business units.

I want to thank all our partners, customers and colleagues from the fields of science, economics 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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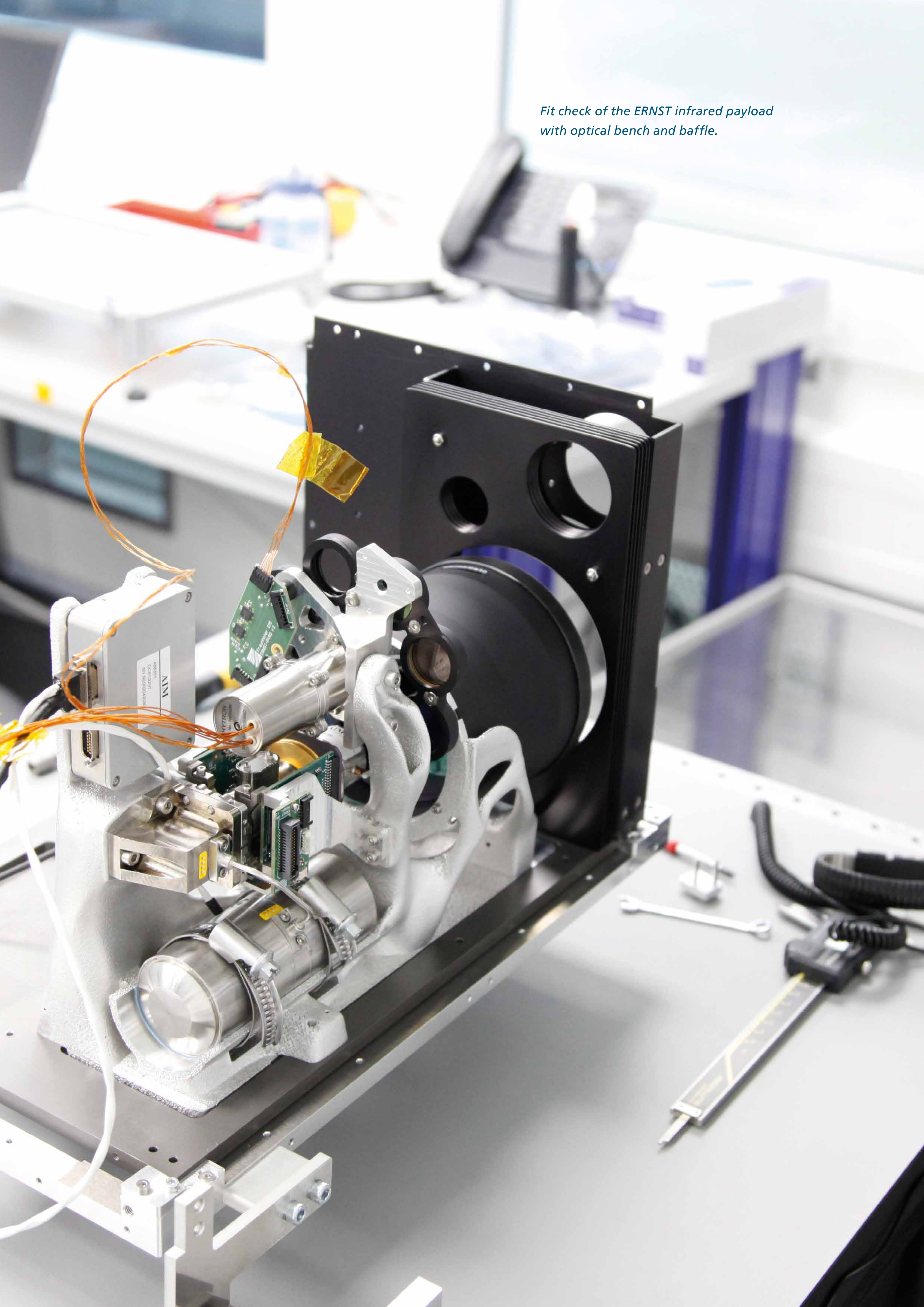

Fit check of the ERNST infrared payload with optical bench and baffle.

Business units

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

The German Federal Armed Forces (Bundeswehr) need future-proof systems and technologies for land, air and sea, as well as for cyberspace. Today, the Bundeswehr includes the military use of space as an essential prerequisite for the effective deployment of modern armed forces.

In cooperation with the Fraunhofer Institutes IOSB and INT, Fraunhofer EMI is using the ERNST small satellite platform to demonstrate the potential of near-Earth space for defense against hypersonic and ballistic missiles.

The technology of the small satellites is an example of how general technology development, driven by economic development opportunities, leads to new solutions for future military capabilities through the connection with in-depth knowledge of defense technology requirements.

In general, our society is experiencing a dramatic change in the way which technological solutions are used to fulfill upcoming tasks due to rapid technological development. This also applies to the application areas of high-speed dynamics and their integration into a digitized system environment.

The Fraunhofer institutes of the Fraunhofer Segment for Defense and Security VVS have the capability to combine general technological progress with the special requirements of defense technology. They contribute to the Bundeswehr being able to deal with the rapid technological changes and benefiting from application-oriented research with improved performance in the future.

Fraunhofer EMI investigates scientific and technological issues in the areas of protection and effects as well as security and systems 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 stress in conjunction with the most modern technologies and exploitation of the potential 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.
We would like to thank the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support of the German Armed Forces (BAAINBw) in Koblenz for funding our research work.

> "We contribute to enabling the Bundeswehr to deal with the rapid technological changes and profit through application-oriented research with improved future performance."
>
> Dr. Matthias Wickert

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Head of business unit Defense
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s.fhg.de/emi-defense

People in Defense research


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Here, we present seven individuals from Defense research.

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First small satellite for the German Armed Forces — 12U CubeSat ERNST for missile detection

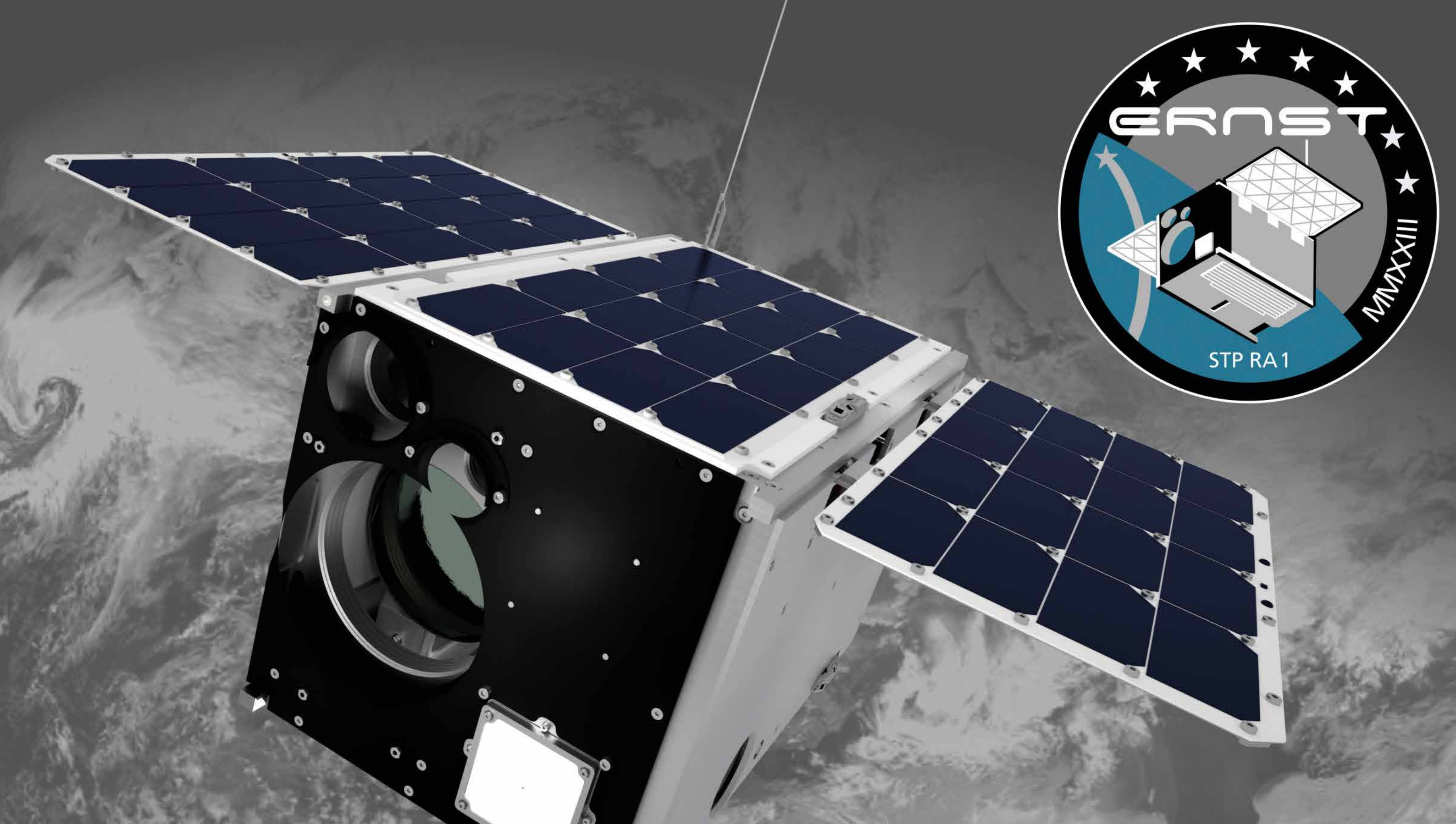
A contribution by Dr. Martin Schimmerohn, martin.schimmerohn@emi.fraunhofer.de

Demonstration of a small, standardized, low-cost satellite in an ambitious mission

With its research project to build a small satellite platform and prepare a mission to investigate potential applications for threat detection, Fraunhofer EMI is making its first substantial contribution to the new capability dimension of space. With the completion of the ERNST flight model, the first small satellite mission for the German Armed Forces is imminent. ERNST is a 12U CubeSat equipped with a cryogenically cooled infrared imager for demonstrating the potential of small satellite technology for military purposes while providing knowledge on early detection of ballistic or hypersonic missiles from low Earth orbit.

The ERNST satellite mission represents a first step in several respects. ERNST is not only the first CubeSat to be demonstrated specifically for the purposes of the German Armed Forces. The small satellite is also the first spacecraft developed by Fraunhofer, which so far has contributed to innovations at component and subsystem level only. ERNST also sets technical standards. Foremost is the demonstration of a complex cryogenically cooled infrared payload in a 12U CubeSat. The "U" for "unit" defines the size metric of the CubeSats, with one unit corresponding to a cube with an edge length of ten centimeters. This gives ERNST external dimensions of 24 by 24 by 36 cubic centimeters with less than 20 kilograms total mass.

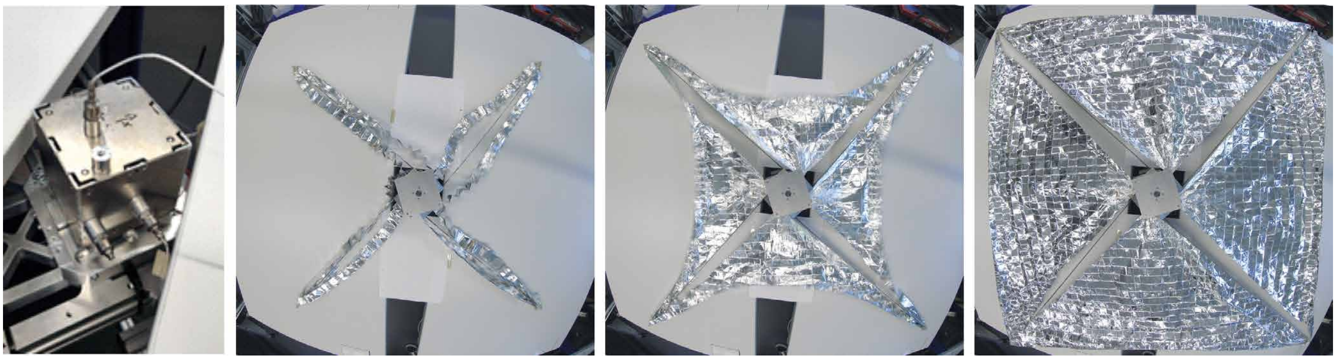
Primary payload of ERNST is an infrared imager, which is used to demonstrate concepts for missile detection developed at Fraunhofer IOSB. Effective detection and tracking of approaching threats demand fast and reliable image exploitation to ensure sufficient time for initiation of countermeasures. The combination of different spectral ranges allows fast and reliable detection of the infrared signature of a missile or hypersonic vehicles during their different operational phases like boost and gliding phases. One of the advantages of early warning from



ERNST mission: 12U CubeSat for demonstrating small satellite and missile detection technologies.

low Earth orbit platforms compared to geostationary wide-field view sensors is the higher spatial resolution leading to a higher signal-to-clutter ratio. A step-stare approach is used for increasing the observation times of ERNST in case of target detection or for realizing higher integration times for weak signals in defined regions of interest along the 96-kilometer swath of ERNST. The ERNST mission will not only collect reference data of the Earth's background in the relevant wavelength ranges, but also characterize the signatures of a missile launch and demonstrate their tracking.

The ERNST main payload is a cryogenically cooled multispectral infrared imaging system consisting of the following elements: 1) an infrared objective, 2) a filter wheel, 3) a pyrometer, 4) an infrared detector, ►


ERNST de-orbit dragsail: stowed subsystem (left) and deployment testing sequence (right).

ERNST main payload: infrared imager.

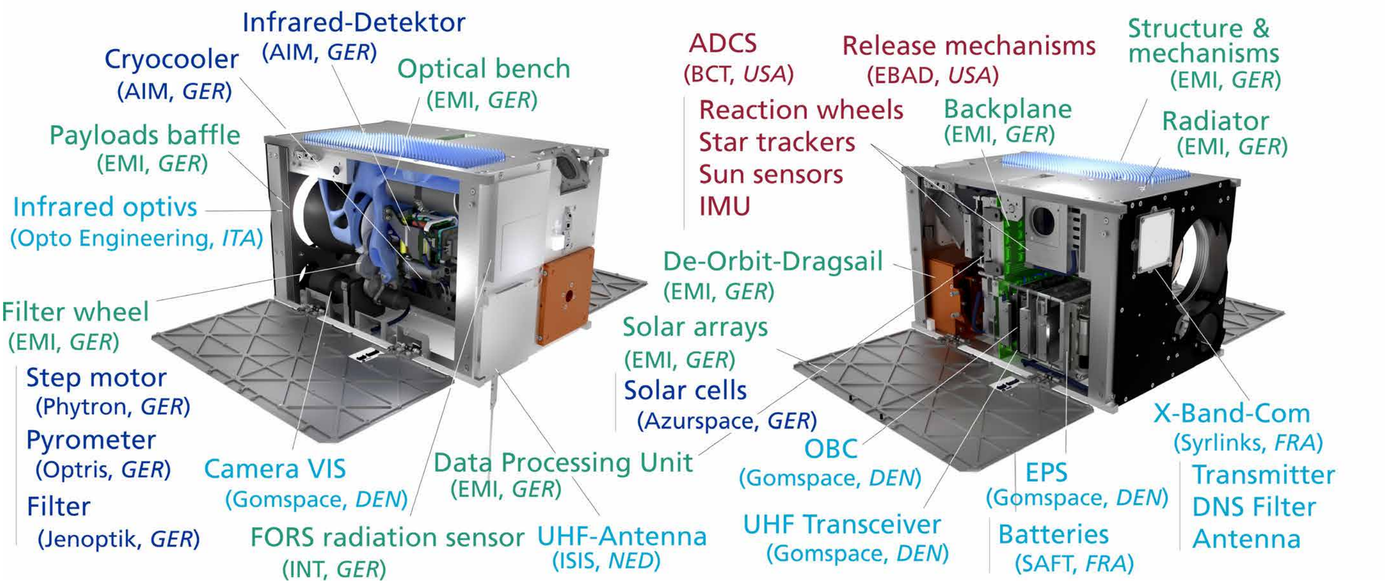
5) a Stirling cryocooler, 6) a data processing unit and 7) an optical bench housing the components. The latter is additively designed and manufactured, which gives it a bionic appearance. It also integrates a 3D-structured radiator for emitting the significant thermal loads of the payload on a much smaller area compared to flat radiators. As for the entire satellite, the development approach of the main payload is combining commercial components, adapted and extensively tested, with in-house solutions developed by Fraunhofer EMI.

Secondary payloads are a visual camera for georeferencing and the radiation monitor FORS developed by Fraunhofer INT. FORS measures the total dose of energetic radiation received by the satellite as well as protons and neutron radiation by using differently shielded electronic memory modules.

Beyond the specific applications of missile detection and radiation monitoring, ERNST will demonstrate the capabilities of small satellites for military utility.

Small satellites are characterized by significantly lower costs, a higher risk tolerance with a verification over certification approach, and a high temporal coverage in a constellation of several small satellites. For the satellite bus, the most powerful CubeSat products available were tested and, if not available, developed in-house at Fraunhofer EMI. For example, a dragsail ensures a rapid de-orbit at the end of the mission for sustainable orbit utilization.

After completion and integration of the platform flight hardware, ERNST is currently prepared for acceptance testing and launch as part of the Space Test Program in cooperation with the US Space Force (page 69). ■



ERNST 12U platform with components and their origin indicated.

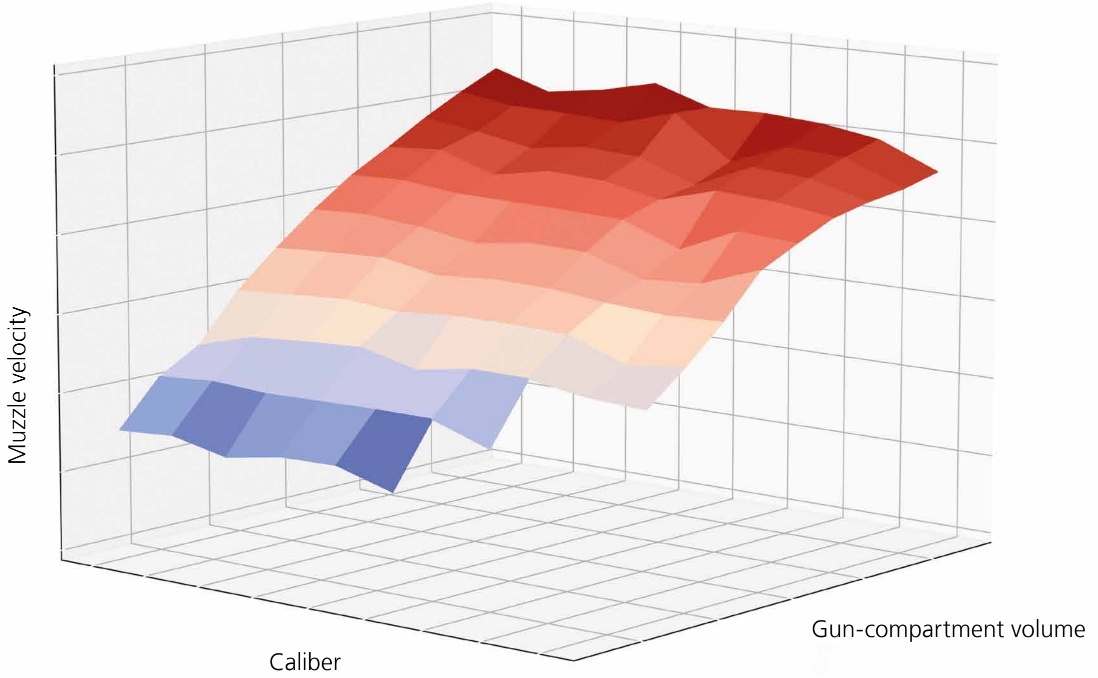
Interior-ballistics software family SimIB for the development of next-generation guns of the Bundeswehr

A contribution by Axel Sättler, axel.saettler@emi.fraunhofer.de, and Nicolas Wilhelm, nicolas.wilhelm@emi.fraunhofer.de

In order to achieve high velocities and for the impact effects on a target, projectiles require kinetic energy which is provided through an interior ballistic propellant system. Inside the gun compartment, first the propellant charge is ignited. The charge usually consists of a large amount of propellant powder grains which feature a distinctive and purpose-driven geometry that tailors their combustion properties. In a short period of time, the pressure rises in the compartment, and the projectile is accelerated. The hot gases from the burning propellant rush through the bore and drive the projectile until it leaves the gun. A high muzzle velocity requires a quick rise in pressure which should then be maintained at high level for as long as possible without exceeding the loading capacity of the system. Fraunhofer EMI provides simulation tools for governmental parties and industry to derive suitable design solutions for specific requirements, for example, demands related to an increased range for future artillery systems. Furthermore, the simulation software allows aspects of safe handling to be evaluated.

Zeitenwende — turning point in history

In the times that followed the Cold War, the profile of actions taken on by the Bundeswehr shifted from defending country and allies to out-of-area missions. This was clearly reflected in the equipment of the forces. Guns, other than rifles, lost importance, as there was a technical superiority compared to the opponents in asymmetric conflicts. Since the annexation of Crimea by the Russian Federation in 2014, but also especially since the invasion of the Ukraine, followed by what was called "Zeitenwende" in 2022 denoting a turning point in German history, this has changed widely. The capability of fighting military conflicts of great intensity and with use of heavy weaponry is now back in focus, most importantly concerning the use of main battle tanks and artillery.



SimIB-0D-based parameter study.

Performance enhancement of guns in the center of interest again
As modernizations have not been conducted in years, it would be risky to still assume technical superiority of the own weapon systems. Modern software tools are necessary to check for options to increase the performance of existing systems and their ammunition or allow to develop superior systems. The tools should therefore reflect the current state of scientific knowledge and provide reliable results with respect to accepted assumptions. It is before this background that Fraunhofer EMI develops a set of modern interior ballistics tools called SimIB. These tools are meant to replace the older simulation programs that date back from the 1980s and 1990s, setting a new national standard.

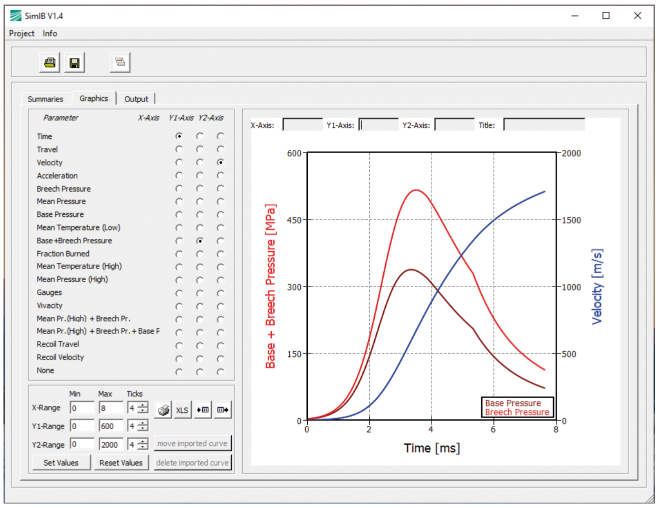
First stage: SimIB-0D
The first part of the software family is presented by SimIB-0D. It is a tool based on the STANAG 4367, which has been successfully used by national authorities and the German industry since 2015. It contains utilities, which allow to investigate classical guns but also two-chamber systems for mortars or grenade launchers and small arms weapons.

The equation solver of the program is independent from the whole tool, making it possible to control it via a scripting language such as python, and utilize it for optimization of a ballistic system. The objective of such an optimization usually is to obtain a high muzzle velocity for the projectile while also not exceeding the mechanical loading limits. This approach also facilitates the evaluation of different powder grain geometries. To assure the safe usage of a gun, a certain pressure limit is not to be exceeded in the bore. In SimIB, this can be considered as an additional boundary condition, meaning this pressure is always acting as a limit which is even possible without using an additional programming language to control the solver. ►

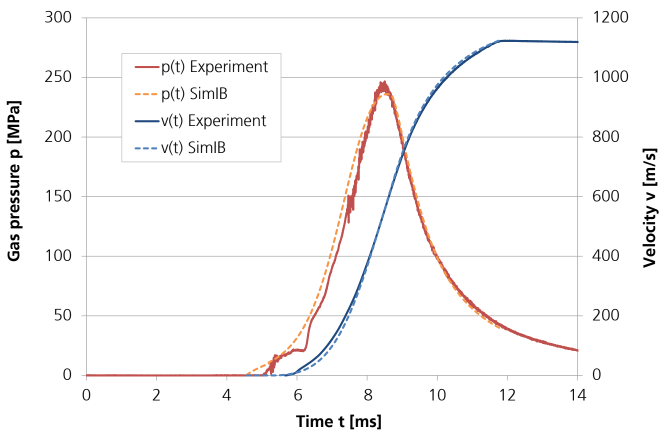
Current research: gasdynamic simulation models
Today, the further variant SimIB-1D is in development. This allows for a gas- or fluid-dynamic observation of interior ballistics processes and provides the possibility to investigate the fluid flux as well as behavior of the powder bed inside the tube.

Especially for large-caliber systems such as gun artillery with larger gun compartments or tank guns that accelerate projectiles to above 1.700 meters per second, the process of ignition is of special interest. With an inadequate design, pressure waves may develop in the gun compartment or the cartridge and, in the worst case, may first lead to breaking of powder grains that may induce gun failure with catastrophic effects on both operators and system. The safety requirements can be analyzed via SimIB-1D. The necessary current version is capable of calculating basic charge designs. In the future, the software is to be successively enhanced in order to provide the same functional capabilities as SimIB-0D.

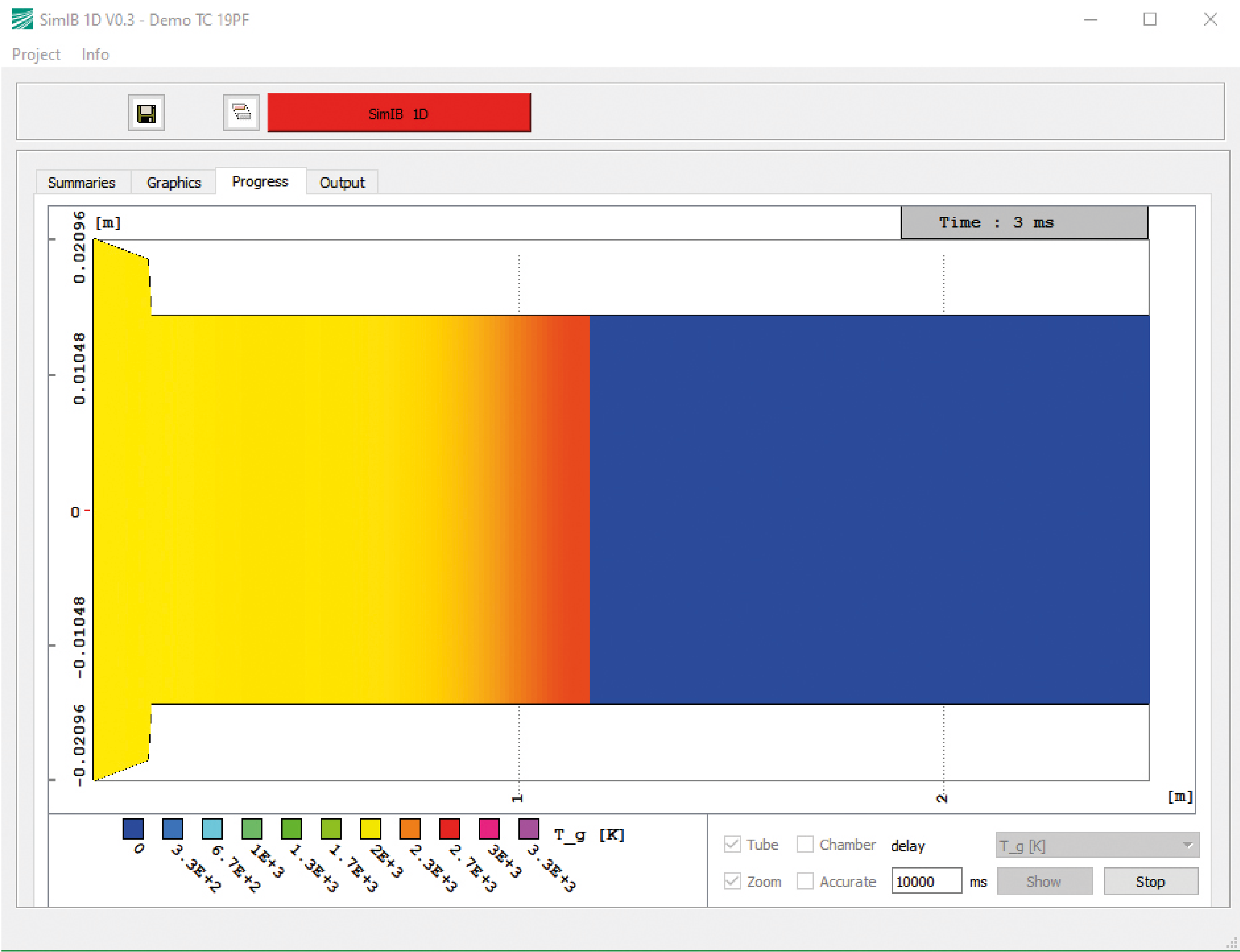
The future: high-performance simulation in 3D
Future, three-dimensional simulations appart, will allow a much deeper modelling of residual details of the complex interior ballistic processes of the effects of launch dynamics. ■



Graphical user interface of SimIB-0D.



SimIB-0D — the comparison of calculated and experimentally determined pressure and velocity curves shows good agreement.

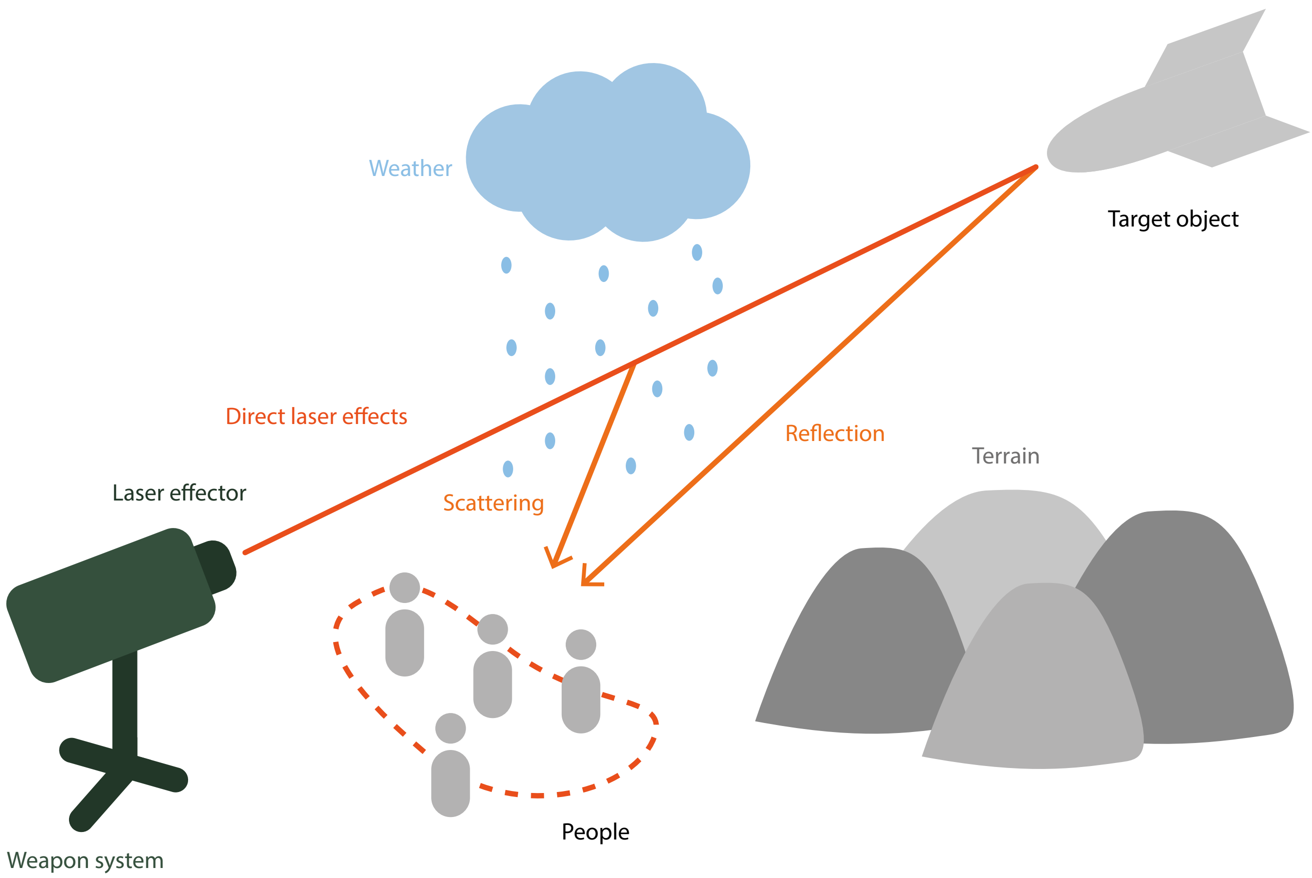


SimIB-1D — spatial temperature field gradient behind the projectile.

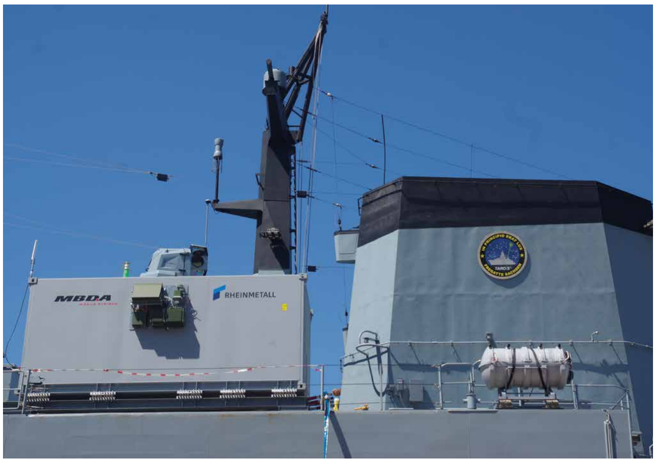
Safety analysis of open-air laser operation

A contribution by Wolfgang Niklas, wolfgang.niklas@emi.fraunofer.de,
and Dr. Martin Lück, martin.lueck@emi.fraunhofer.de

Weapon systems can be designed with simulation programs and examined and tested in the laboratory. Ultimately, they are to be available to soldiers in the field. While decades of experience are available for the use of modern barreled weapons, a completely different physical principle of effects comes into play with laser weapons. In many previous outdoor applications, the laser is often used for its ability to primarily transmit information. In this case, rather low laser beam intensities are usually sufficient. Or the laser radiation is limited to low powers, as in the case of a laser pointer. For a laser weapon, other approaches must be used to ensure safety in a potential mission application. Civilian laser outdoor applications could also benefit from these novel analyses.



Laser radiation during outdoor laser use poses hazards that can be calculated with the laser safety tool.



In 2022, the BAAINBw (Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support) tested a high-energy laser weapon aboard the frigate Sachsen and irradiated flying drones off the German coast. Picture above and center: © Bundeswehr, PIZ Ausrüstung, Informationstechnik und Nutzung. Picture below: © MBDA, Rheinmetall, PIZ Ausrüstung, Informationstechnik und Nutzung.

Laser hazards and safety calculations

Laser weapon systems use high laser powers outdoors. The analysis for a safe application requires a different approach for direct as well as possibly reflected laser radiation than for laser applications in an enclosed environment, such as machines for laser welding or laser cutting. To quantify potential hazards and risks, the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, is developing a laser safety tool that can simulate a dynamic outdoor application scenario and calculate the propagation of laser radiation using numerical methods. Based on the calculated beam propagation, the tool can determine and display safety distances and potentially hazardous areas.

Reflection measurements and modeling

Reflections from the irradiated target play a central role in the propagation calculation. Especially when quantifying the hazard from reflected laser radiation, it is important to realistically represent the complex reflection behavior of potential target materials and structures in the simulation. Among other things, the type of material, the surface properties and the angle of incidence are essential here. In addition, it must be considered that the surfaces of irradiated objects change dynamically during exposure to high-energy laser radiation. Laboratory experiments are carried out at Fraunhofer EMI to characterize the specular and diffuse reflection behavior. The reflection measurements are transferred into suitable models for the reflection calculation in the laser safety tool.

The chassis developed by charismaTec OG (right) and a ZIESEL, provided by DIEHL as swarm partner.

ARTUS — Autonomous Rough-terrain Transport UGV Swarm

A contribution by Dr. Christoph Glößner, christoph.gloessner@emi.fraunhofer.de

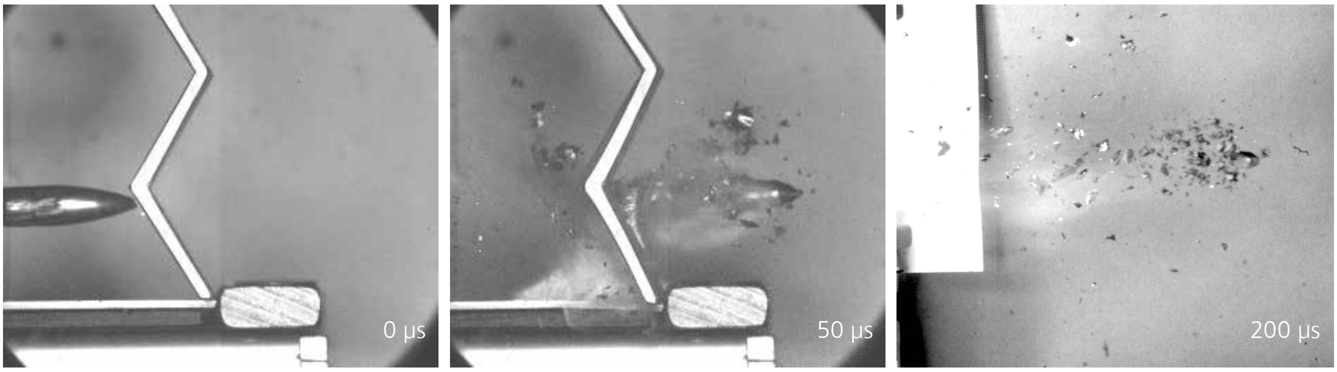
ARTUS is an EDA project for the development of an autonomously navigating swarm of small all-terrain UGVs that relieves infantry troops.

Our 2020/2021 annual report already described how autonomously maneuvering robotic targets can be used for dynamic target display, which can be used for live-fire training at military training areas to depict the enemy's possible movements and thus enable realistic training. In the future, autonomously navigating robotic systems will also make it possible to support soldiers directly in the field. Fraunhofer EMI has participated in and coordinated the international ARTUS research project.

The ARTUS project aimed at developing a feasibility concept and at building a demonstrator for a swarm of small all-terrain UGVs, navigating autonomously in the field. Extreme demands on troopers in terms of equipment to be carried in adverse surroundings necessitate a support system. Unmanned vehicles of various sizes are being developed all about, as are systems for autonomous navigation and swarm functionality. What is new in ARTUS is the conflation of these aspects in the collective development of a support system that takes over corresponding transport and supply functions without direct intervention of a soldier. The project consortium consisted of Diehl Defence GmbH — a global player in the field of defense — handling autonomous navigation, the French research organization ONERA being responsible for the swarm functionality and the Austrian SME charismaTec OG, which developed and built the new chassis of the ARTUS vehicle. EMI had the project lead and was investigating the vehicle protection and system robustness of the swarm. In consecutive steps, the system parameters were outlined through the selected mission scenarios, the interfaces between the system components were defined and integrated into the corresponding vehicle. Finally, the functionality of the whole system was proven in a set of representative scenarios.

Ballistic protection with additively manufactured titanium perturbation structures

A contribution by Elmar Straßburger, elmar.strassburger@emi.fraunhofer.de



High-speed photographs of projectile interaction with a corrugated titanium structure. The strong fragmentation of the projectile core is clearly visible after 200 microseconds.

Principles of lightweight protection such as the destruction of the projectile core are of fundamental interest for lightweight protection. Particularly in terms of flexibility and adaptability, protective structures can benefit if they can be manufactured using metallic 3D printing processes. Fraunhofer EMI is conducting research into suitable materials and structural configurations for this purpose.

Because of their ability to be easily adapted to geometric constraints, 3D printing processes may provide new solutions to shield critical components of robotic systems. The following is an example of how the simultaneous use of the effects of spacing and inclined surfaces can enhance the ballistic protection.

Ballistic protection aimes at avoiding perforation and reductions penetrant at low weight. Small-caliber, armor piercing projectiles include a hard core which consists either of hardened steel or tungsten carbide. Protection against this type of projectiles can be realized in an efficient way when the hard core is fragmented severely during the interaction with the armor.

Whether fragmentation of the projectile core occurs or not, depends on the mechanical properties of the armor material and the thickness and inclination angle of the target plates. Particularly the asymmetric forces exerted on the projectile during penetration of inclined targets contribute to the break-up of the core. If the second layer of the armor is separated from the first one by a spacing, the projectile fragments can separate from one another which will lead to a reduction of penetration and increase of protection.

Investigations at EMI have demonstrated, that tungsten carbide projectile cores are getting strongly fragmented during the interaction with thin plates of Ti6Al4V at an inclination of 30 degrees. However, the use of inclined plates of large dimensions is always connected with a significant increase of armor volume. If the flat plate is replaced by a structured plate with a corrugated or saw tooth profile, the projectile will hit inclined surfaces although the structure is oriented parallelly to the subsequent armor. Titanium perturbation structures have been manufactured additively using the laser powder bed fusion process. Ballistic tests and analyses by means of numerical simulations have proven an enhanced protection of configurations with titanium perturbation structures.

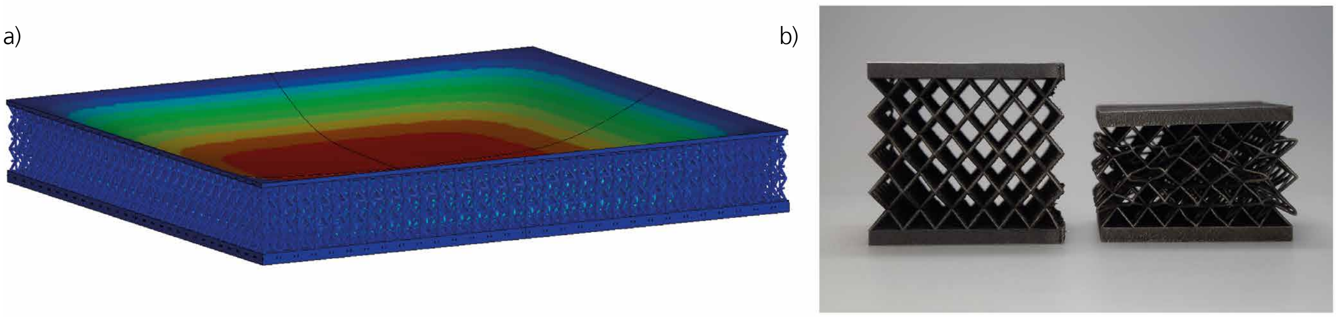
Generative engineering: design optimization of energy-absorbing lattice structures

A contribution by Konstantin Kappe, konstantin.kappe@emi.fraunhofer.de

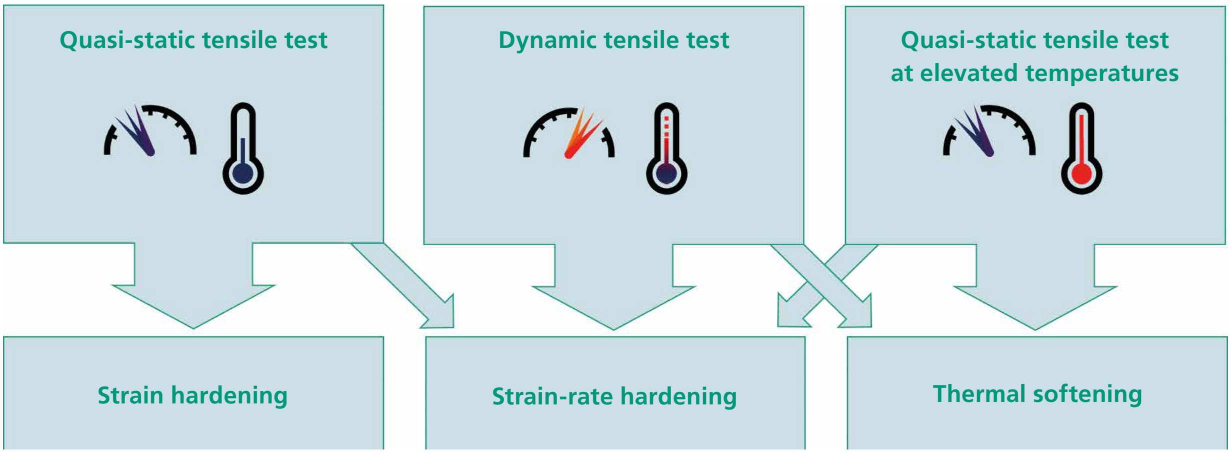
While the impact of a projectile causes a very localized material stress, the impact of an explosion usually results in a planar material load. In high-speed dynamics, it is generally of great importance to be able to design materials and structures that are capable of absorbing energy while still offering a high residual load-carrying capacity. Metallic 3D printing allows a high degree of design freedom, and especially locally adaptable lattice structures appear to be particularly suitable due to their lightweight construction. To find an optimal design of these complex structures, the use of machine learning and evolutionary algorithms in combination with numerical simulations is being explored.

Potential and challenge of additively manufactured lattice structures for energy absorption
Lightweight cellular lattice structures can exhibit remarkable mechanical properties such as increased specific strength or energy absorption. This makes them particularly attractive for use in crash, impact and blast loaded applications. Due to major advances in additive manufacturing techniques, such as laser powder bed fusion, it is now possible to fabricate filigree and complex structures with new materials and tailored material properties. This offers countless opportunities to use function-driven design to improve the mechanical properties of components and structures. However, the possibilities are numerous and difficult to oversee. To exploit the full potential, this requires new optimization methods on the meso- and macroscopic scales.

New design optimization methods for energy-absorbing lattice
In this context, Fraunhofer EMI is researching the development of new optimization methods for the design of lattice structures, which can be used for energy absorption under dynamic load scenarios. Thereby, neural networks are used to predict the complex structural behavior and to reduce the number of costly FE simulations. Together with evolutionary algorithms, the structural behavior can be optimized. Furthermore, the optimized structures are investigated in laboratory scale. The results show that a significant improvement of the properties can be achieved.



Sandwich structure with lattice core under explosive loading (a) and additively manufactured specimens with a size of 60 by 60 by 50 cubic millimeters tested in blast experiment (b).



Different material tests are designed to target individual physical effects. With machine learning techniques, the unavoidable interconnections with other effects can also be taken into account.

Terminal ballistics: AI methods in materials science

A contribution by Dr. Robbert Rietkerk, robbert.rietkerk@emi.fraunhofer.de, and Dr. Andreas Heine, andreas.heine@emi.fraunhofer.de

Methods from machine learning provide powerful capabilities to recognize complex patterns in large amounts of experimental data, which goes beyond what is possible with conventional data analyses of limited numbers of experiments. Fraunhofer EMI investigates how machine learning can facilitate the simulation of terminal ballistic processes, in particular concerning the central challenge of modeling material properties under highly dynamic conditions.

Material tests under idealized conditions

Simulation-based analyses of terminal ballistic effects, such as the response of an armor under impact, require predictive models that describe the resulting material behavior quantitatively. To this end, various material tests are employed to characterize the performance of material specimens under different types of loads. As an example, quasi-static tensile tests are used to study the effect of very slow deformations at constant temperature. The behavior under fast deformations or at high temperatures are considered in separate experiments, such as dynamic tensile tests, or quasi-static tensile tests at elevated temperatures.

Capturing reality with machine learning

The approach described so far, however, does not capture real material behaviour entirely accurately. Since a material deformation cannot be achieved at zero deformation velocity, the quasi-static tensile test is merely an idealization. Similarly, deformations cannot be achieved without heating up the specimen. In actual material tests, the central quantities of interest such as strain, strain rate and temperature always vary simultaneously. Capturing their highly complex cross relations can be achieved, though, with methods from machine learning. Along this line, machine learning is employed to acquire improved models for simulations in the field of terminal ballistics.

Warhead experts from seven European nations during the kick-off meeting in December 2022 in Schrobenhausen, Germany. © TDW

NEWHEAT — European defense research

Fraunhofer EMI contributes to the NEWHEAT project by bringing in its competences in the field of material testing and modeling, as well as numerical simulation of projectile-target interaction. Within the framework of the European Defence Fund (EDF), which was proposed by the European Commission in 2018 and approved by the European Parliament in 2021, common capabilities in the field of defense technology are being built up with European partners.

The increasing complexity of technologies and systems, limited national resources as well as potential threats from the outside make the cooperation of the European nations necessary. An example for such a collaboration in the field of defense research is the EU project NEWHEAT (New European WarHEAd Technologies). In this project, industry and research organizations from Germany, Finland, France, Norway, Poland, Sweden and Spain work on new technologies to defeat armored vehicles and infrastructure targets.

Together with partners from other nations, Fraunhofer EMI investigates new concepts with a focus on concrete penetration.

Future Security 2023: Our security is indivisible

A contribution by Birgit Bindnagel, birgit.bindnagel@emi.fraunhofer.de

Future Security
Security Research Conference

The Future Security conference has been a meeting platform for researchers, experts and other stakeholders from science, industry and politics in Germany since 2006.

Focusing on resilience, quantum technologies and drone detection and defense, the Future Security conference took place in Berlin, Germany, from February 6 to 8, 2023.

The conference was entitled "Our security is indivisible! Should internal and external security be viewed together?"

The research conference of the Fraunhofer Segment for Defense and Security VVS has been a meeting platform for researchers, experts and other stakeholders from science, industry and politics in Germany since 2006.

EMI was represented at Future Security with several contributions: Professor Stefan Hiermaier gave a keynote speech headed "Resilience — engineers overcome crises". He showed how resilience engineering can help meet the challenges posed by climate change, energy crisis and other threats. Dr. Kai Fischer spoke on the topic of "Data-driven assessment of the crisis resilience of municipalities — resilience assessment using data room functionalities".

In the accompanying exhibition, an EMI exhibit on drone defense illustrated how laser radiation can be used to combat drones and how the drone is damaged by high energy laser beams. The topic of critical infrastructure protection was addressed by an EMI model of a pipeline damaged by an high explosive detonation.

The Future Security conference is organized by the Fraunhofer Segment for Defense and Security VVS. Fraunhofer VVS stands for research and development in the fields of defense and civil security. Through its diverse competencies and research services, the VVS convinces with application-oriented solutions up to operational support — both on a national and international level.

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

Business unit Security and Resilience

Business unit
Security and Resilience

A turning point in military and civil security

With the Russian war of aggression on Ukraine, Europe has been experiencing a turning point since March 2022 that goes far beyond purely military perspectives on security and defense and is challenging politics, business and society in Germany in equal measure. Be it the secure and reliable supply of energy and raw materials, the security of public transport, finance or even supply chains via global trade routes — the issue of security as the basis of prosperity and freedom is at the top of the agenda.

This massive disruption is taking place at a time that is already characterized by tremendous change processes: the energy transition in Germany, increasing digitization and related cyber vulnerabilities, the increase in automation in almost all areas of life with artificial intelligence methods, to name just a few examples. Each of these topics poses new challenges in the context of security and resilience. On the one hand, there are opportunities to use digital solutions to make security and resilience easier to plan and experience, or to strengthen the resistance of societies to future pandemics with the help of available data and corresponding resilience models. On the other hand, the increasing degree of networking and automation also creates additional vulnerabilities to disruptions and shocks that must first be identified and then limited by means of new types of security concepts.

In the following chapter, Dr. Malte von Ramin gives an overview of the topic of critical infrastructure protection and shows the range of topics in which Fraunhofer EMI is developing solutions for this. The HERAKLION project shows how a data room concept can be used to strengthen the resilience of municipalities in the face of various disasters. The security of energy storage systems is then discussed, before the HamsTeR project is presented, which has set itself the goal of determining the potential danger posed by printed plastic weapons.

"The changing times extend far beyond military perspectives of security and will also impact civil security research."

Daniel Hiller

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Protection and resilience of infrastructures

A contribution by Dr. Malte von Ramin, malte.von.ramin@emi.fraunhofer.de

Infrastructures in Germany are not only of outstanding importance with regards to supply security and their role for ensuring the economic capabilities, but also vital to the way of how we as a society would like to live.

The critical infrastructures certainly are of primary focus for what is to be protected. Increasingly, however, the maybe not vital, but still high societal importance of other infrastructures is also recognized as especially worthy of protection. How susceptible our infrastructures are to natural hazards, man-made crises, cyber-attacks, terrorist attacks and the impact of wars was clearly observable in the past year 2022.

Most infrastructures today are highly complex technologically as well as software-based, rendering them vulnerable. Typically, another shared property is their physical vulnerability. The communication cables of the Deutsche Bahn were physically manipulated in October 2022; the three strands of the Nord Stream pipelines were targets of an attack with explosives in September 2022. Both systems could have been disturbed by cyber-attacks as well. It is quite apparent that they were physically more vulnerable because their respective protection was not sufficient. In addition to such targeted attacks, the buckling of utility poles due to the load of an ice cover and the failure of utility lines during flood conditions demonstrate the high vulnerability of our infrastructure to natural hazards, the intensity of which will increase as a result of climate change.

Protective structures and concepts for risk management

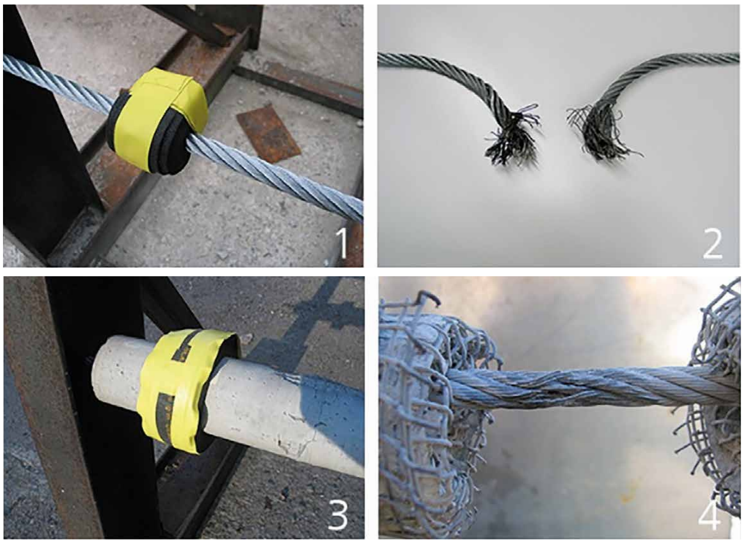
For decades, the Protective Structures department at EMI has been working on the physical protection of infrastructures against extreme loading, resulting both from natural and man-made hazards. In the past, as well as currently, improving the robustness of built infrastructure was of concern. Now, however, the preservation of load-bearing structures is not an end in itself, but serves to maintain the functions of the structures for people's needs. These, most importantly, include the need for protection — of life and limb, of economic requirements, of ways of life. Derived from this is the importance of EMI exploring the risk for people exposed to the respective hazard, which is quantified in risk analyses. In a further step, the risk can be controlled through concepts for risk management and, as a result of the analysis, limited to a tolerable range. The risk is calculated from probabilities — of the occurrence of the event itself as well as the event being hazardous at all —, the consequences and the exposition, describing in which time frame individuals and groups are exposed to the hazard. Furthermore, in the period of 2022/2023, this area

The protection of utility networks from man-made and natural hazards is a topic of current research at Fraunhofer EMI. © Adobe Stock

was the subject of successful scientific work and research in several projects for public authorities, ministries and the private sector, as well as of projects of high public interest like, for example, the support for the Swiss Federal Office for the Environment with respect to the assessment of the works around the former ammunition depot Mitholz. Also, the basic research was advanced further, for example with the characterization of concrete subjected to high-speed dynamic loads under cryogenic temperature conditions relevant for safe and secure storage of liquid natural gas in tanks, which is described in an additional contribution on page 41.

From robustness analysis and risk management to the quantification of technical resilience

Individual infrastructures often fulfill their function as linked components in interconnected networks, which quickly fail once a single component is not able to contribute anymore. Some years ago, the next logical step followed at EMI by extending the subject area beyond the robustness analysis and risk management. With the quantification of the technical resilience, the focus shifts to the level of the entire system. This does not only include the mapping of multi-dimensional systems and their vulnerability to cascading effects, but also the resilience of socio-technical systems independent of a specific type of disruption. ►



1. *Experimental setup of a wire rope with a securing cutting charge.*
2. *Damage after impact of a cutting charge on an unprotected wire rope.*
3. *Test setup with a protective cover made of high-performance concrete around the wire rope including the cutting charge.*
4. *Damage pattern after exposure to a cutting charge of a wire rope previously encased in a high-performance concrete sleeve.*

Technical resilience includes the assessment of robustness, but additionally looks at the time frame in which a system can return to at least its original state after a loss of performance. Furthermore, the ability to learn and the adaptability of the system are part of this, such that future disturbances can be better responded to. Consequently, a resilient system is minimally affected by a disturbance of any kind and returns to its original state in the shortest possible time span.

Concerning the resilience improvement of infrastructures, the areas currently investigated include electricity grids, road and rail transport, gas supply and airports. These are supplemented by reliability studies for financial transaction networks and the analysis of the resilience of economic companies. The combination of economic resilience assessment and identification of effective structural refurbishments on the structural and utility levels against extreme loadings, which are

Gas storage facilities and wind farms are important infrastructures for ensuring our economic performance and security of supply.
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The shock-tube facility BlastStar at Fraunhofer EMI can be used to simulate shock wave loads resulting from explosives and gas explosions. The knowledge gained is used to optimize the materials and structures in use.

expected because of future climate change scenarios, was, for example, focus of the works for ResCentric (www.ResCentric.com). ResCentric provides an economical cost-benefit analysis of measures increasing the resilience of individual buildings against floods and extreme wind events transformed by climate change, specifically with focus on the consequences for the entire building portfolio of investors.

Another example of successful projects of the past year related to the resilience of infrastructures is RESIST, where EMI is looking at the challenges for the electricity grid that result from climate change as well as its expansion. This project, in addition to several other projects related to the protection and resilience of infrastructures, is described on the EMI homepage under the research subpages of the Security and Resilience business unit at EMI.

Looking at the challenges we are facing in Germany, in Europe and globally with respect to man-made crises and climate-caused threats, we are confident to have successfully contributed to the task of countering them with our research in the numerous projects of the past year. ■

Data-driven municipal resilience analysis to assess the coping capacity with shocks and crisis

A contribution by Dr. Kai Fischer, kai.fischer@emi.fraunhofer.de

In the project HERAKLION funded by the Federal Ministry of Education and Research (BMBF), a data space is developed to characterize the resilience of municipalities using multi-layered heterogeneous data sources.

HERAKLION – heuristic resilience analysis using data space functionalities

Various hazardous situations, such as the corona pandemic or extreme weather events, lead to crises and disasters. The consequences have become significantly more complex for a highly engineered and globally acting society and require the assessment and increase of municipal resilience. Reliable information provides a decisive contribution for decision supporters in the event of a crisis. In HERAKLION, a data space concept is used to develop an innovative methodology to assess the resilience of municipalities. Various data sources of a local authority are digitally merged, and statistical or heuristic methods provide an understanding of cause and effect as well as the effectiveness of countermeasures. The resilience is quantitatively characterized and allows an analysis before, during and after the occurrence of a disruptive event.

The methodology enables the characterization of single resilience phases such as preparation, prevention, protection, response and recover. A dashboard summarizes the results and provides a basis for decision makers within municipal crisis management.

Ten associated municipal partners on county level support the end-user view in this project and help to investigate the fundamental questions:

- How can a methodology be developed to measure and increase the municipal resilience?
- How can a data-based process be established to support decision-making in the event of a crisis?

The data space demonstrator covers the use cases pandemic and extreme weather and identifies potential weak spots of a municipality and shows how quantitative resilience analysis can sustainably increase the robustness. With the help of various performances, the behavior of a municipality in the occurrence of disturbances is characterized.

Further information is available at www.heraklion-projekt.de

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Protection of LNG tanks using cryogenic concrete

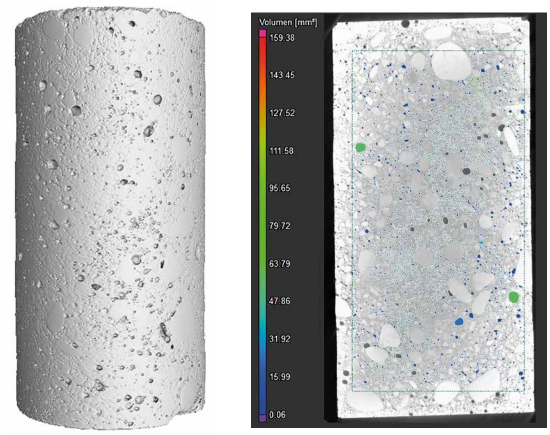
A contribution by Christoph Roller, christoph.roller@emi.fraunhofer.de, and
Dr. Maria Luisa Ruiz Ripoll, maria.luisa.ruiz.ripoll@emi.fraunhofer.de

How can future energy supply systems such as LNG tanks be made more efficient and resilient against natural and man-made hazards?

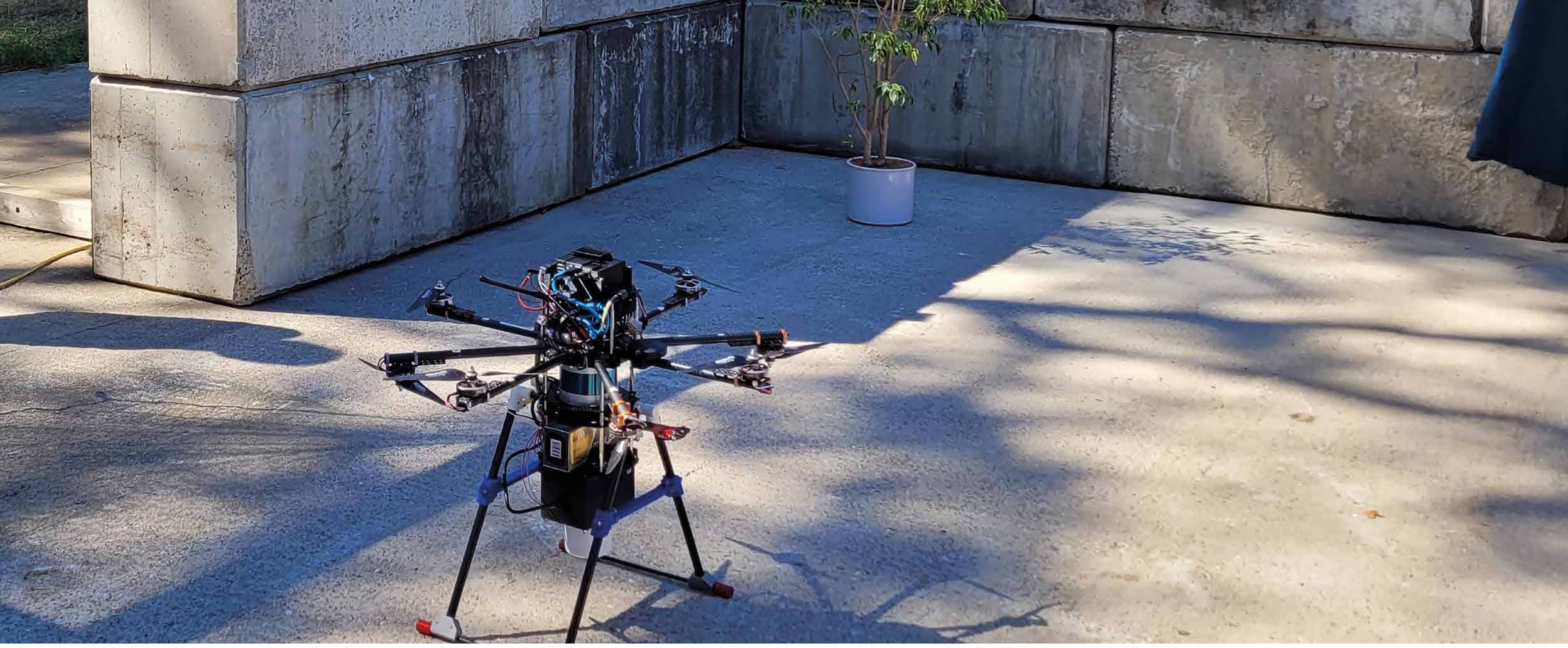
The aim of the present study was to characterize the behavior of concrete at cryogenic temperatures to develop a material for the design and construction of cryogenic tanks for the storage of liquified natural gas (LNG) and other types of liquified gases. The interest in this work comes from the rising requirements in transportation and storage of LNG as a fossil fuel, caused by the need of promoting clean energy sources and boosted by the energetic crisis that appeared as a consequence of the last conflicts arisen in Europe.

A complex experimental campaign has been carried out in the frame of a collaborative work between Universidad Politécnica de Madrid (UPM) and Fraunhofer EMI. In a first step, we focused on the characterization of two concrete materials — a standard concrete for reference and a cryogenic composition. These materials were tested at a temperature range from room temperature down to -50 degrees Celsius analyzing the influence of the water content and loading rate under compression and tension. Even though room-temperature results showed the expected trend for both concretes, the cryogenic tests offered some interesting and remarkable results that need to be validated further within the continuation of the collaboration.

The safety requirements for transport and storage tanks for LNG as a fossil fuel have increased. © Adobe Stock



3D CT-scan of a cryogenic concrete specimen (left) and the result of an analysis of its pore content (right).



Measurement scenario with the UAV system with sensors (lidar, radar) in a non-vital-sign setting during a measurement campaign at THW training site in Wesel.

Saving lives with UAVs

A contribution by Dr. Victoria Heusinger-Heß, victoria.heusinger-hess@emi.fraunhofer.de

Vital-sign detection with drone-based sensors in case of a catastrophe

Drone-borne sensors can help finding victims in case of a catastrophe. EMI participates with new AI-method-based data analysis for detecting signs of life.

The BMBF-funded project UAV-Rescue researches the possibilities of sensors carried by semi-autonomously navigating UAVs (unmanned aerial vehicles) to detect vital signs in crumbled buildings.
UAV-Rescue is an interdisciplinary, bilateral project funded in the context of BMBF Security Research, with a partner project in Austria. The main goal is to research if, how and with which consequences UAV-borne radar and lidar sensors can be used to find people in need of rescuing in case of natural or man-made disasters, such as the 2023 earthquake in Syria and Turkey. The German part of the project focuses on the indoor exploration in not yet manually accessible areas, while the Austrian project rather concentrates on the overall situation of the disaster area.

Within this context, EMI researches the possibilities to use radar data, which are mainly recorded for navigational purposes, for detecting vital signs in the area. That radar can be used in the context of life-sign surveillance was already shown in the setting of patient health status monitoring. However, in the catastrophe context, it is unclear if there even is a person, and the surroundings can be very rough, especially concerning disturbances like the movement of the drone itself or smoke, dust or water in the area. During the project, EMI was able to show that artificial neural networks can be used to analyze such slow-time radar data sufficiently to identify vital signs and to distinguish them from other harmonically moving objects in the room, like textiles or plants swaying in air drafts. Together with the partner Ruhr-Universität Bochum, the ethical and operational determining factors of applying AI methods in such a life-and-death-deciding situation were determined and integrated.

UAV-Rescue

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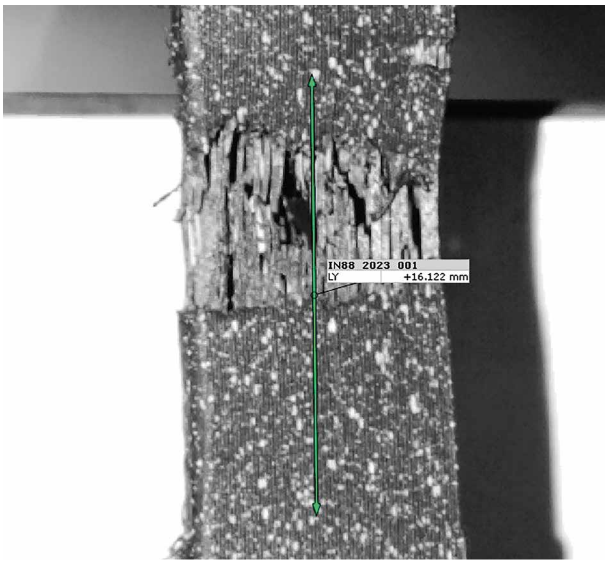
EMI supports security authorities regarding 3D-printed firearms

A contribution by Johannes Solass, johannes.solass@emi.fraunhofer.de

3D-printed firearms pose new challenges for security authorities and legislation.

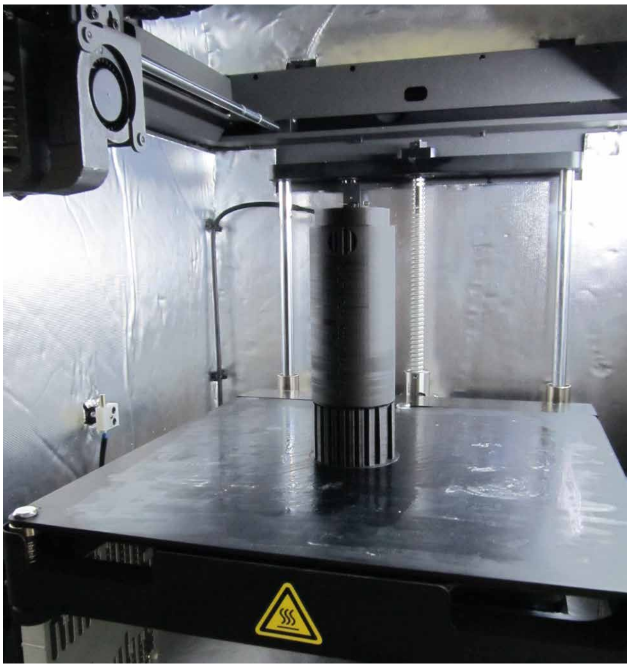
The hazards emanating from firearms manufactured using 3D printing are manifold. Since the presentation of the first printed plastic weapon in 2013, the manufacturing technology has advanced significantly in addition to increased availability. However, there are only a few well-known scientific studies on this topic. Together with project partner Bundeskriminalamt (BKA), Fraunhofer EMI is investigating some of these threats as part of the BMBF joint project HamsTeR — "Handwaffen mit selbstgedruckten Teilen — eine Risikoabschätzung". These include:

- How much effort does it take to produce a printed weapon?
- What is the risk potential of printed weapons?
- Which forensically usable traces arise during production and firing?
- Is it possible to simulate the firing process of a printed plastic weapon realistically?



Optical strain measurement on a printed specimen.

For this purpose, firearms printed at EMI, are manufactured and intensively examined experimentally and numerically. In this way, valuable information can be obtained for assessing the risk potential. The information serves to avert danger and is used by the joint partner BKA. They could be used, for example, in court proceedings, in which the course of events must be reconstructed as precisely as possible, to answer relevant questions regarding the weapon and the projectiles found. Furthermore, the expertise gained in the subject area could be used to advise political decision making.



Printed gas pressure measuring tube in the printer.

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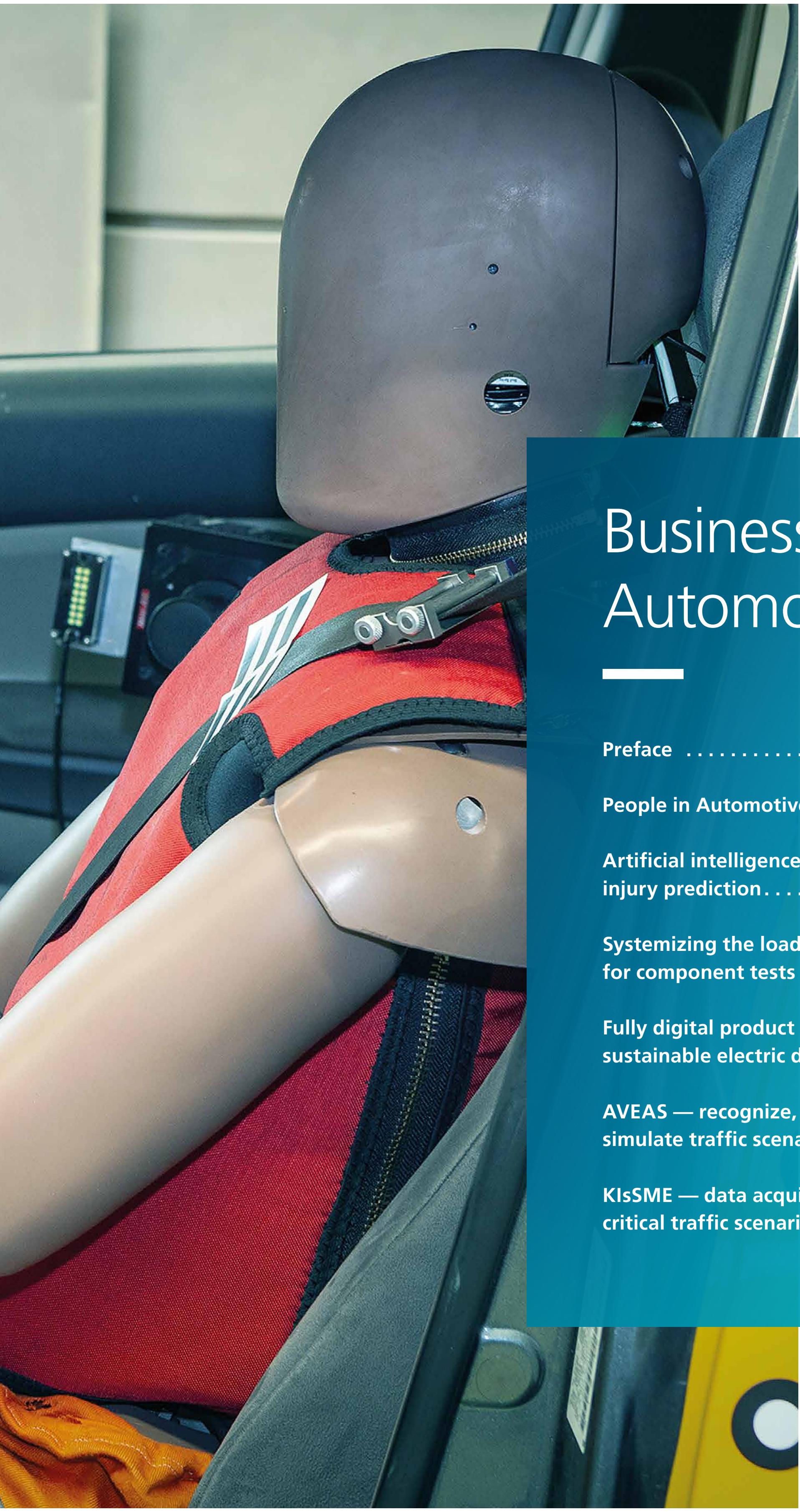
The risk of head, neck, chest and abdominal injuries is examined using the THOR-50M dummy in X-ray crash tests.



Business unit Automotive

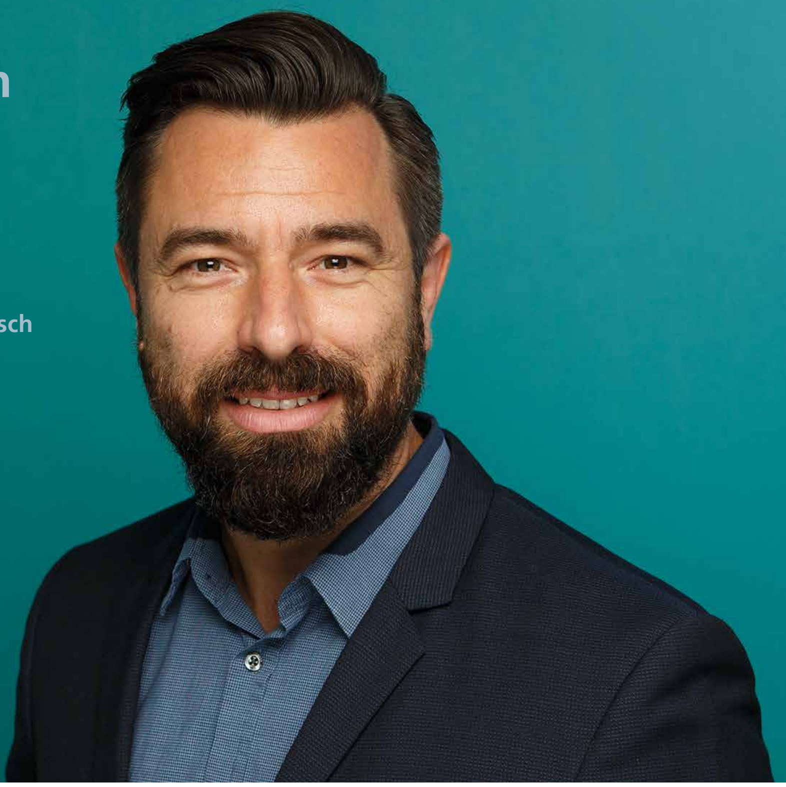
Business unit Automotive

Mobility is an essential feature of modern society. A decisive prerequisite for both the approval and acceptance of new vehicles continues to be their safety. We are currently seeing a significant expansion of this concept from classic passive vehicle safety — namely crash safety — to active vehicle safety and the safety of vulnerable road users. In this context, new technology trends such as alternative drive systems as well as the constant tightening of approval criteria and ratings and the continuous shortening of development cycles are leading to permanently increasing demands on vehicle development. To meet these demands, increasing digitization and virtualization are required to ensure the safety of all road users.

These challenges are addressed in various working groups in the Automotive business unit. In the group Agent-Based Modeling, the focus is on the further development of realistic traffic flow simulation and the identification of critical situations. The consequences such critical situations can have for vulnerable road users are being investigated in the Human Body Dynamics group in the ATTENTION project. A completely new approach to predictive material modeling with the vision of even more predictive structural design is being researched in the joint project AIMM.

„Increasing digitization and virtualization serve the safety of all road users.”

Dr. Jens Fritsch



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Artificial intelligence for real-time injury prediction

A contribution by Niclas Trube, niclas.trube@emi.fraunhofer.de

Fraunhofer EMI with focus on VRU-car collision simulations

The goal of the ATTENTION project is to develop a method for real-time injury prediction of vulnerable road users (VRUs), such as pedestrians or cyclists. For this purpose, data-driven methods are used to determine a situation-specific injury risk from vehicle-based video data and virtual tests with the help of digital human models. Prospectively, injury prediction enables both safe and efficient traffic through automated vehicle risk mitigation strategies.

Multimodal traffic and human individuality as major challenges for autonomous driving

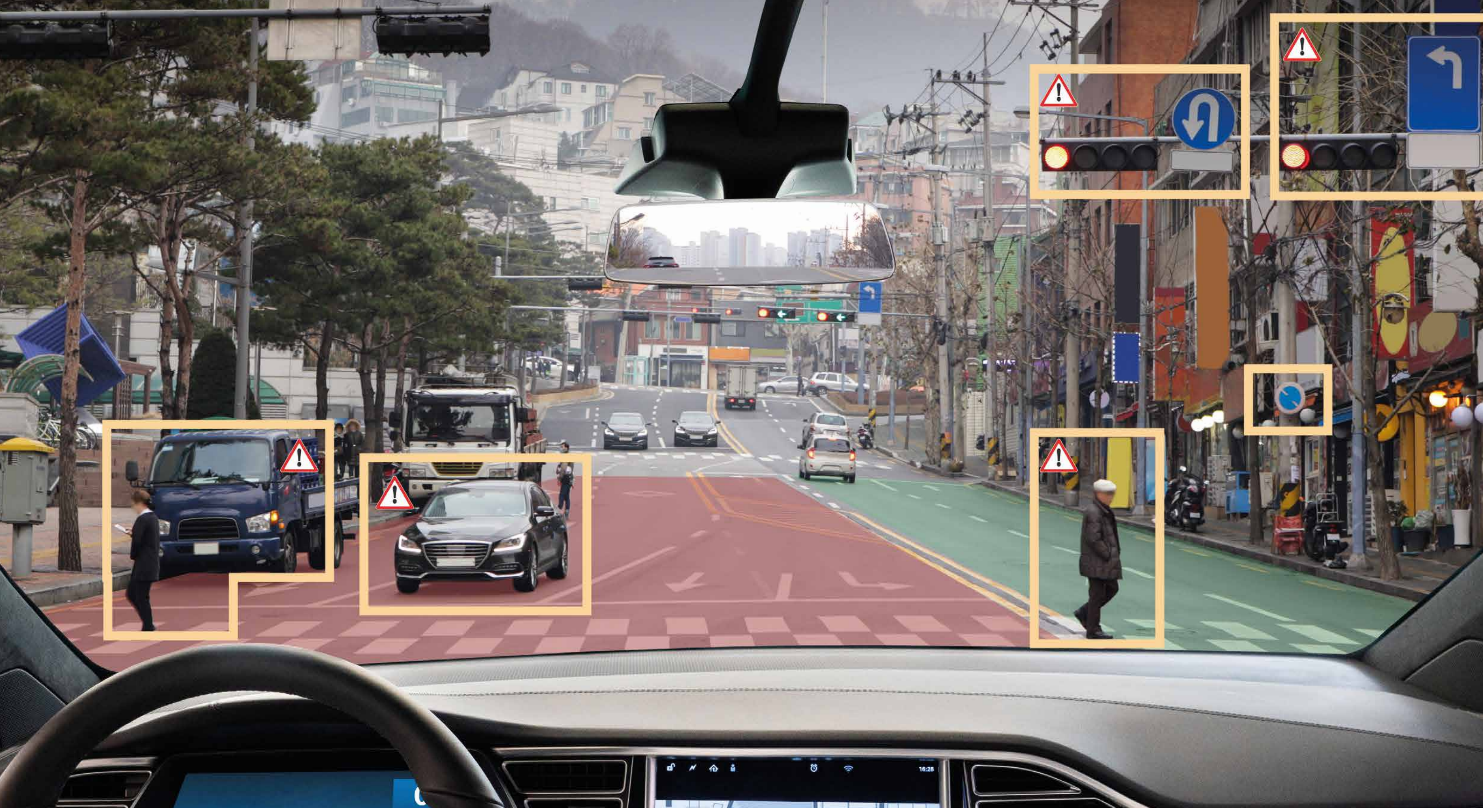
In many German inner cities, urban mobility is characterized by the multiple use of limited and narrow traffic areas and a large number of different road users, which in their entirety constitute multimodal traffic. A key future issue for cities and mobility service providers is the efficient and, at the same time, safe use of shared public spaces. Participating road users differ substantially in terms of speed, maneuverability and vulnerability. The large-scale establishment of automated traffic promises to reduce traffic accidents and fatal road injuries through their interaction. Nevertheless, complex inner-city scenarios, undirected traffic flows and human individuality pose major challenges to increasing automation.

Classification in existing safety concepts

Collisions between vehicles and VRUs still lead to a large number of accident fatalities. The number of traffic accidents involving cyclists has not decreased in the EU since 2010 and has even increased in Germany. Even in future multimodal traffic, collisions between vehicles and VRUs cannot be ruled out due to the previously mentioned aspects.

With regard to the road safety of VRUs, the primary goal must be to avoid an accident as best as possible. Sensor technology and communication systems implemented in the vehicle are already being used to identify potential collisions at an early stage and, for example, to adjust the safety distance via assistance systems and avoid collisions with active braking and steering systems. But what if the accident is unavoidable?

If the “Vision Zero” (no more traffic fatalities by 2050) is to be addressed realistically, it must be accepted that not all accidents are preventable and that current and future traffic is therefore accompanied by an uncertainty factor, for example, due to human individuality. Consequently, in addition to accident avoidance strategies, accident mitigation measures and, thus, injury reduction must also be considered, which raises the question: In the event of an unavoidable collision: Which



technical measures can be taken to reduce the situation-specific injury risk of VRUs? The project ATTENTION addresses this gap in a proof-of-concept study.

Concept and aim of the project

With the aim of a situation-specific prediction of injury risks, various databases are being set up in the project, and artificial intelligence (AI) methods are being used and linked together.

At the beginning of the project, vehicle-based video data of actual vehicle-VRU collisions are analyzed. In this framework, biomechanical and AI-based motion prediction methods were applied to build a VRU position and motion database. The subsequent stage involves extracting the most frequently occurring pre-impact positions of pedestrians and cyclists and positioning the corresponding human body model (HBM) utilized in the project in the finite-element (FE) environment accordingly. These positions include, for example, a mean cyclist posture and various pedestrian defensive postures, which were observed accordingly in the analyzed video data. In addition, a muscle model with position-specific muscle activities is integrated into the human model to best approximate the real collision behavior of VRUs.

The positioned HBM equipped with muscles is then subsequently integrated with an FE bicycle and vehicle model in a virtual collision scenario in order to numerically compute a vehicle-VRU collision in the FE code after defining boundary conditions (for example, initial velocity and impact angle). The HBM is instrumented beforehand to ensure extraction of injury-relevant information such as strains or accelerations for specific body regions from the simulation. This makes it possible to calculate situation-specific injury risks via the FE simulation for a wide variety of collision scenarios. With the goal of data-driven injury prediction, an injury database is built over a large number of vehicle-VRU collision simulations. Single, representative collision simulations are compared with real data from Bosch accident research and checked for plausibility, thereby increasing confidence in the simulation-based injury prediction. In addition, the real accident data are used to define the limits of the parameter space (for example, permissible combinations of relative speeds and collision angles) for the collision simulations.

The synthetic data sets generated by FE simulations are used in the next step to train different AI models. This shall make it possible to predict a plausible injury risk even for non-simulated parameter combinations, ▶

Visualization of VRU and object detection in highly automated vehicles.
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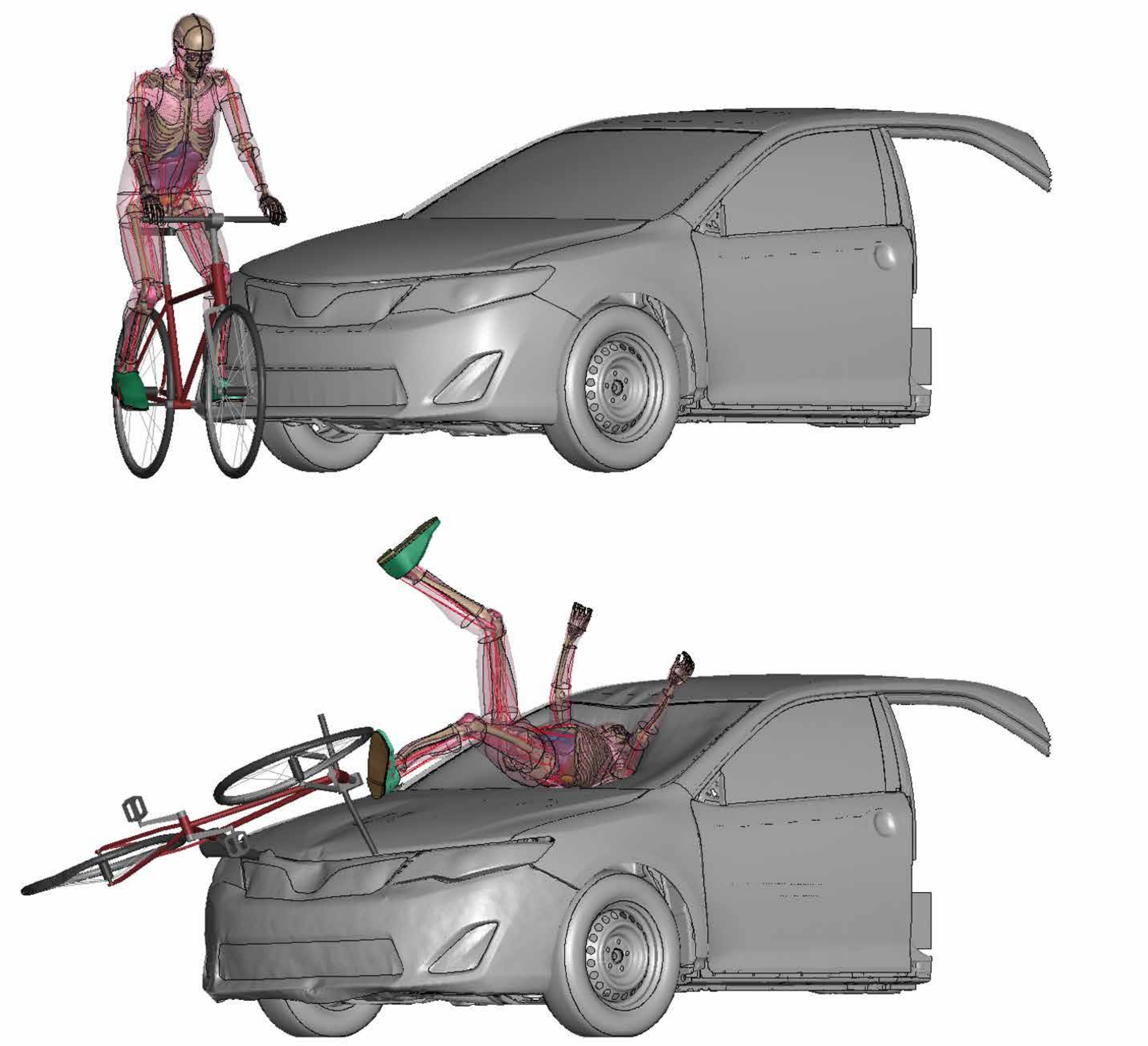

Example of a collision simulation between a muscle-driven cyclist and a vehicle model.

for which a time-intensive FE simulation would otherwise be necessary. The ambitious goal of the project is to predict this situation-specific injury risk in real time.

In the final step of the project, the AI-based prediction of injury risks will be demonstrated in a virtual driving environment. In detail, the motion prediction and AI-based injury prediction methods of this project will be integrated as an active safety tool into a virtual vehicle in the driving environment. The corresponding VRU model is detected by a virtual camera and its further movement until the time of collision is predicted, taking into account the distance between the vehicle and the VRU, the impact angle and the relative speeds. Based on this information, the braking and steering actions are then adjusted to best reduce the VRU injury risk in the remaining time period. Through prior training with the synthetic data from the collision simulation, the AI derives the parameter combination that can still be achieved to reduce the predicted VRU injury risk as best as possible.

Fraunhofer EMI with focus on VRU-car collision simulations

As part of the ATTENTION project, Fraunhofer EMI will contribute to the development of the collision and injury database and is represented by the groups Human Body Dynamics and Digital Engineering. Different competences of the two groups will be combined. On the one hand, the individual FE models must be prepared appropriately for data generation and extraction of biomechanical injury information. Further, single simulations are compared with real accident data for single collision scenarios to increase trust in the generated simulation data. To create a large variety of vehicle-to-VRU collision simulations, which are also observed in real accident data, the vehicle and VRU FE-models must be arbitrarily combinable to allow for different parameter combinations of, for example, the impact angle and the VRU-position in front of the bumper. On the other hand, in order to cover the large parameter space of possible collision scenarios as efficiently as possible, the development and application of methods for adaptive data generation is beneficial. Thus, despite the long computation times of FE collision calculations, a sufficient information basis can be generated to train corresponding AI models with the goal of injury prediction for this specific application case of frontal impact. Based on the expertise in biomechanics and human body models as well as on profound knowledge in data-driven methods and efficient generation of simulation-based training data, EMI builds up a collision and injury database within the ATTENTION project.

The ATTENTION project will end in June 2024 and is funded by the German Federal Ministry for Economic Affairs and Climate Action within the framework of the research program "New Vehicle and System Technologies". ■

ATTENTION

Supported by:

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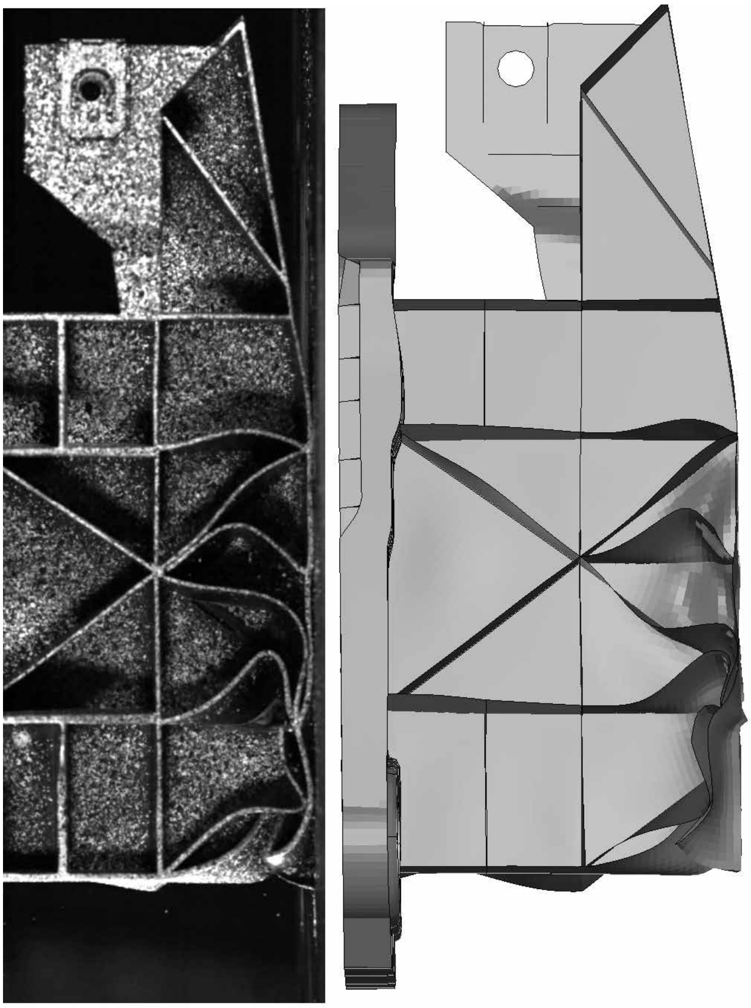

Component test of a vehicle crash box eight milliseconds after impact from the right-hand side. Left: Test. Right: Simulation.

Systemizing the load case definition for component tests

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

Component tests are expensive and time-consuming. Therefore, these tests should be performed in such a way that a maximum benefit out of the measured data can be achieved.

Crashing a component — the smart way!
Within the AIMM project (Artificial Intelligence for Material Models), new material models based on machine learning (ML) algorithms are developed. These models give for each strain input the corresponding stress output. We use component tests to validate the models, in the best case at all strain states that can occur theoretically. Therefore, such tests are preferred, during which as many strain states as possible can be observed in the component during loading.

Development of a tool to rate different tests
Fraunhofer EMI developed a Python tool that can be used to rate different tests concerning the strain states that occur in the component, before only the most suitable test is conducted for real. For this purpose, simulations of the tests are performed. The tool then calculates several characteristic numbers out of the simulation data for each test. One example is the relative area coverage of the strain space, which is the ratio of the area covered with data points to the total area of the strain space. The higher this number, the more suitable is the corresponding test for validation.

Another application of this tool is the geometry optimization of specimens used for the generation of experimental training data for ML material models. The aim of such an optimization is to obtain training data, which provides information for the material model at many different points in strain space.

Fully digital product development of sustainable electric drive architectures

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

The DigiTain (Digitalization for Sustainability) research project for fully digital product development of sustainable electric drive architectures picks up speed.

Digitalization for sustainability
Consisting of 26 funded and 2 associated partners from industry and science, the DigiTain research project started on January 1, 2023, with a total duration of 36 months. In DigiTain, processes, methods and models for fully digital product development and certification of sustainable electric drive architectures are being developed and tested using a prototype. The project is being funded by the German government and the European Union as part of the economic stimulus package number 35c in module b, which aims at new, innovative products as the key to vehicles and mobility of the future. "In particular, the holistic approach, which integrates several technological innovations at once, the cross-value-added networking of the partners and their specialist expertise as well as the associated transfer potential to industry and society make DigiTain a lighthouse project in our specialist program," said Stefan Heidemann from the German Federal Ministry for Economic Affairs and Climate Action. The project sponsorship for DigiTain has been taken over by TÜV Rheinland Consulting GmbH.

At the kick-off meeting on January 31, 2023, around 100 participants of the consortium met mostly on site at the consortium leader Mercedes-Benz AG in Sindelfingen, but also partly virtually. In addition to the presentation of the work packages and planning of the collaboration, the meeting offered the partners the opportunity for an overarching exchange on the planned research content.

Participants of the kick-off meeting on January 31, 2023, at the consortium leader Mercedes-Benz AG in Sindelfingen, Germany.
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DigiTain

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NextGenerationEU

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on the basis of a decision by the German Bundestag

AVEAS — recognize, analyze and simulate traffic scenarios for autonomous driving

A contribution by Florian Lüttner, florian.luettner@emi.fraunhofer.de

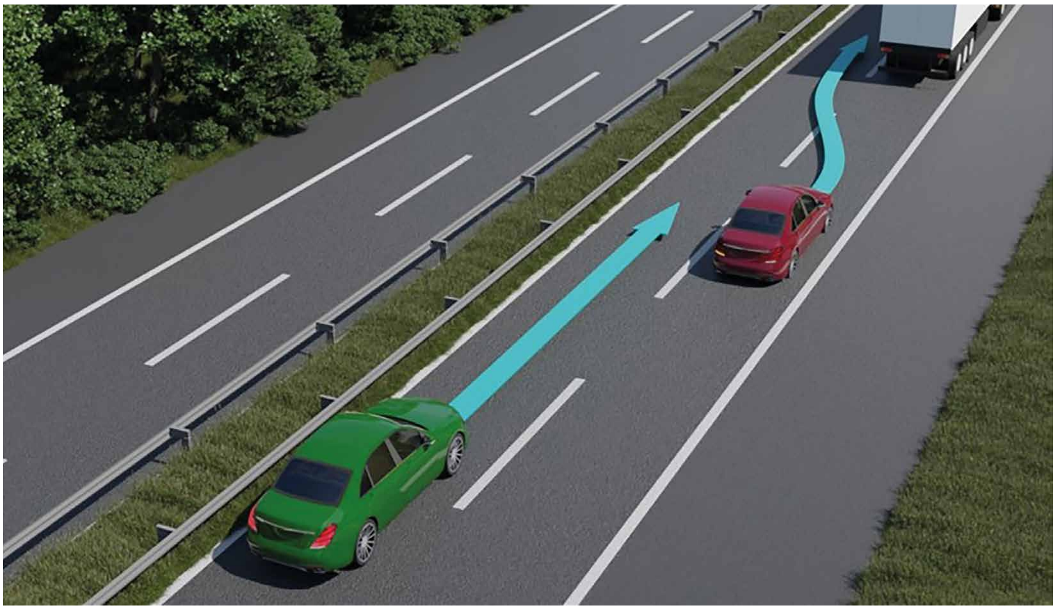
The basis for assessing autonomous vehicles are extensive data from traffic scenarios. To create such a basis is one goal of the AVEAS project, which is funded by the Federal Ministry for Economic Affairs and Climate Action.

Motivation
For a long time, autonomous driving has been a vision of the future — now we are on the way to making this vision become real. The Mercedes-Benz highway pilot is already approved for level three of five in the development of autonomous vehicles. Level four is already under test on defined routes. But the effort required to assess such vehicles increases considerably for higher levels. The basis for this protection is an extensive database of traffic scenarios that serve all protection needs. In addition, valid simulation environments are becoming ever more important in assessing autonomous vehicles.

Assessment-relevant scenarios
In the AVEAS project, Fraunhofer EMI researches the generation of such a database. For this purpose, data from three different recording perspectives as well as simulated scenarios from an optimized traffic flow simulation are combined. Fraunhofer EMI develops methods for the automated evaluation of the assessment relevance of recorded scenarios as well as algorithms for the generation of virtual scenarios to supplement the database.

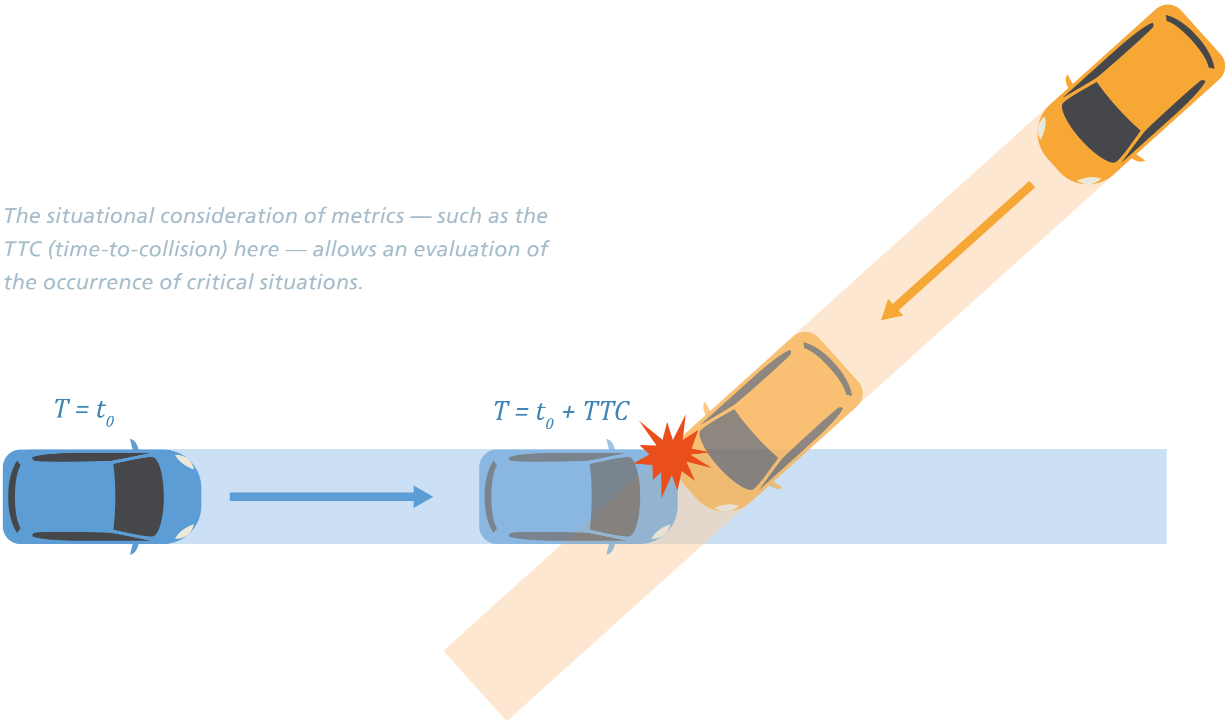
Optimization of behavioral models
In the future, realistic simulations will be of considerable importance for the assessment of autonomous vehicles. One of the goals of Fraunhofer EMI is to adapt and further develop optimization methods in order to make behavior models in current simulation environments as realistic as possible on the basis of data.

The data and models generated in this way are to be utilized in a permanent digital platform and, if successful, the methodology for data collection in real traffic is to be consolidated for validation purposes.



Expanding the targeted database through sampling and simulations.

The situational consideration of metrics — such as the TTC (time-to-collision) here — allows an evaluation of the occurrence of critical situations.



KIsSME — data acquisition of critical traffic scenarios

A contribution by Dr. Mirjam Fehling-Kaschek, mirjam.fehling-kaschek@emi.fraunhofer.de

Collecting the most relevant data is fundamental for further developing and validating autonomous driving functionality.

Selective data recording
Huge amounts of data are needed for the testing and validation of autonomous driving functions. In particular, this data needs to cover emerging critical situations and accidents. Here, the recording of traffic situations by test vehicles plays an important role. Yet, data storage capacity becomes easily a limiting factor when recording all sensor data. Therefore, the main goal of the KIsSME project, funded by the Federal Ministry for Economic Affairs and Climate Action, is the development of algorithms to enable an immediate and directed selection of relevant traffic situations.

Criticality assessment for traffic scenarios
An assessment system for evaluating the criticality of trajectory data of vehicles was developed by EMI in close collaboration with the project partners. For the assessment of total criticality, it is key to define an initial set of metrics. These metrics are transformed into single criticality values, using a scaling approach, and are ultimately combined into the total criticality value.

The criticality assessment system can be applied twofoldly: first, in the identification of critical situations in available datasets and, second, in the identification of trigger moments to start recording, as per the project proposal.

In addition, Fraunhofer EMI has developed a method to predict vehicle trajectories supported by AI methods. Based on the actual movement of the vehicle, possible paths for the next three to five seconds are projected. These predictions allow to generate large sets of virtual critical scenarios. At the same time, these predictions are the basis for an improved real-time assessment of criticality in the test vehicles of the project.

Further information can be found at
www.kissme-projekt.de

KIsSME uses artificial intelligence for selective near-real-time recording of scenario and maneuver data in the testing of highly automated vehicles.

At EMI, we develop our own nanosatellite ERNST.

Business unit Space

Business unit Space

Computer simulation of collision and fragmentation processes at the highest strain rates, such as space-debris impacts on spacecraft, has been a core competence of the Ernst-Mach-Institut for almost 30 years. At the institute, the focus has so far been on engineering models based on continuum theory, such as finite-element methods (FEM) and smooth particle hydrodynamics (SPH). The potential of mesh-free particle methods for materials research has not been exploited. With the development of the discrete element method (DEM) at EMI, we have laid the foundation for the numerical simulation of extremely complex impact and fragmentation processes. Key to this was, among other things, the development of a material model the material parameters of which are derived from the macroscopic material properties. The first material models were developed for aluminum as well as for orthotropic materials such as CFRP. With the parallelizable DEM computational method, we are now able to compute collisions between satellites as well as their debris distribution much faster than with existing continuum methods.

EMI's data processing unit (DPU) is a powerful computer system for small satellites that processes data from Earth observation payloads on board the satellite. The DPU was successfully demonstrated on the International Space Station (ISS) in 2022 as part of the LisR mission and is installed on our ERNST satellite. Now, a fully redundant version of the DPU will again significantly increase the reliability of the unit for use in a satellite constellation.

Augmented reality (AR) systems are increasingly used in our satellite laboratories for remote control and monitoring of laboratory operations. The process developed at EMI enables efficient control and monitoring of all laboratory equipment during extensive development, qualification and test phases of satellite systems from a remote workstation. Holographic headsets are also used, allowing distributed teams to collaborate efficiently.

"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
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People in Space research

Here, we present seven individuals from Space research.

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Simulating hypervelocity impact and spacecraft breakup with discrete elements

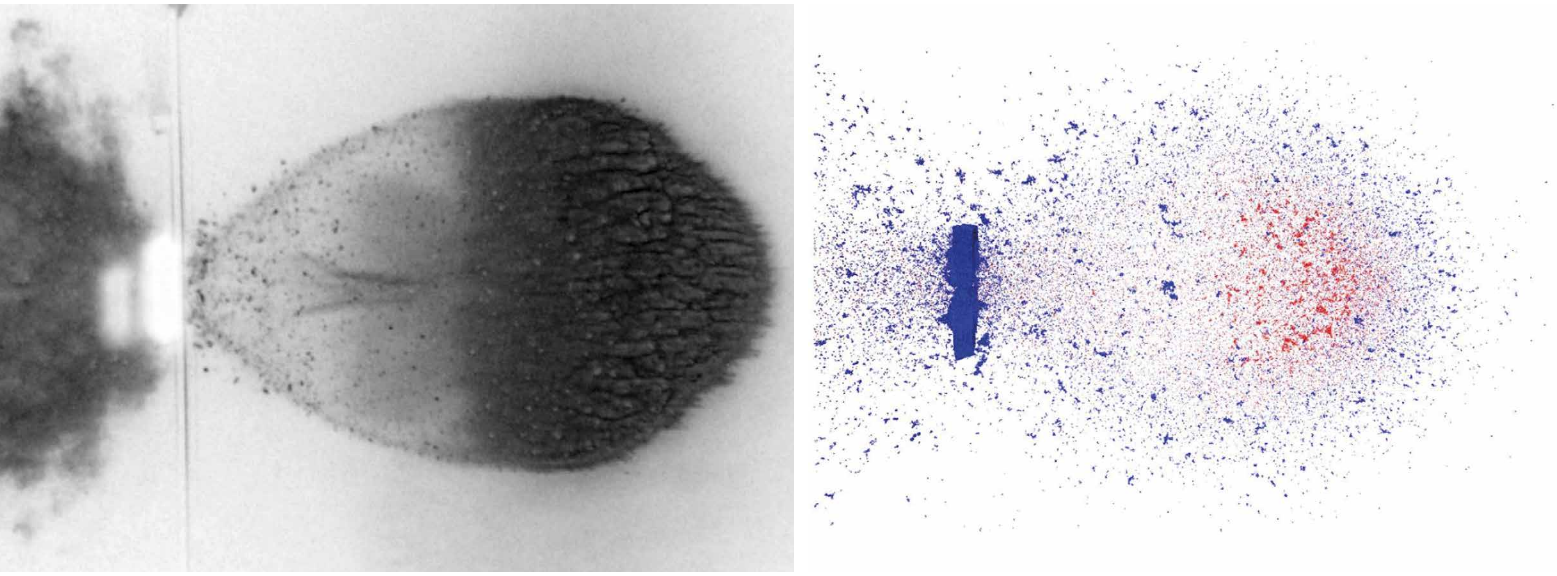
A contribution by Erkai Watson, erkai.watson@emi.fraunhofer.de

The impact of a piece of space debris and an orbiting satellite usually results in the breakup and fragmentation of the satellite into thousands of new fragments of space debris. This complex phenomenon is being studied with a unique type of numerical simulation based on millions of small particles.

The increasing number of spacecraft launches in recent years continues to exacerbate the risks space debris poses to satellites around Earth's orbits. A worst-case scenario, known as the Kessler syndrome, predicts a cascade of collisions as space debris impacts spacecraft causing catastrophic breakups. The fragments generated from such collisions join the growing quantity of space debris, each event further increasing the probability of more collisions. This ever-worsening cycle ends with certain Earth orbits rendered unusable for generations.

One key way of preventing the Kessler syndrome from becoming a reality is to better understand and model the complex phenomena that occur when spacecraft are hit by space debris traveling at a relative speed of up to 15,000 meters per second. A hypervelocity impact (HVI) is incredibly energetic, and even millimeter- to centimeter-sized debris fragments can knock out a small satellite. Larger impacts cause not only localized damage, but can also cause the breakup of large satellites.

When simulating HVI and satellite breakups with numerical methods, it can be challenging to accurately capture the transition of a material from a solid to a fragmented state with traditional continuum-based simulation codes such as finite-element methods. At Fraunhofer EMI, we have developed a new type of simulation approach based on the interaction of many millions of discrete particles to simulate spacecraft fragmentation events. Our discrete element method code, called MD-Cube, performs exceptionally well in modeling the transition from solid to fragmented state that occurs the during a HVI collision.



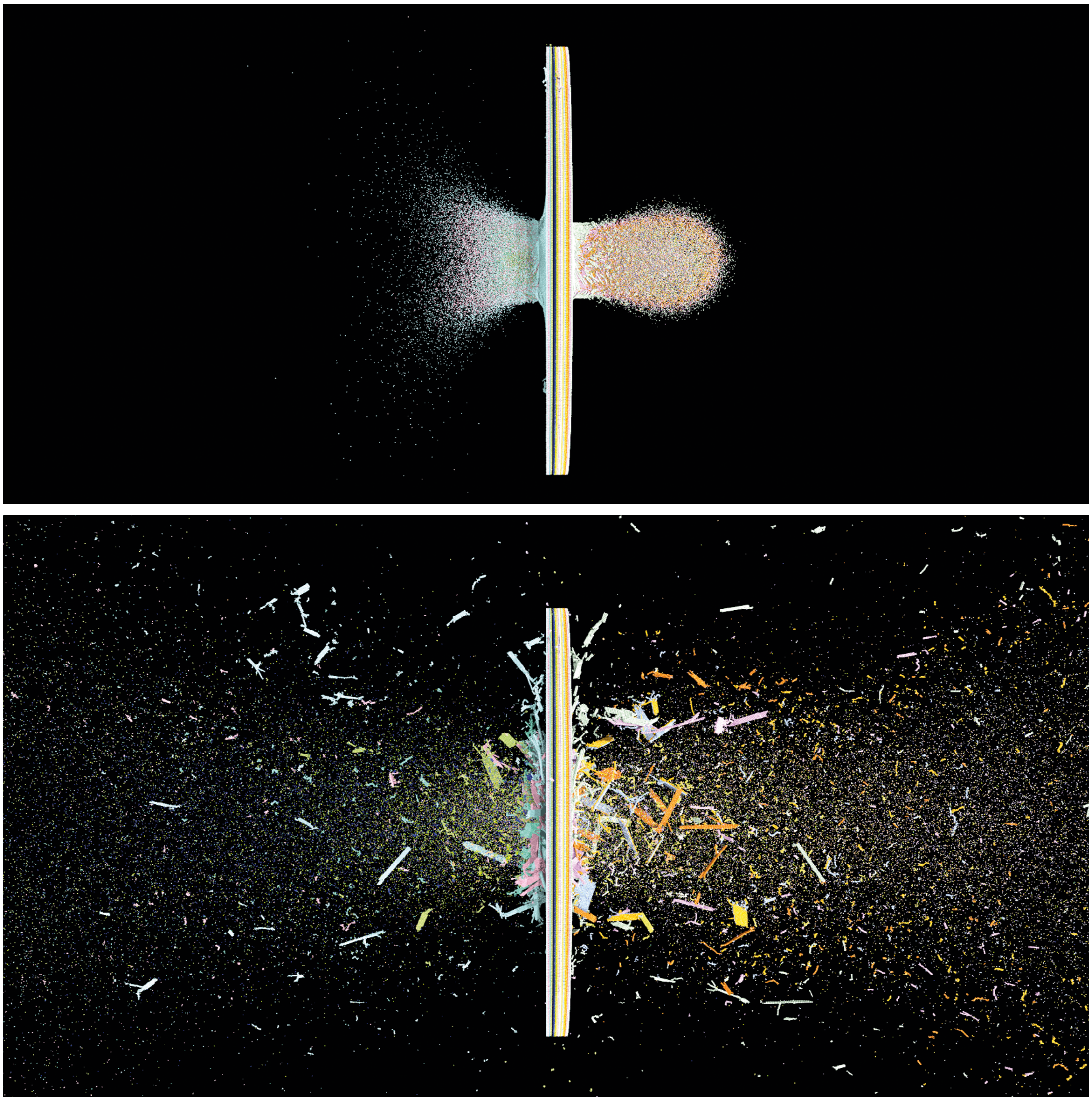
The discrete element simulation code MD-Cube accurately captures the fragmentation after a hypervelocity impact into aluminum. Left: experiment; right: simulation.

Simulating with millions of particles
Our discrete-element-method-based simulation code MD-Cube has been specially developed to accurately simulate fragmentation. This is achieved by using millions of small particles linked together by springs to create a solid material. The forces in the springs are collectively calibrated to approximate the macroscopic response of a given material. When the material is loaded, the springs fail upon reaching a predefined extension, leading to cracks and finally failure of the material. In this way, a natural and realistic fragmentation is achieved.

A key aspect of the success of MD-Cube in simulating fragmentation events is its highly developed parallelization scheme. MD-Cube is parallelized with the message passing interface (MPI) that allows the computationally intensive tasks of calculating particle interactions to be spread over hundreds of CPUs in parallel. The relative simplicity of particles as the fundamental building block of the simulation allows a huge number of particles to be used in a model, generally ranging in the tens of millions. This results in a very fine "resolution" of the simulated materials and allows the whole range of fragmented debris, from large chunks to dust-like particles, to be accurately reproduced.

Explosive fragmentation under hypervelocity impact
The explosive fragmentation seen in experimental HVI images is well captured and reproduced in MD-Cube simulations. Aluminum, for example, fails in a brittle manner in the immediate vicinity of a hypervelocity impact, leading to the formation of thousands of fragments. The MD-Cube simulations capture this well, particularly the wide-ranging distribution of fragment sizes.

While the majority of simulation parameters for a given material can be derived from generic material properties such as the bulk modulus, one simulation parameter needs to be calibrated based on HVI experimental data. We perform this calibration by directly comparing the shape, size and velocity of the fragment cloud between experimental and simulated images. We also calibrate the low-velocity (non-hypervelocity) mechanical behavior via comparisons with ballistic limit penetration studies. ►



Hypervelocity impact on a CFRP plate. The delamination of the CFRP and the long fibrous fragments are well reproduced by the simulation.

Apart from isotropic aluminum, MD-Cube is currently also able to simulate anisotropic materials such as carbon-fiber-reinforced polymers (CFRP). CFRP is an important material in modern satellites, often replacing aluminum in many structural components of newer spacecraft. We are able to simulate the orthotropic nature of CFRP by assigning different types of springs in different directions, corresponding to the material properties of the carbon fiber and epoxy matrix, respectively. This approach not only captures the orthotropic behavior, but also the unique pattern of delamination and generation of long, thin fibrous fragments completely. The ability to accurately predict not only the number and size of fragments, but also the shape is one of the many advantages of simulating satellite impacts with MD-Cube.

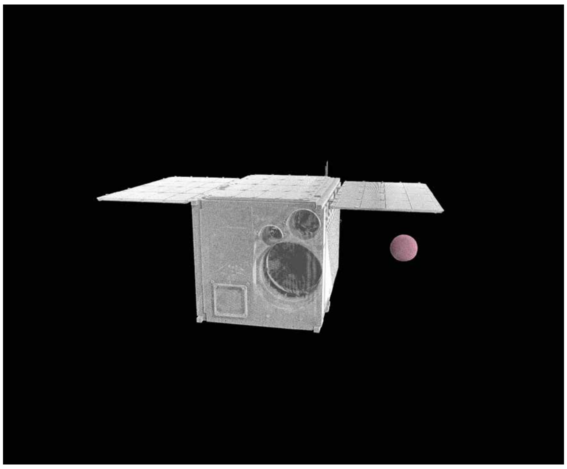
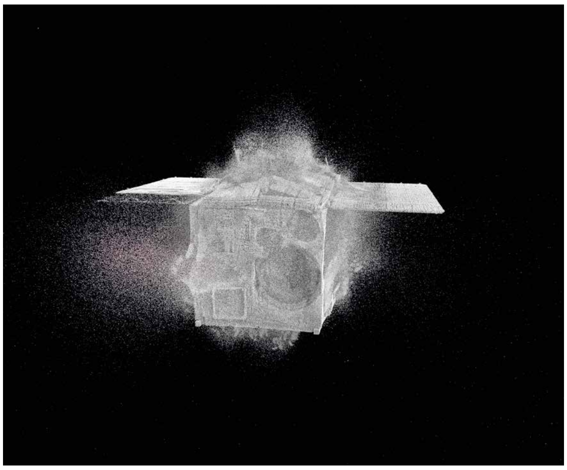
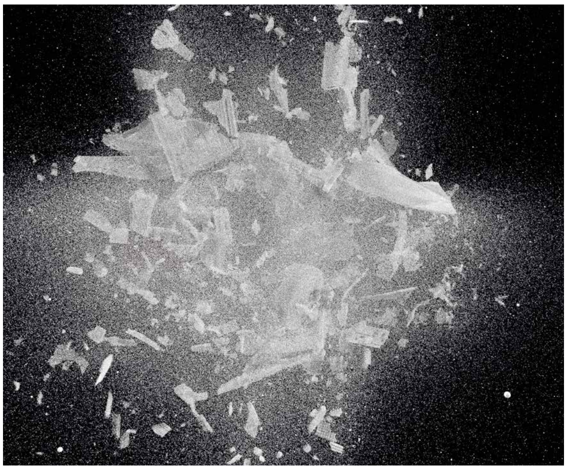
The road to modeling spacecraft breakups

With the end goal of understanding and modeling the breakup of spacecraft after impact with orbital space debris, we apply MD-Cube to a variety of spacecraft impact scenarios. A CubeSat can be simplified as a hollow cubic box of ten centimeters side length made with thin plates and filled with a number of internal thin plate components. Using such a model, we demonstrated the ability of MD-Cube to handle large simulations of tens of millions of particles by studying the fragment distributions following various impacts such as a small sphere impacting a CubeSat or a two-CubeSats collision. Resulting fragment distributions correspond well to existing empirical models such as the NASA Satellite Breakup Model when simulating aluminum satellites. Applying similar comparisons with CFRP satellites highlights known discrepancies in existing empirical models that could potentially be improved using simulation results.

Satellites in full detail, down to individual screws and electrical components, can be accurately and efficiently modeled in MD-Cube via a simple import from a CAD program. We discretized ERNST, a 12U nanosatellite currently under development at Fraunhofer EMI, with 13.5 million particles to perform parameter studies investigating the breakup of this particular satellite under a variety of impact conditions. For the time being, only a single material can be chosen for the entire satellite, but plans are being made to allow multi-material configurations as well.

The strengths of MD-Cube in simulating fragmentation allows realistic satellite breakup scenarios to be investigated to a level of detail not previously possible. We study the breakup and fragment distribution resulting from the impact of ERNST with space debris of various shapes (sphere, rod, disk) and sizes. Another interesting aspect that we study is the effect of impacts on different parts of the satellite and from different directions. The resulting fragment distributions are compared and analyzed.

We believe that numerical simulations that specialize in fragmentation, such as MD-Cube, are a powerful tool to study in-orbit satellite breakups. Unlike ground-based experiments, the range of conditions and sheer number of parameter studies that can be efficiently conducted make them invaluable for developing new and improved empirical models that can be used to understand the ever-changing orbital environment around our Earth. ■

Simulating the ERNST nanosatellite being hit by a large piece of space debris traveling at eight kilometers per second. The high energy impact leads to a catastrophic breakup of the satellite.

On-board data processing for the New Space

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

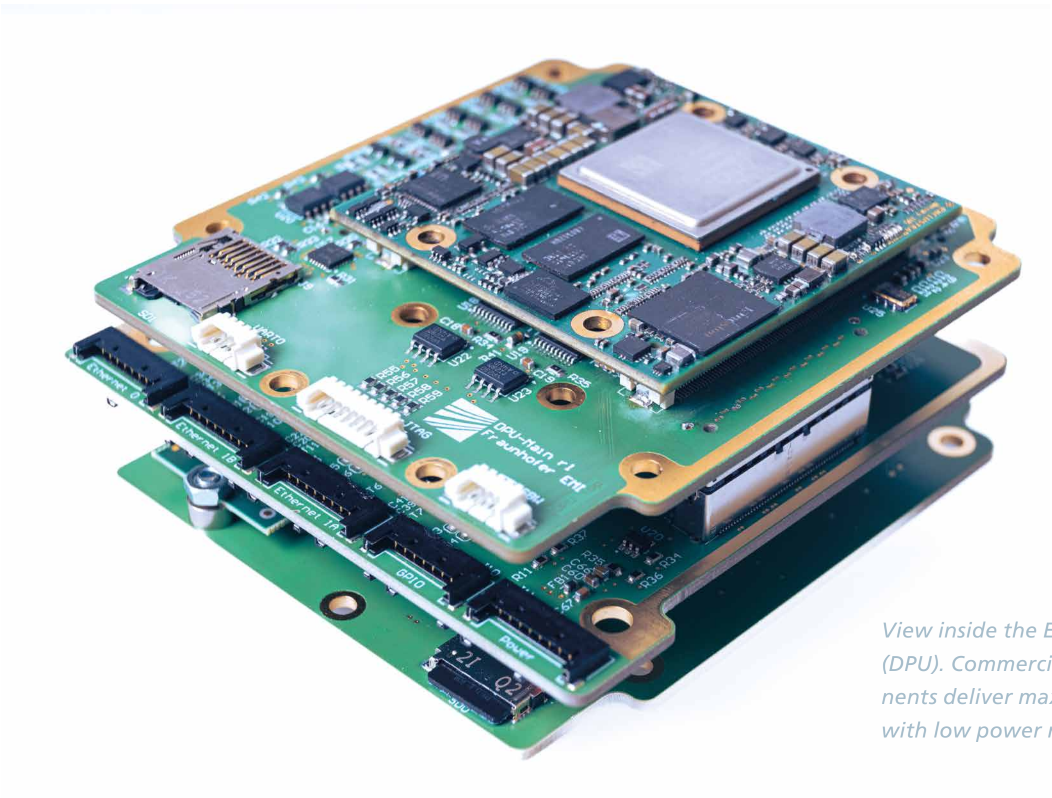
Following the successful demonstration of EMI's data processing technology on the International Space Station, the next generation is now on the horizon.

The so-called New Space is characterized by the growing influence of private players and start-ups. The trend is towards large constellations of small satellites. Fraunhofer EMI has been working on solutions for data processing on board such small satellites for several years.

Fraunhofer EMI's data processing unit (DPU) is a computer system designed for use in small satellites. Its field of application is primarily on payloads for Earth observation. These camera systems capture images of the Earth's surface or atmosphere in different spectral ranges. The DPU is based on commercial electronics and can therefore achieve high performance with minimal power and space requirements. The lower reliability of these components is largely compensated for by the system design of the DPU.

Following the use of the DPU in several of our customers' missions, in 2022 the DPU was successfully demonstrated on the International Space Station (ISS) as part of the LisR mission.

The next evolutionary stage of the DPU is now in the starting blocks for the HiVE satellite constellation of EMI spin-off constellr. This enhanced version of the DPU is designed specifically for its use in microsatellites, that is, somewhat larger small satellites. To further increase reliability, the device will include full redundancy to compensate for possible failures. Beyond that, EMI is researching the integration of artificial intelligence into the DPU. In future, the actual information could be extracted from the recorded images directly in space.

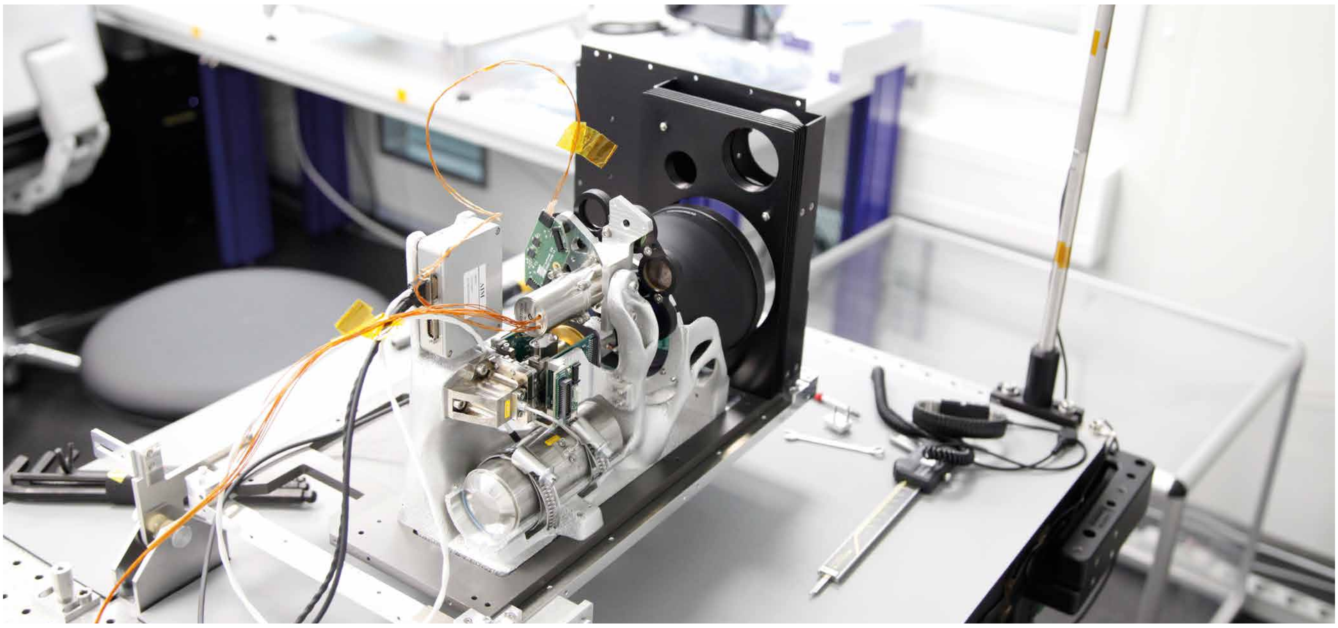


View inside the EMI data processing unit (DPU). Commercial electronic components deliver maximum performance with low power requirements.

ERNST update — new launcher, new launch date

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

While we completed the ERNST flight model and prepared it for acceptance testing in 2022, we face a delay of the launch to 2024.



Fit check of the ERNST infrared payload with optical bench and baffle.

We would have liked to report here about the accomplished launch of ERNST to orbit. In 2022, we completed the ERNST subsystems and prepared the ERNST flight model for final integration and acceptance testing. A shortage in the currently available launch capacities now requires more patience until this milestone will be reached.

ERNST will be launched as part of a cooperation between the German Ministry of Defence and the U.S. Department of Defense in their "Space Test Program". With the designated LauncherOne rocket failing in January 2023 and the providing company filing for bankruptcy in April, a timely launch of ERNST was prevented. Instead, ERNST, along with other prominent small satellites from Australia and the United Kingdom, needed to be re-manifested onto another launcher, provided by the U.S. company ABL Space Systems. After the inaugural flight of their RS1 launcher failed in January 2023 as well, a second launch attempt is currently being prepared. For ERNST, this means a delay of the launch date to April 2024.

One objective of the ERNST mission is to explore the potential of the New Space, characterized by constellations of smaller satellites and new launch systems with short development times. In this context, this delay is emblematic of the dynamics of the current upheaval in the space industry, even though we would have gladly done without demonstrating this specific aspect. We are using the additional time on system tests of the satellite in a so-called flat-sat configuration.

A reliable heat shield for ESA's Space Rider mission

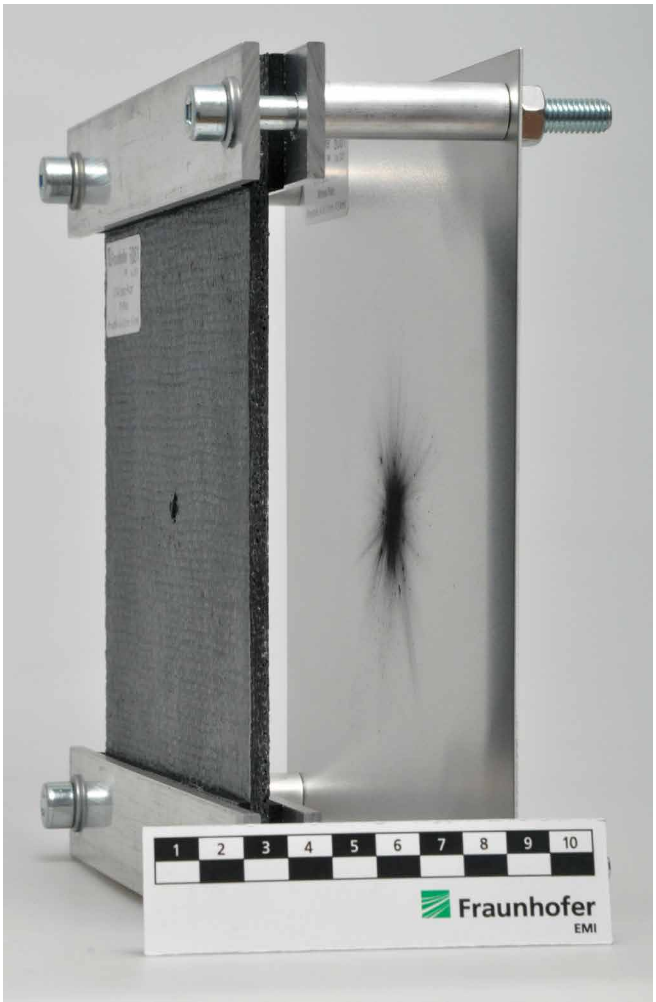
A contribution by Robin Putzar, robin.putzar@emi.fraunhofer.de

Fraunhofer EMI contributes to the ESA's Space Rider re-entry design with hypervelocity impact tests and impact damage modeling.

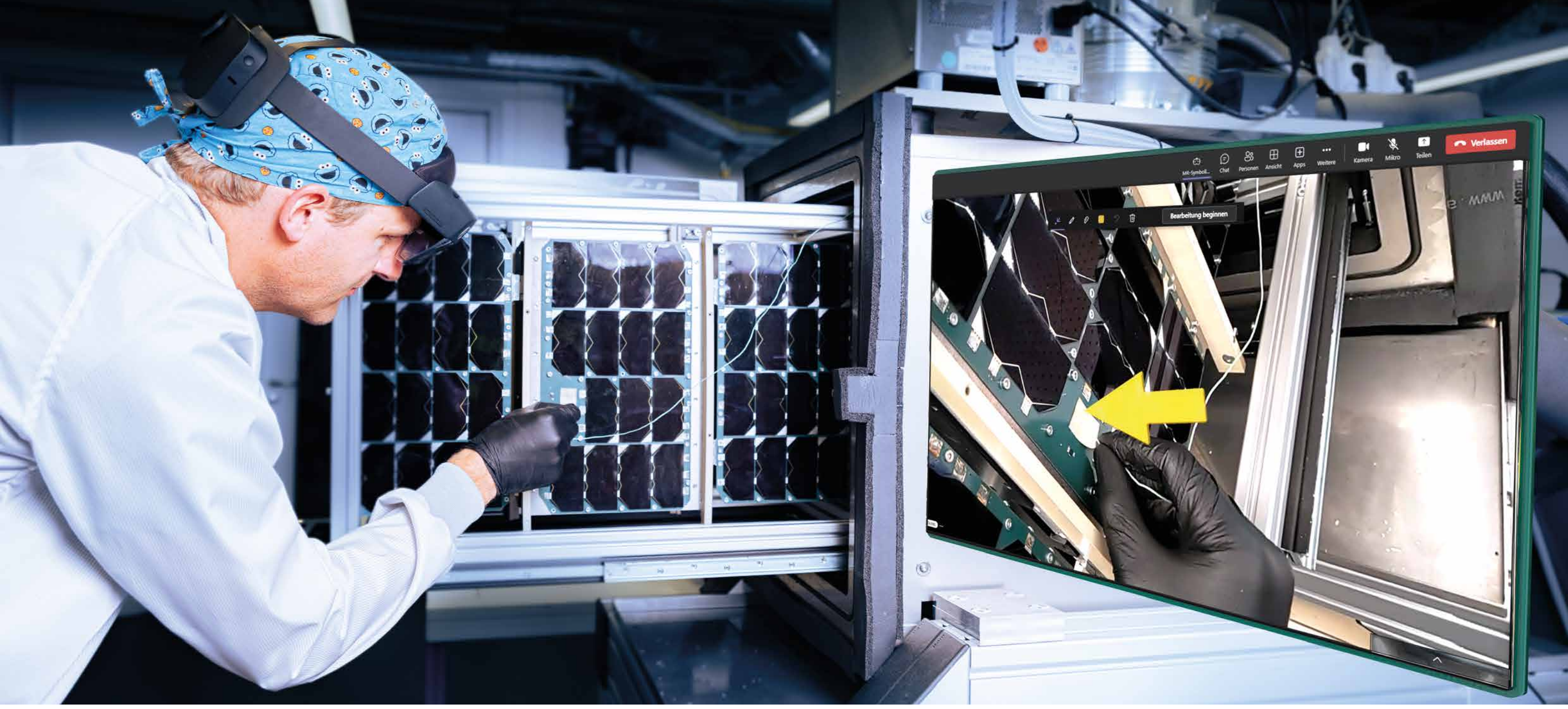
In 2024, ESA wants to launch Space Rider, its first reusable uncrewed spacecraft. Currently, six missions are planned. At the end of each mission, Space Rider shall re-enter into Earth's atmosphere and perform a soft landing. Prior to re-entry, while in orbit, the heat shield is impacted by space debris and micrometeoroid particles. Depending on size and position, the damage caused by those impacts can be negligible, or it can prevent a successful re-entry and be responsible for the loss of the vehicle.

To assess the actual risk posed by hypervelocity impact damage during the re-entry phase, damage models applicable to the re-entry heat shield material are required. Those significantly depend on the individual material properties. Since only few heat shield materials have been characterized in hypervelocity impact tests so far, no general damage models are available. The Italian Aerospace Research Center CIRA is heavily involved in the Space Rider development, one of its tasks being the design of the heat shield. To help CIRA with this task, Fraunhofer EMI investigated the behavior of their carbon-fiber-reinforced silicon carbide in hypervelocity impact tests. In those tests, we reproduced the actual on-orbit conditions in ground tests. We then used the test data to successfully develop the damage models required for risk analyses.

CIRA plans to expose some of the impacted samples to a simulated atmospheric re-entry in its Scirocco plasma wind tunnel. This allows to evaluate the combined effects of different environmental conditions. Such combined tests are currently only rarely performed. However, they provide valuable data, supporting the Space Rider mission as well as future space missions.



Carbon-fiber-reinforced silicon carbide (outermost layer of the re-entry heat shield) and an aluminum witness plate after impact testing at Fraunhofer EMI.



External view (left) and first-person view (right) of the engineer in the clean room, collaborating with a remote assistant who can add documentation and 3D assets to the mixed virtual environment.

Augmented-reality-based remote assistance for satellite integration and test campaigns

A contribution by Dr. Stephan Busch, stephan.busch@emi.fraunhofer.de, and
Konstantin Schäfer, konstantin.schaefer@emi.fraunhofer.de

Advanced automation of satellite integration, test campaigns and operations is becoming a key factor in the New Space domain. Augmented reality can maximize the level of telepresence for complex remote assistance tasks.

In the context of the development of a capable and flexible nanosatellite bus for Earth observation missions, Fraunhofer EMI has developed a modular test and operations software framework to promote easy remote and automated control of a heterogenous set of electrical ground support equipment. The system facilitates flexible interaction between test operator and distributed infrastructure, therefore optimizing effectiveness, reproducibility and equipment utilization. This helps to promote rapid design, integration and test cycles or high-quality batch production.

The system has proven to be particularly beneficial in the context of the recent pandemic, as it allowed efficient control and monitoring of the entire laboratory equipment from remote workstations during comprehensive satellite integration and test campaigns. In phases, where manual interaction with the local hardware was indispensable, the system was helpful to support extensive remote assistance.

The utilization of holographic headsets can further improve efficiency and effectivness of remote collaboration tasks in a high-tech industrial environment, increasing the level of telepresence significantly. While a single local engineer can focus entirely on the installation of a particular hardware of interest, a set of remote experts might participate in a video conference session — with full access to the telemetry and command interfaces of the entire equipment. Augmented reality allows to create more context-sensitive interaction by sharing a first-person perspective of the relevant scene in realtime. In turn, the remote engineer can augment the scene with context-specific documentation and interactive 3D assets.

Bundeswehr in Dialog, Berlin Congress Center, May 31, 2022

A contribution by Prof. Dr. Frank Schäfer, frank.schaefer@emi.fraunhofer.de

The five Fraunhofer Institutes EMI, FHR, FKIE, INT and IOSB presented current research and solutions in the field of military reconnaissance and information gathering.

The Federal Ministry of Defence held the "Bundeswehr in Dialog" event in Berlin on May 31, 2022, which served to promote intensive dialog and exchange of experiences between military and civilian employees from all Bundeswehr locations. Specialist workshops with exhibitions were held in parallel to the panel discussions. The Fraunhofer-Gesellschaft, the University of the Bundeswehr Munich and the German Aerospace Center were invited to contribute to the workshop and exhibition on the topic space.

The contributions of the five Fraunhofer Institutes EMI, FHR, FKIE, INT and IOSB were coordinated by the Fraunhofer Aviation & Space Alliance, an association of about 30 Fraunhofer institutes with the aim of supporting the aerospace industry and public authorities with applied research services. Under the slogan "Know earlier. See more. Decide faster. Communicate more securely.", EMI, FHR, FKIE, INT and IOSB introduced Fraunhofer solutions for military reconnaissance and information gathering and for satellite-based early warning: The nanosatellite ERNST for space-based early warning and imaging reconnaissance (EMI), the radar system GESTRA for air and space surveillance (FHR), the system ABUL for automated image analysis for reconnaissance and surveillance (IOSB) and 3DMapping, a system for creating terrain models (FKIE), were presented.

Prof. Dr. Frank Schäfer presents the RASCAT reconnaissance support tool to Lieutenant General Dr. Ansgar Rieks, Vice Chief of Staff of the German Air Force.

Top right: The Fraunhofer Aviation & Space appearance was themed "Know earlier. See more. Decide faster. Communicate more securely.".

Bottom right: General (ret.) Eberhard Zorn (right), Inspector General of the German Armed Forces until March 16, 2023, as well as Major General Michael Traut (middle), Commander of the German Armed Forces Space Command, and Major General Jürgen Setzer (second from right), Vice Chief of the German Cyber and Information Domain Service and Chief Information Security Officer of the German Armed Forces, let Brigitta Soergel (front left) explain how satellite-based early warning is realized with the ERNST nanosatellite from a near-Earth orbit.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Früher wissen. Mehr sehen. Schneller entscheiden. Sicher kommunizieren.


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E. ZORN

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

Business unit Aviation

Business unit Aviation

Fire and aircraft are never a good combination. Researchers at Fraunhofer EMI investigate phenomena, which can cause a fire on board of an aircraft. These phenomena include foreign objects impacting a fuel tank (see Concorde accident in the year 2000) or thermal runaway of batteries built into portable electronic devices, such as laptops or cell phones. The following articles describe a small extract of these activities.

> The only time there was too much fuel aboard any aircraft was if it was on fire."
>
> Ernest K. Gann (1910–1991),
> US-American pilot and author

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People in Aviation research


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4

Here, we present four individuals from Aviation research.

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SMAUG — what is happening if an aircraft collides with a drone?

A contribution by Benjamin Schaufelberger, benjamin.schaufelberger@emi.fraunhofer.de

Validated simulation models give a deep insight into possible collisions of airplanes and helicopters with drones.

With the increasing availability of drones to a wider public, the probability of a collision with an airplane or a helicopter increases. A comprehensive understanding of the impact event is therefore an essential requirement to simulate and assess possible collisions.

Currently, there are more than 400,000 drones in Germany, most of them are privately used. In fact, a license is needed to pilot a drone having more than 250 grams, a collision with an aircraft cannot be excluded in any case.

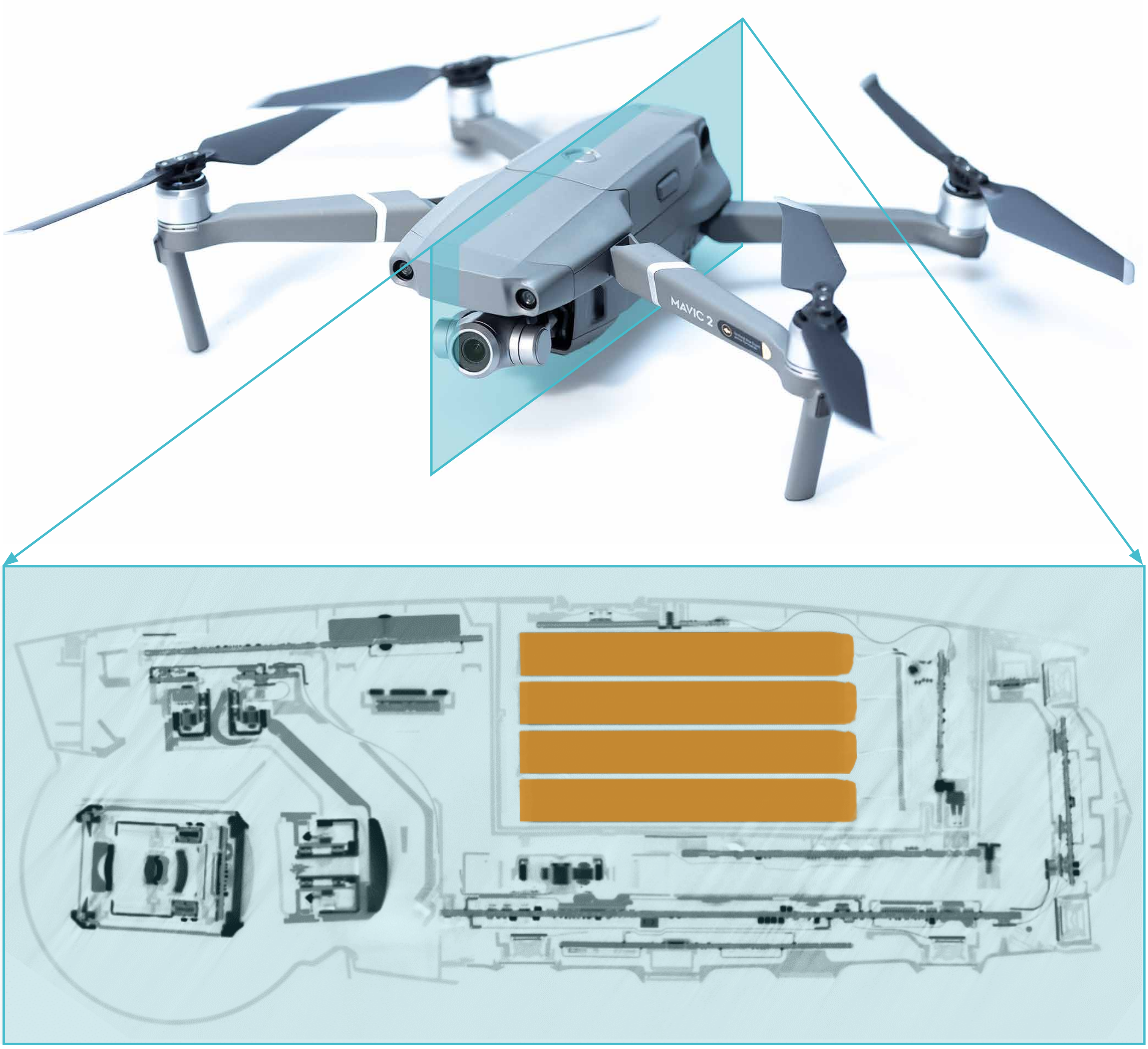
Thus, it is of large scientific interest to assess the response of aerostructures during a collision with a drone. Relevant collision scenarios are aligned to typical take-off and landing velocities of airplanes and on cruise speeds of helicopters. The speed range is therefore roughly between 50 and 150 meters per second. In SMAUG — Simulation Methods to Analyze Collisions between Drones and Aircraft — simulation models for respective collision scenarios were developed. The project was financed by the Federal Ministry for Economic Affairs and Climate Action (BMWK) within the aviation research program LuFo VI.

Selection of the drone

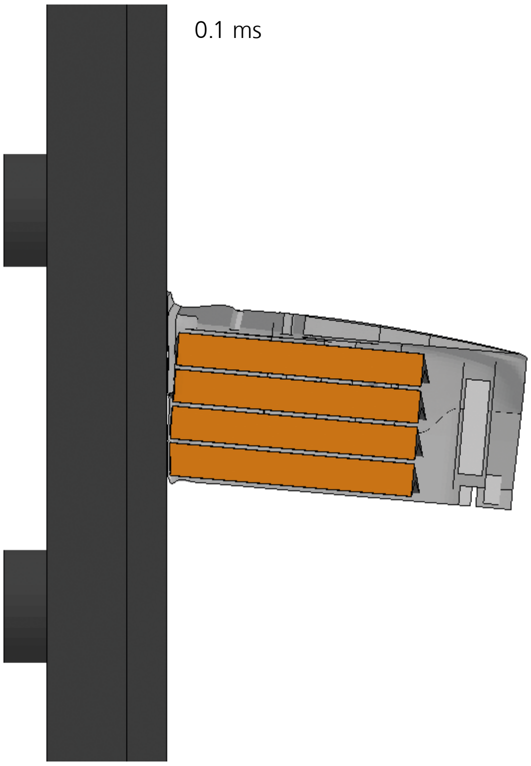
Experimental and numerical investigations in SMAUG were conducted on the popular quadcopter DJI Mavic 2 Zoom. Besides the wide distribution, its mass of 907 grams (which corresponds to two pounds) was one selection criterion. So, by selecting this drone, an analogy with the certification specifications for small commuter aircraft regarding bird strike could be drawn, since in these requirements a bird mass of two pounds is taken as reference. The selected drone consists of four arms, to where electric motors and rotors are attached, as well as a fuselage that contains a camera and a battery. First experimental investigations on the components motor, camera and battery showed that the motors, but especially the battery are a potential risk. The battery is of special interest due to its compact, however very complex construction, and its comparatively high mass of 292 grams.

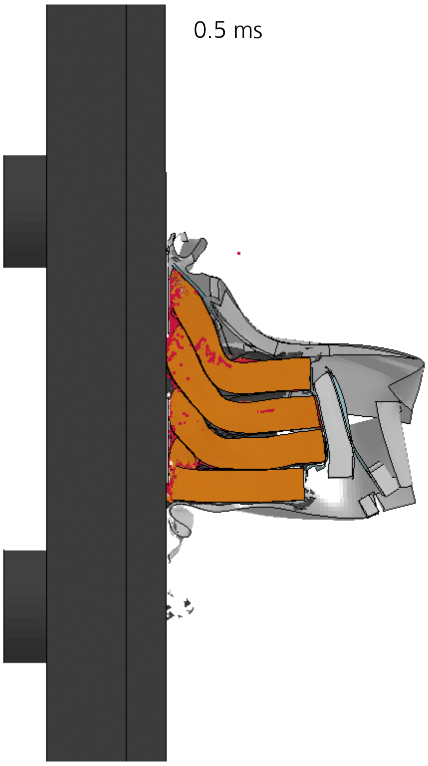
Characterization of the battery of the drone

For the characterization of the mechanical properties of the battery of the drone, a building block approach was used. ►



Top: The DJI Mavic 2 Zoom — representative private-purpose drone weighing approximately one kilogram.
Bottom: Computed tomography image of the drone (scanned in a folded configuration), battery cells are highlighted in orange.



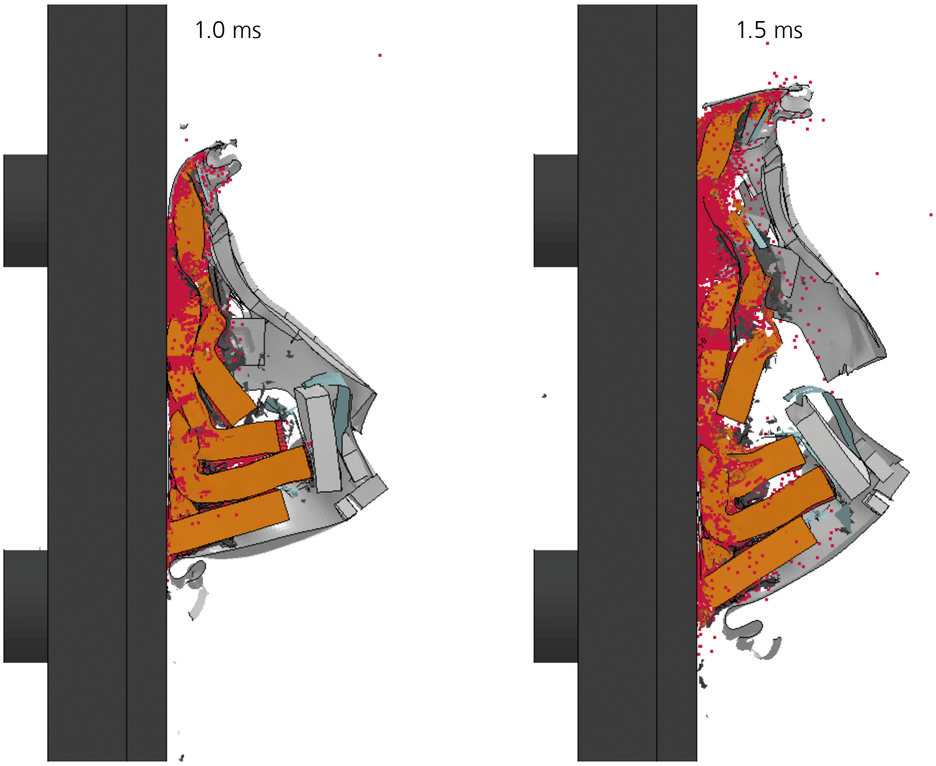


Thereby, the understanding of the whole drone is deduced from the behavior of the single components and their materials. The battery of the drone basically consists of a polymer casing, four battery cells as well as a circuit board and cables. To determine the material parameters for the simulation model, specimens were extracted and afterwards tested mechanically. In a next step, the mechanical behavior of the total battery was identified in length and width direction. Based on static compression tests, the stiffness and the failure behavior of the battery could be determined.

Battery model: development, validation and application

The comprehensive experimental data builds a good basis for the development of a detailed simulation model of the battery with a high degree of complexity. However, with the outlined approach, one essential phenomenon cannot be caught sufficiently up to now: the shattering of the battery of the drone at higher impact velocities. Therefore, using a specifically adapted test stand, impact experiments were conducted in the relevant velocity range. The breaking of the casing and the fragmentation of the battery cells could be documented with a high-speed camera. In the simulation, the fragmentation of the battery cells was modeled by switching the numerical method. In the early stage of the impact, the battery cells, as well as all other components, are modeled with a mesh-based method (FEM, finite-element method). For larger deformations, finite elements are replaced by particles (SPH, smooth particle hydrodynamics). This adaptive change of the numerical method allows to simulate the experimentally observed impact behavior both qualitatively and quantitatively. After the validation of the model against the impact experiments, the applicability of the developed model was tested. For this purpose, the impact of a battery against a windshield of a generic helicopter structure was modeled. Helicopters are of particular relevance due to their comparatively low flight altitude and their operation in urban areas. In the virtually investigated collision scenarios, a strong deformation but no failure of the windshield occurred.

After completion of the SMAUG project, a validated simulation model of the battery of the drone is available. In a next step, it is planned to develop a model of a full drone, so that in the future the response of aerostructures during a collision with a drone can be investigated virtually. ■



Simulated impact of the battery of the drone on a steel plate. The finite elements of the battery cell (brown) are strongly deformed and (after 0.5 milliseconds) transformed to particles (red).

Impact on aircraft

- In the future, sizing of aircraft structures against impact events is expected to be virtual, utilizing validated simulation models.
- Impact experiments are a fundamental basis for the development of a detailed simulation model of the battery of the drone.
- The risk of a collision between drone and aircraft is especially high in urban areas.

Left: Flight Test Facility of the Fraunhofer Institute for Building Physics in Holzkirchen, Germany. © Fraunhofer IBP
Right: Test chamber at the Battery Test Center TEVLIB of Fraunhofer EMI in Efringen-Kirchen, Germany.

Using laptops, tablets and smartphones more safely in flight

A contribution by Dr. Simon Holz, simon.holz@emi.fraunhofer.de

The risks associated with laptops, tablets and smartphones used by passengers in flight are assessed within the LOKI-PED project, funded by the European Union Aviation Safety Agency (EASA).

In flight, people carry their portable electronic devices (PED) with them. Due to crushing in seats or overheating during charging, the lithium-ion batteries within PEDs can heat up and blow up and release hot, toxic and flammable gases. These events may threaten the safe conduct of the flight as well as the health of passengers and crews. The amount of heat and gas released is linked to the energy content of the battery. Actually, each PED on board is limited to 100 watt-hours. Recent power tools and laptops scratch this limit. Hence, guidelines and mitigation measures need to be assessed scientifically.

Thus, the Fraunhofer Institutes for High-Speed Dynamics, Ernst-Mach-Institut, EMI, and Building Physics IBP team up with the Airbus Operations GmbH within the LOKI-PED project. Multiple test facilities, namely the Battery Test Center TEVLIB at EMI, an A320-mock-up for cabin fire tests and the Flight Test Facility of IBP are used to investigate the consequences of fire and smoke caused by PEDs. These experiments are the basis for numerical simulations and the risk assessment, providing a deeper understanding of both, the thermal runaway consequences and the associated risks. Airlines, authorities, cabin and cockpit crews as well as passengers will benefit from the project results in multiple ways.

LOKI-PED

Stay tuned and visit: www.loki-ped.de

Presentation at the AIAA SciTech Forum

A contribution by Dr. Georg Heilig, georg.heilig@emi.fraunhofer.de,
and Dr. Michael May, michael.may@emi.fraunhofer.de

The American Institute of Aeronautics and Astronautics (AIAA) — founded in 1963 — organizes annual conferences to promote aeronautics and space sciences. The AIAA conferences are the world's largest in this field, with more than 5,000 professionals from 44 countries attending. They offer scientists the opportunity to present their work in specialist lectures.

In January 2023, the AIAA SciTech Forum was held at National Harbor near Washington, D.C., USA. Dr. Georg Heilig and Dr. Michael May from Fraunhofer EMI had the opportunity to present their results on the hydrodynamic RAM effect (HRAM) in a technical session. The HRAM effect plays an important role in the safety of civil and military aircraft, since shock waves triggered by external loads in a fuel tank potentially lead to the complete loss of the aircraft. A prominent example is the crash of a Concorde in July 2000 (Paris, Charles de Gaulle Airport). Experimental and computational results are being developed at EMI, in which tanks filled with water are hit by metallic projectiles at speeds in excess of 300 meters per second. The initiation and propagation of shock waves in water, the formation of cavities and the delayed structural response of the tanks are computed, measured and visualized using high-speed cameras.

Dr. Georg Heilig (right) and Dr. Michael May after the technical session January 1, 2023, AIAA SciTech Conference, National Harbor, USA.

Presentation on drone collision

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

The risk of unintentional collisions between aircraft and drones is increasing. © Adobe Stock

Researchers of TU Braunschweig, Airbus Defence and Space and Fraunhofer EMI jointly presented their work on collisions of aircraft with drones at the 2nd European Conference on Crashworthiness of Composite Structures.

The increasing availability of drones on the hobby market increases the risk of accidental collisions between aircraft and privately piloted drones. Whilst collisions between aircraft and birds have been widely studied, to date only limited information is available on the consequences of collisions between aircraft and privately piloted drones. Due to the high strength and stiffness of the drone components, it is expected that a drone causes more damage to an aerostructure than a bird of identical mass. In a joint presentation at the 2nd European Conference on Crashworthiness of Composite Structures (ECCCS-2) in Toulouse, researchers of TU Braunschweig, Airbus Defence and Space and Fraunhofer EMI shared their insights on this topic based on a wide range of experimental and numerical studies. Building on quasi-static and dynamic experiments on relevant drone components — such as the motors and the battery — a simplified finite-element model was developed, which was subsequently used for parametric impact studies onto a representative aerostructure. For the range of parameters investigated within this study, the drone did not pose an increased threat to the aerostructure.

The Clean Aviation program is a central pillar in reaching the goal of a decarbonized aviation. © Adobe Stock

Clean Aviation launched

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

Clean Aviation is Europe's leading research and innovation program for transforming aviation towards a sustainable and climate-neutral future.

The Clean Aviation program is a central pillar in reaching the goal of a decarbonized aviation in the year 2050. In the framework of this research program, the aviation industry, research organizations (such as Fraunhofer-Gesellschaft) and universities work jointly on technologies, which will enable decarbonized flights in the future. These technologies include — amongst others — hybrid-electric propulsion, fuel cells for aviation use and hydrogen direct combustion engines. At the beginning of 2023, several research projects were launched within the framework of Clean Aviation. Fraunhofer EMI participates in the project UP Wing, which develops technology bricks for ultra-performance wing structures.

CLEAN AVIATION

Co-funded by the European Union

UP Wing is a Clean Aviation project funded by the European Union under grant agreement ID: 101101974.

EMI in wide angle


In the “EMI in wide angle” section, we open up our perspective and look at topics that were important beyond the business units in the past year. © Adobe Stock

EMI in wide angle

EMI in wide angle

With EMI in wide angle, five employees open the view on topics that were important beyond the business units in the past year.

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3 *Dr. Sebastian Schopferer*
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4 *Dr. Pascal Matura*
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5 *Heide Haasdonk*
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The team of the LZN office (from left to right): Lorenz Bayer, Dr. Juri Lienert, Jessica Nuss and Christiane Felder from Fraunhofer EMI.

Sustainability Center Freiburg

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

The Sustainability Center Freiburg links research of Fraunhofer and the University of Freiburg with applications in business and society.

A Fraunhofer performance center for the promotion of application and future-oriented solutions to the environmental problems of our time

With the cooperation of the five Fraunhofer Institutes in Freiburg and the University of Freiburg, researchers at the Sustainability Center Freiburg (LZN) contribute to developing solutions for a sustainable future. At the LZN, projects related to sustainability are promoted and transfer offers are developed in close cooperation with companies, associations and other stakeholders from the Freiburg region and beyond. The focus is on sustainable materials, energy systems, resilience engineering as well as ecological and societal transformation. Since the founding of the LZN, Fraunhofer EMI researchers have participated in various research projects — as, for example, currently in the WEiTeR pilot project. The aim of the project is to develop solutions for extending the service life, reuse and even high-quality recovery of carbon fibers used in hydrogen containers and to make them available to the industry in order to improve the CO_2 footprint.

Strengthening Freiburg as an innovation location for founders with innovative and sustainable ideas

As part of the LZN's start-up support, Fraunhofer teams with ambitions to spin-off are enabled financially as well as through arranging professional guidance. The goal is to strengthen the start-up scene of the city and to bring sustainable and technological ideas into application. Support also includes, for example, the annual Innovation Bar event, where prospective founders can inform themselves, exchange ideas and network.

Additive manufacturing — focus on sustainability aspects

A contribution by Dr. Klaus Hoschke, klaus.hoschke@emi.fraunhofer.de

Sustainability in lightweight design with additive manufacturing: For an efficient manufacturing process, the design is directly linked to the digital manufacturing plan.

Resource-efficient production of lightweight components

Additive manufacturing opens new possibilities in lightweight design and thus contributes to sustainability. At Fraunhofer EMI, this topic is being intensively researched to make components more efficient and at the same time reduce the ecological footprint.

Lightweight construction as a key technology for resource-saving products is of particular importance in additive manufacturing. 3D printing enables near-net-shape fabrication, which means that lighter components also require less raw material. Lightweight design thus leads to a reduction in material consumption and to lower energy requirements during production.

Reliable models and optimized manufacturing plan

Fraunhofer EMI develops methods and analyses that specifically optimize the lightweight design and the digital manufacturing plan. In order to consider sustainability aspects along the entire process chain, these are already addressed in the product design. An innovative design method is being developed at Fraunhofer EMI for this purpose.

By linking models for topology optimization with analyses of manufacturing and the life cycle analysis of the product, key aspects of sustainability can also be considered in the design. This makes it possible to make important decisions regarding sustainability in the early design phase, to compare materials and production parameters and to optimize the manufacturing plan regarding sustainability.

Efficient scaling and highest quality: Thanks to optimized geometry and optimum placement, many components can be printed in a single printing job. In the picture: several lightweight wheel carriers with support structures after printing.

Destructive safety testing of large lithium-ion batteries

A contribution by Dr. Sebastian Schopferer, sebastian.schopferer@emi.fraunhofer.de

A new laboratory for investigations on the safety of lithium-ion batteries has been established at Fraunhofer EMI — financed by the state of Baden-Württemberg, the federal government and by the Fraunhofer-Gesellschaft.

The rapid increase in the market share of battery-electric vehicles and the still dynamic development in battery technology require significant testing capacities to support the industry in developing safe products. EMI is therefore opening a new battery testing laboratory to perform destructive safety tests.

The range of services offered by the Automotive business unit includes experimental and simulative investigations into the crash behavior of battery cells, modules and high-voltage storage systems. In addition, thermal propagation — the dreaded chain reaction within a battery pack — can be studied and suitable countermeasures researched in the new test facility. Moreover, there is still a lot of research to be done on stationary battery storage systems, which are now also finding their way into homes as a result of the increasing expansion of renewable energies, in order to arrive at safer systems.

The new battery testing laboratory TEVLIB picks up speed

The "Test facility for research into the failure of large lithium-ion batteries under misuse conditions" — TEVLIB for short — features a robust bunker in which the tests take place. Unique selling points in the testing technology are the new battery crash facility and the in-situ X-ray technology. It is not uncommon for the tests to end in a fire in the battery storage unit, emitting considerable quantities of combustion gases and particles. The laboratory building therefore has extensive safety equipment and a gas scrubber for exhaust air purification in order to be able to carry out the destructive tests on large battery systems while maintaining the highest safety standards for employees, infrastructure and the environment.

Top: the new TEVLIB laboratory for research into the failure of large lithium-ion batteries at EMI Efringen-Kirchen.
Bottom: test chamber for battery failure investigations by means of in-situ X-ray technology.

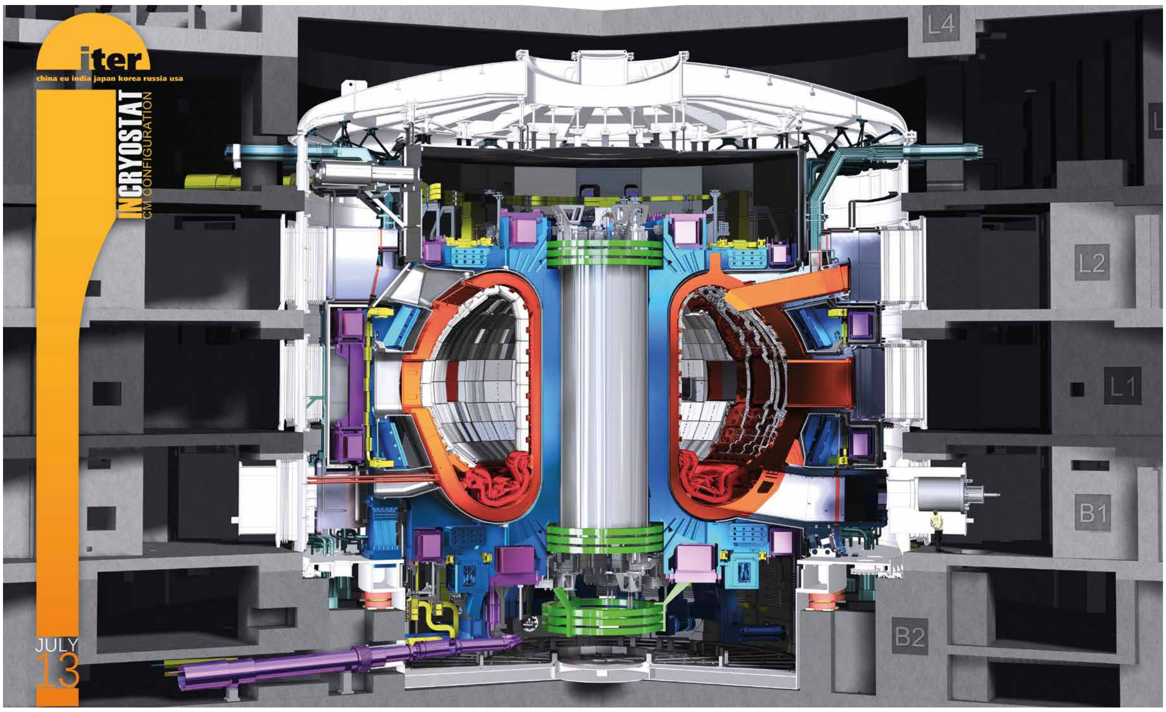
Breaking the ice cleverly — a contribution to fusion research

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

Current forecasts predict a worldwide increase in primary energy and electricity demand. To meet this demand and at the same time meet the enormous challenges of climate change, CO_2-neutral renewable energy sources such as wind and solar power play an important role. But nuclear fusion power plants could also make their contribution to electricity generation to cover the base load in the future.

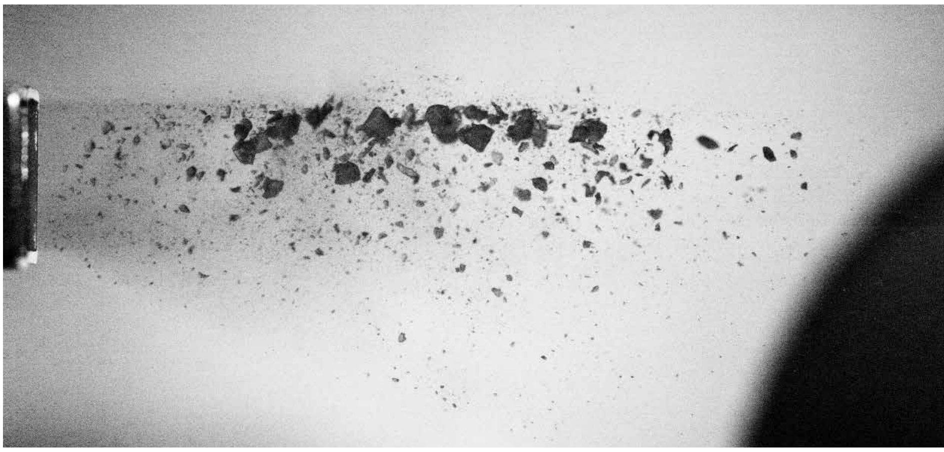
However, there is still a long way to go before the first power plant of this kind will be built. And on this way — in the truest sense of the word in Latin — is the major international research project ITER (International Thermonuclear Experimental Reactor). The world’s largest nuclear fusion reactor to date, which is currently under construction in Cadarache in southern France, is intended to demonstrate for the first time that a net energy gain is technically possible when hydrogen is fused into helium — that is, with a process that takes place similarly in the sun. In contrast to the sun, the two hydrogen isotopes deuterium and tritium are used for this purpose because of their higher efficiency.

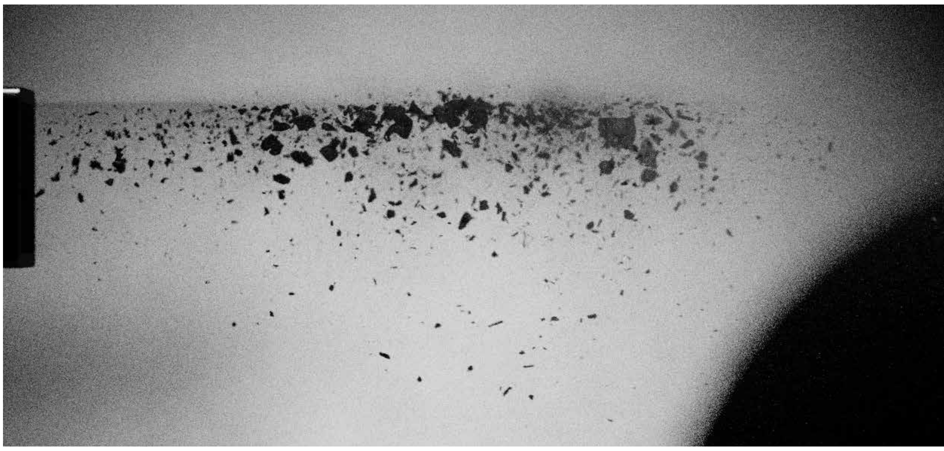
This energy gain, fed by the strong nuclear force, is only effective over very short distances in the atomic nuclei. For fusion to take place at all, a large amount of energy must first be expended to overcome the repulsive Coulomb forces of the positively charged atomic nuclei: The hydrogen is heated to extremely high temperatures, between 100 and 200 million degrees Celsius, and must at the same time be held together. Since, at these temperatures, the hydrogen is no longer a gas but a plasma, it can be influenced by means of magnetic fields and thus enclosed in a ring-shaped magnetic field cage (tokamak principle). If this plasma is sufficiently dense and enclosed for long enough at high temperatures (Lawson criterion), the fusion processes are setting in, releasing enormous amounts of energy. On the one hand, this energy is used to further heat



Sectional model of the ITER tokamak. © ITER Organization

Fragment cloud from a laboratory impact experiment (top, ASDEX Upgrade SPI project of IPP Garching (MPG) and ITER Organization) and corresponding simulation by Fraunhofer EMI using MD-Cube software (bottom).





the plasma, and on the other hand, it is released to the outside, namely to the blanket, the inner structure of the plasma vessel: A coolant is heated up, and the steam generated via a heat exchanger powers a turbine, thus driving a generator to produce electricity.

One challenge is to keep the plasma in a controlled state. So-called plasma disruptions — suddenly occurring disturbances leading to a loss of the plasma-confining plasma current and accompanied by high energy release — can cause high thermal and mechanical loads on reactor components and lead to damage. That would result in additional maintenance time for the replacement of these components. Therefore, a system called disruption mitigation system (DMS) is being installed for ITER to reduce the effects of such disruptions. Its operating principle is to inject fragments of, for example, frozen hydrogen and neon into the plasma within a short period of time. For this sake, cylindrical pellets of the appropriate material are frozen at temperatures of minus 268 degrees Celsius and then shot onto a shattering unit at speeds of up to 1,800 kilometers per hour, where they fragment under the enormous impact load. The effectiveness of the DMS depends on the optimal size and velocity distribution of the fragments. Therefore, it is important to know how the impact conditions affect the fragmentation properties. To this end, the ITER DMS Task Force has specifically established a program to characterize and study fragmentation experimentally.

As part of this program, Fraunhofer EMI is developing numerical models and computer codes to simulate and analyze the complex fragmentation process as part of an ongoing research project. The above-mentioned experiments serve, among other things, to calibrate and validate the developed models and procedures. The validated models will then be used to significantly expand the experimentally determined database and to make predictions for the fragment size distribution under different boundary conditions. The goals here are to optimize the design of the shattering unit and to derive guidelines for optimized impact conditions in order to obtain the desired fragmentation properties. Or, to put it somewhat casually: It is about answering the question of how to break the ice most cleverly.

For the female researchers of tomorrow: Girls' Day 2022 at Fraunhofer EMI

A contribution by Heide Haasdonk, heide.haasdonk@emi.fraunhofer.de

After a two-year break due to corona, Fraunhofer EMI was once again able to invite girls to the Girls' Day on April 28, 2022.

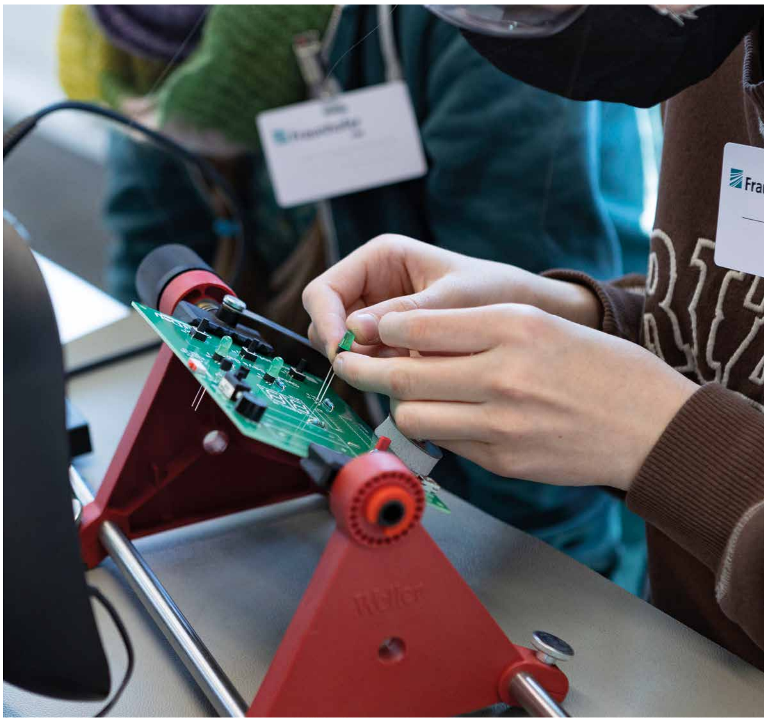
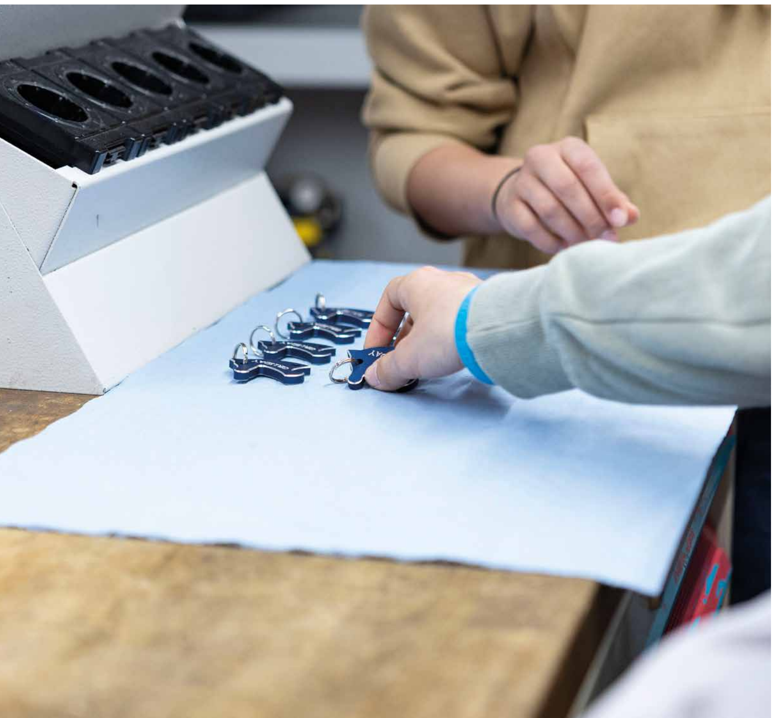
Girls' Day impressions (left to right and top to bottom): drag sail of the nanosatellite ERNST, exhibit of protective concrete after explosion, soldering, keyring pendants as a workshop souvenir and group photo in good spirits.

A glimpse behind the scenes
The aim of the Germany-wide Girls' Day, also known as Girls' Future Day, is to introduce schoolgirls to professions or fields of study in which the proportion of women is below 40 percent. Thanks to the active participation of many EMI employees, a diverse and captivating program awaited eight visitors from Freiburg and the surrounding area. For the 16th time, EMI offered a glimpse behind the scenes of this engineering and technical research institute.

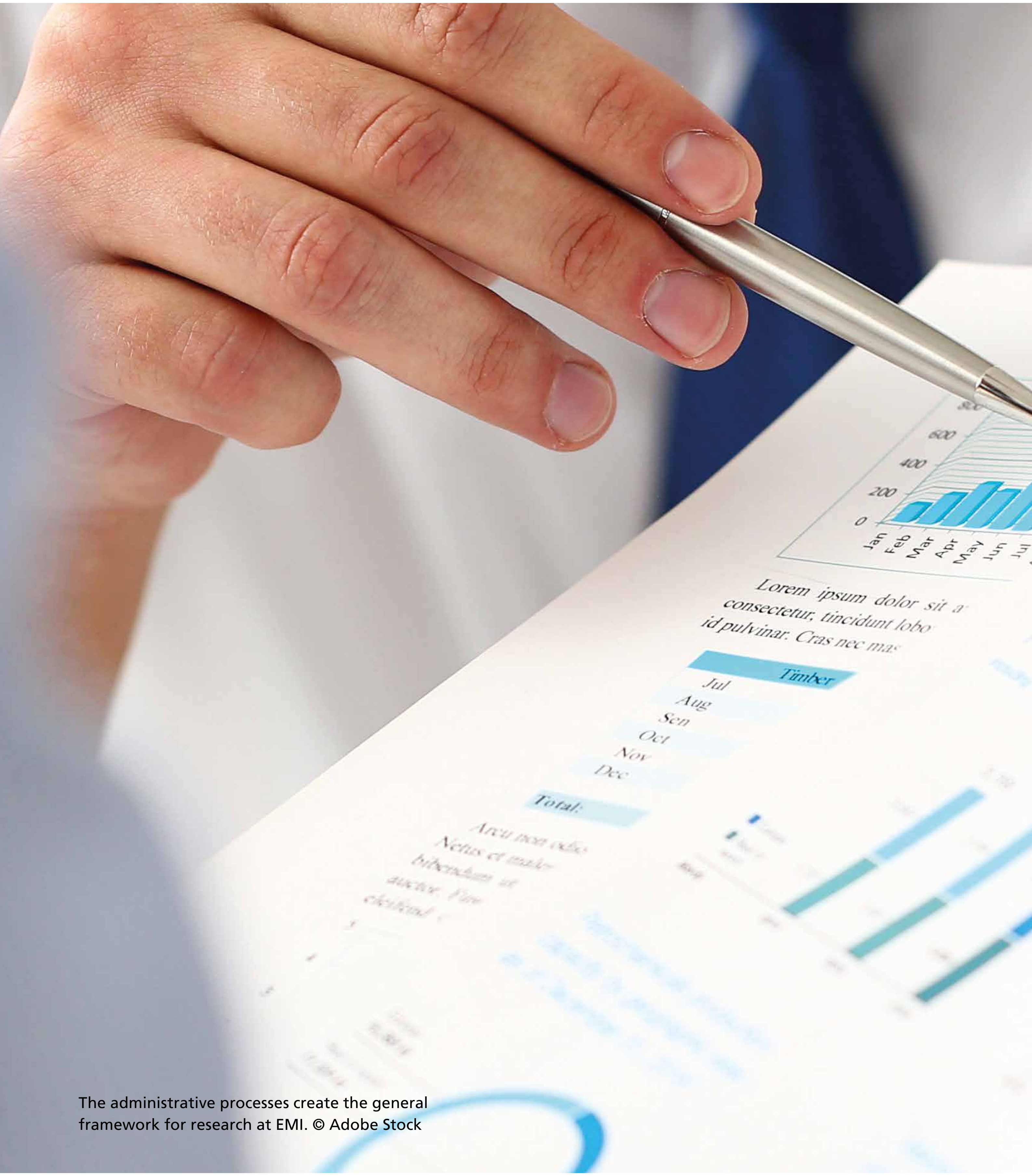
One institute — many professions and activities
The schoolgirls had the opportunity to learn about various professions and fields of activity. A tour of the precision mechanics workshop invited them into the world of milling machines and CAD programs, with first-hand information from the trainees there. In a presentation on "What does a civil engineer actually do? From research to industry, from Spain to Germany, a European journey in the world of construction", female scientists traced stages in their professional careers and sparked the audience's enthusiasm for their field of work. Exhibits of experiments brought along from Efringen-Kirchen served as impressive illustrations. EMI's own satellite ERNST even allowed a mental excursion into space. For the two scientific assistants, who brought this space highlight closer to our audience, ERNST not only provides the stuff of dreams, but also tangible material for their respective student research projects.

Do it yourself: soldering for an electronic game
In an extensive practical part, the students skillfully wielded the soldering irons under the guidance of our experts from the electronics laboratory and built the electronic game "Simon Says" themselves. In addition to many impressions, they therefore also took home a little souvenir from EMI.




Administration



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

Administration

Administration

The start of 2023 is, in several respects, marked by new beginnings.

In December 2022, I started my new role as a head of the institute's administration. After a phase of interim leadership, the task of this position now is to devote full strength and attention to the department areas, identify potential for improvement and, if needed, define the processes respectively.

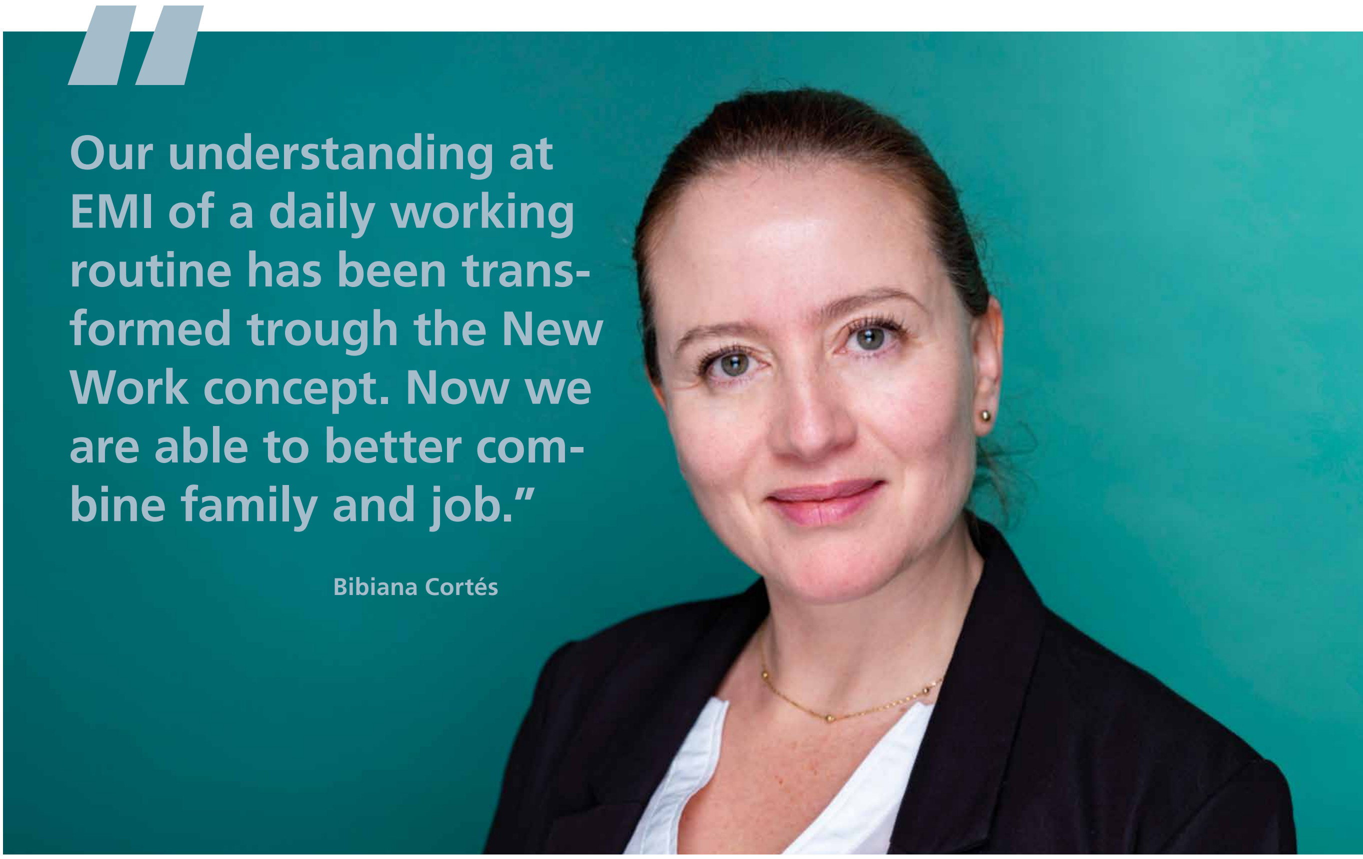
Through the implementation of the legal requirements for the measures of the Occupational Health and Safety regulation related to the coronavirus, EMI has found good solutions and established new structures and processes over the past years. Those measures allow all of us to organize our daily routines using digital tools and hybrid work. Nevertheless, it can also be clearly seen that the opportunity to work in presence at the institute is increasingly being embraced again because of the staff's desire to meet colleagues in person.

The situation on the labor market presents us at Fraunhofer EMI with challenges. Despite the increase in the number of employees, including research staff, there has been a decline in applications for apprenticeships and dual studies in comparison to the previous years.

The implementation of SAP is still representing a higher workload and effort, especially for our administration staff. Many processes are continuously further developed and adapted.

The federal government's plan to cut the R&D budget casts its shadows ahead. EMI is looking ahead to find suitable ways to compensate for this.

We remain optimistic and look forward to the upcoming months with confidence. I consider myself lucky to be able to count on very well qualified and experienced teams in all areas of the department which collaborate with me in order to face future challenges while continuing to provide a good administration service for our EMI scientists.



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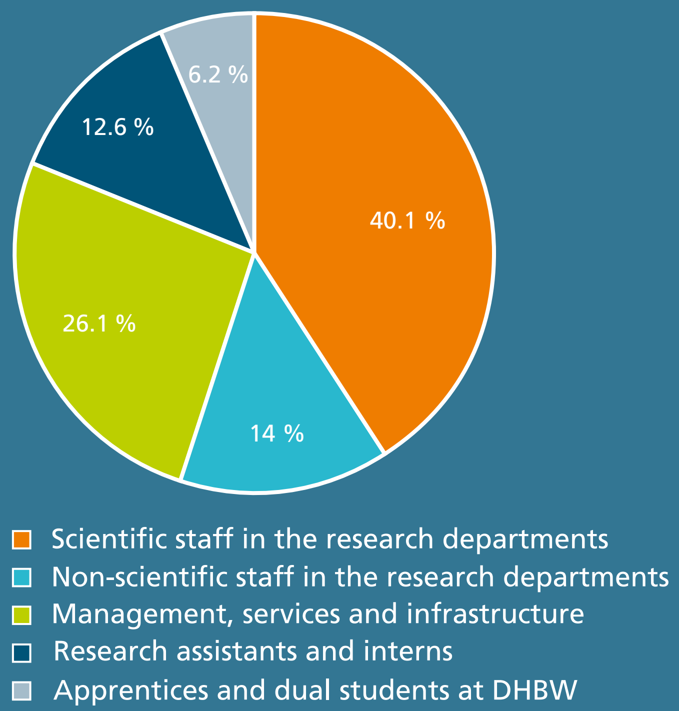
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12.6 %
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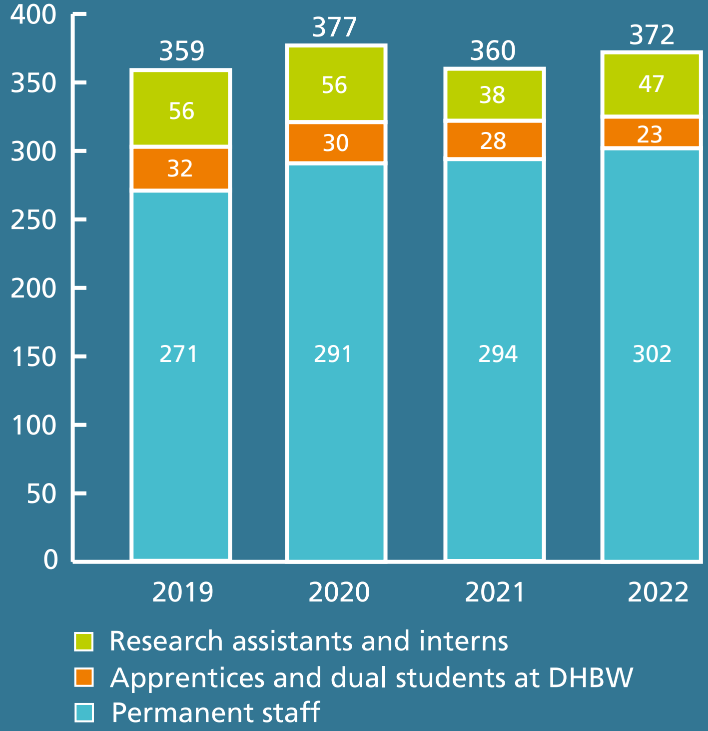
Scientific staff in the research departments
Non-scientific staff in the research departments
Management, services and infrastructure
Research assistants and interns
Apprentices and dual students at DHBW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2019
2020
2021
2022
Research assistants and interns
Apprentices and dual students at DHBW
Permanent staff

Staff structure

At the end of 2022, 372 people were employed at Fraunhofer EMI: 302 employees as permanent staff, 23 as apprentices and dual students, and 47 as research assistants and interns. 205 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 24.8 percent.

15 of the 23 apprentices worked in the fields of precision mechanics, electronics and media design. 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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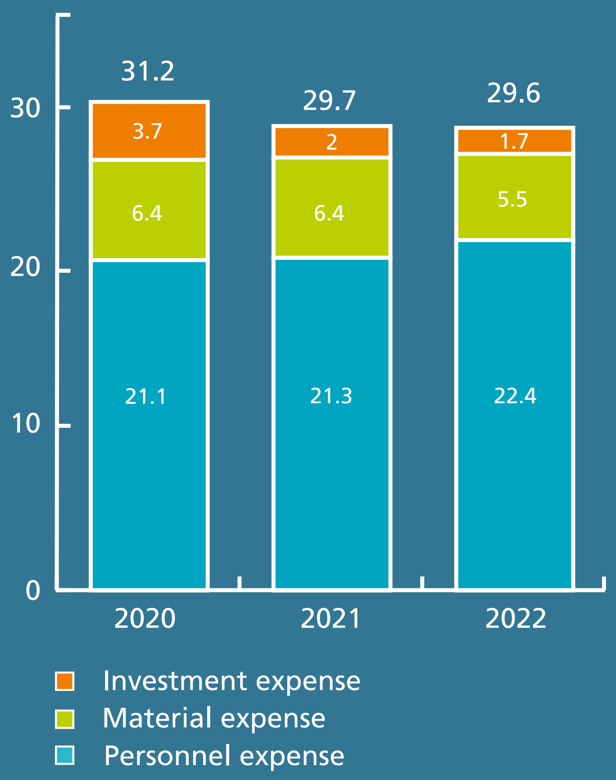
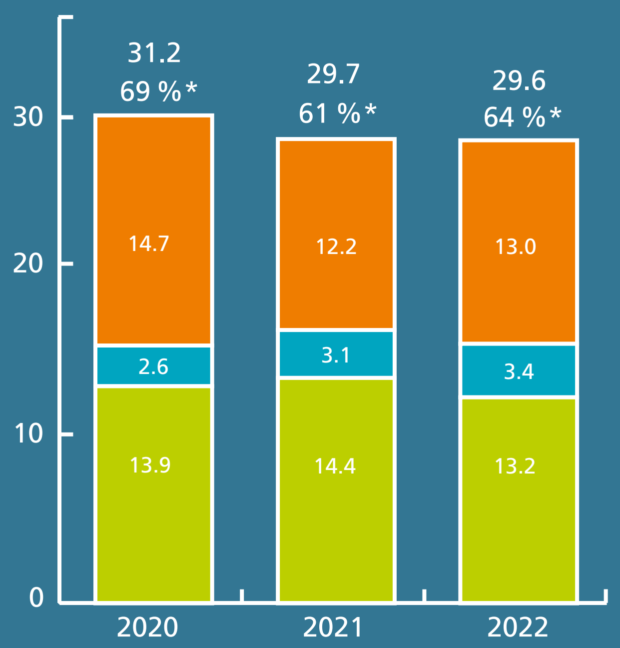
The total budget of Fraunhofer EMI in 2022 is approximately the same as in the previous year: around 30 million euros. The operating budget (personnel and material expenses) has grown to 27.9 million euros, while the investment budget, at 1.7 million euros, was 17 percent lower. An important factor here 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 16.4 million euros of external revenues, a better value was achieved compared to the previous year (15.3 million euros in 2021). In particular, the scope of orders from industrial customers has grown from 3.1 million euros (2021) to 3.4 million euros (2022), and federally funded research projects have grown from 9.5 million euros (2021) to 10.6 million euros (2022). EU revenues decreased from 1.2 million euros (2021) to 0.9 million euros (2022) compared to the previous year. In 2022, the biggest share of the operating and investment budget, namely 64 percent, was financed by the German Federal Ministry of Defence (2021: 61 percent).

Financing of the total budget in million euros



Total budget in million euros



*Federal Ministry of Defence share of total budget

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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.

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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

Univ.-Prof.in Dr.-Ing. habil. Dr. mont. Eva-Maria Kern, President of the University of the Bundeswehr Munich, Neubiberg

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

Brigadier General Michael Meinl
Director French-German Research Institute Saint-Louis ISL, Binzen

Michael Schätzle
Vice President Product Line Cayenne, Porsche AG, Weissach

Brigadier General 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. A trailblazer and trendsetter in innovative developments and research excellence, the Fraunhofer-Gesellschaft supports science and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.

At the Fraunhofer-Gesellschaft, interdisciplinary research teams work with partners from industry and government to turn pioneering ideas into innovative technologies, coordinate and implement system-relevant research projects and strengthen the German and European economies with a commitment to value creation that is based on ethical values. International collaboration with outstanding research partners and companies from around the world brings the Fraunhofer-Gesellschaft into direct contact with the most prominent scientific communities and most influential economic regions.

Founded in 1949, the Fraunhofer-Gesellschaft now operates 76 institutes and research units throughout Germany. Currently around 30,800 employees, predominantly scientists and engineers, work with an annual research budget of about 3.0 billion euros, 2.6 billion euros of which is designated as contract research. Around two thirds of Fraunhofer contract research revenue is generated from industry contracts and publicly funded research projects. The German federal and state governments contribute around another third as base funding, enabling the Fraunhofer institutes to develop solutions now to problems that will drastically impact industry and society in the near future.

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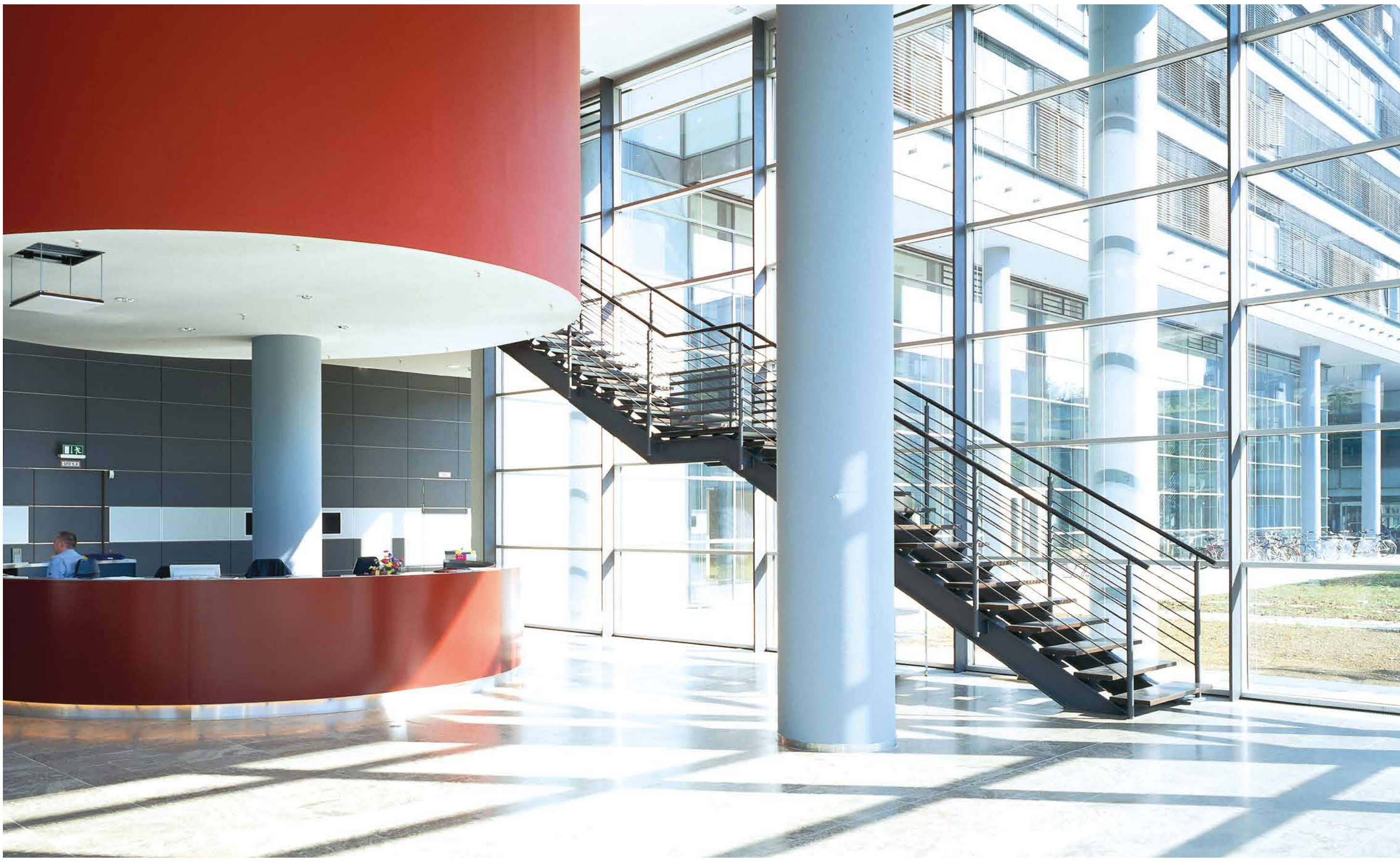

Publications, scientific exchange, lectures 2022/2023

Publications

Publications in books, specialist journals and proceedings with peer review

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Imbert, M.; Hohe, J.: Peeling-basiertes Recycling. In: CU Reports German Edition 01/2022, S. 31.

Jäcklein, M. (2022): Werkstoffdesign für ballistische Anwendungen am Beispiel von 3D-gedrucktem Wolfram-Komposit. In: Wehrwissenschaftliche Forschung, Jahresbericht 2021 des BMVg.

Kappe, K.: Finite element modeling concepts for the dynamic compression response of additively manufactured lattices structures. In: Dynamic behaviour of additively manufactured structures & materials: DYMAT 2022.

Kappe, K. (2022): Dynamic behaviour of additively manufactured structures & materials : DYMAT 2022, 26th Technical Meeting Conference Proceedings. Unter Mitarbeit von Institut für Nachhaltige Technische Systeme, Department of Sustainable Systems Engineering und INATECH. In: DYMAT 2022, 26th Technical Meeting Conference Proceedings. Freiburg, 11.–14.9.2022.

Klaß, M.; Drolshagen, G.; Putzar, R.; Koschny, D.; Poppe, B. (2021): Impact flux predictions with MASTER. In: ESA (Hg.): From Measurements to Understanding: MASTER Modelling Workshop, 3.3.2021. ESA.

Kopustinskas, V.; Vamanu, B.; Ganter, S.; Finger, J.; Häring, I.; Zālītis, I.; Zemīte, L. (2022): Gas network modelling to support pipeline hub area risk assessment study. In: Remenytė-Prescott, R., Sanderson, K., Kopustinskas, V., Simola K. (Hg.): Advances in modelling to improve network resilience: Proceedings of the 60th ESReDA Seminar. Grenoble, 4.–5.5.2022: Publications Office of the European Union, S. 159–162.

May, M.; Jung, M.; Pfaff, J.; Schopferer, S.; Schaufelberger, B.; Matura, P.; Imbert, M. (2022): Vulnerability of aerostructures to drone impact – characterization of critical drone components. In: AIAA Science and Technology Forum and Exposition, AIAA SciTech Forum 2022. San Diego, USA, 3.–7.1.2022.

Mejia, M.; Schäfer, K.; Horch, C.; Busch, S.; Schäfer, F. (2022): IAC International Astronautical Congress 18–22 September 2022, Paris, France (IAC-22,B4,IP,x71406) M. Mejia, K. Schaefer, C. Horch, S. Busch, F. Schaefer, On-board image processing with FPGA acceleration using deep neural network inference. In: Proceedings of the 73rd IAC International Astronautical Congress. Paris, 18.–22.9.2022.

Moonen, J.; Ryan, S.; Barter, S.; Marzocca, P.; Forrester, C.; Shekhter, A. et al. (2022): Evaluating UHMWPE-stuffed aluminium foam sandwich panels for protecting spacecraft against micrometeoroid and orbital debris impact. In: Proceedings of the Hypervelocity Impact Symposium. Hypervelocity Impact Symposium. Alexandria, Virginia, USA, 18.–22.9. 2022.

Patil, S.: Towards programming the strain rate dependency into mechanical metamaterials. Unter Mitarbeit von Institut für Nachhaltige Technische Systeme, Department of Sustainable Systems Engineering und INATECH. In: Dynamic behaviour of additively manufactured structures & materials: DYMAT 2022.

Sauer, C.; Heine, A.; Riedel, W. (2022): Development of numer-ical models for the ballistic response of building materials.
In: Periodic Bulletin of the International Ballistics Society (11).

Schaufelberger, B.; Altes, A.; Trondl, A.; Kisters, T.; Fehrenbach, C.; Matura, P.; May, M. (2022): A detailed simulation model to evaluate the crash safety of a Li-ion pouch battery cell. In: Proceedings of the 15th World Congress on Computational Mechanics (WCCM-XV) and 8th Asian Pacific Con-gress on Computational Mechanics (APCOM-VIII). 15th World Congress on Computational Mechanics (WCCM-XV) and 8th Asian Pacific Congress on Computational Mechanics. Online, 31.7.2022–5.8.2022.

Schimmerohn, M.; Horch, C.; Busch, S.; Ledford, N.; Schäfer, K.; Maue, T. et al. (2022): ERNST: Demonstrating advanced infrared detection from a 12U CubeSat. In: Proceedings of the 36th Small Satellite Conference. Logan, UT, USA, 6.–11.8.2022.

Signetti, S.; Heine, A. (2022): Transition regime between high-velocity and hypervelocity impact and related energy partition in metals: state-of-the-art review, characterization and modeling. In: Proceedings of the 16th Hypervelocity Impact Symposium. Alexandria, Virginia, USA, 18.–22.9.2022.

Scientific exchange, lectures

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

Bauer, S.; Strassburger, E. (2022): On the strength of soda-lime glass under ballistic impact. Lightweight Armour Group for Defence and Security (LWAG). EMI. Freiburg, 16.9.2022.

Bauer, S.; Strassburger, E. (2022): Festigkeit von Kalk-Natron-Glas bei ballistischem Impakt. 24. Tagung »Schutz gegen IED und ballistische Bedrohung«. WTD 91. Meppen, 19.10.2022.

Becker, M. (2022): An inverse model for the peeling-based recovery of unitary layers from laminated structures. 11th International Conference on Mathematical Modeling in the Physical Sciences. Online, 5.9.2022.

Becker, M.; Imbert, M. (2022): Numerische Simulation. Online-Workshop: Digitale Traceability für effizientes Recycling von Composite-Tapes, 1.2.2022.

Busch, S. (2022): Radiation hardening by software: Advanced FDIR and redundancy concepts with COTS in space. 18th International School on the Effects of Radiation on Embedded Systems for Space Applications (SERESSA) at CERN. Genf, 7.12.2022.

Busch, S. (2022): OPM-Anwendung: Satelliten magnetisch vermessen. Industrie-Workshop Quantenmagnetometrie; Technologische Trends in der Quantenmagnetometrie. Fraunhofer IPM. Freiburg, 8.12.2022.

Chen, Y.; Hartrott, P. von; Huschka, M.; Olbricht, J.; Pirskawetza, S.; Schilling, M. et al. (2022): Ontopanel: a diagrams.net plugin for graphical semantic modelling. MSE Congress, 29.9.2022.

Crabbe, S.: Präsentation des SAFETY4RAILS-Projekts auf der Abschlusskonferenz.

Crabbe, S.: Präsentation des SAFETY4RAILS-Projekts bei der Demonstration in Ankara.

Crabbe, S.: Präsentation des SAFETY4RAILS-Projekts bei der Demonstration in Madrid.

Crabbe, S.: Präsentation des SAFETY4RAILS-Projekts bei der Demonstration in Mailand.

Crabbe, S.: Präsentation des SAFETY4RAILS-Projekts bei der Demonstration in Rom.

Crabbe, S.: Präsentation des SAFETY4RAILS-Projekts vor Entscheidungsträgern der Europäischen Kommission und weiteren relevanten EU-Beamten sowie von der EU eingeladenen Experten und Vertretern anderer relevanter europäischer Projekte auf der Tagung der GD HOME CERIS INFRA »Wie unterstützt die Forschung die Richtlinie über die Widerstandsfähigkeit kritischer Einrichtungen?«.

Finger, J. (2022): SifoLIFE-Projekt FreiburgRESIST Sicher Leben in Freiburg: Resilienz-Management für die Stadt. BMBF-Innovationsforum »Zivile Sicherheit« 2022. SifoLIFE – Informationsveranstaltung. Berlin, 2.5.2022.

Fischer, K.; Andreae, M. (2022): Städtebauliche risikobasierte Resilienzanalyse – Exposition und Vulnerabilität. 9. Workshop Bau-Protect: Schutz der baulichen Infrastruktur vor außergewöhnlichen Einwirkungen. Neubiberg, 22.11.2022.

Fischer, K.; Mitschke, A.; Klaproth, O.; Schirrmann, A.; Stolz, A. (2022): Resilience assessment of industrial processes within the aircraft industry. 13th Complex Systems Design & Management (CSD&M) Conference. Paris, 15.12.2022.

Früh, P.; Heine, A.; Wickert, M. (2022): Reaktivschutz für schwere Landsysteme – Potenzial zur Abwehr von KE-Penetratoren. 24. Tagung Schutz gegen IED und ballistische Bedrohung. Meppen, 18.10.2022.

Gebbeken, N.; Fischer, K. (2022): Gebäude und kritische Infrastrukturen – baurechtliche Grundlagen, Risiko und Resilienz. 9. Workshop Bau-Protect: Schutz der baulichen Infrastruktur vor außergewöhnlichen Einwirkungen. Neubiberg, 22.11.2022.

Gutmann, F.: Additive manufacturing of miniaturized pin joints for non assembly metallic metamaterials. ICoNSoM 2022. Alghero, Italy.

Hanke, T.; Huschka, M.; Klawonn, A.; Muth, T.; Olbricht, J.; Schweizer, C. et al. (2022): Mat-O-Lab Demonstrator: a web application showing the benefits of rich semantic material science data and exemplar usage. MSE Congress, 28.9.2022.

Heimbs, S.; May, M.; Hansen, J.; Jung, M.; Pfaff, J.; Calomfirescu, M. (2022): Physics-based drone impact analysis of composite aerostructures. 2nd European Conference on Crashworthiness of Composite Structures ECCCS2. Toulouse, 14.11.2022.

Heine, A.; Sauer, C.; Riedel, W. (2022): Modeling the interaction of a generic hollow projectile with different types of masonry. 3rd International Conference on Impact Loading of Structures and Materials (ICILSM). Trondheim, Norwegen, 14.6.2022.

Hoschke, K. (2022): Multimodale Topologieoptimierung für die Design Exploration und Lösung nichtlinearer, steifigkeitsbasierter Entwurfsprobleme. NAFEMS Seminar »Generativ Design und Optimierung«, 19.5.2022.

Hoschke, K. (2022): Protection potential of cellular structures and graded steels by metal additive manufacturing. Lightweight Armour Group for Defence and Security (LWAG), 15.9.2022.

Hoschke, K. (2022): Potenziale von KI-basierten Methoden für die Strukturoptimierung von Bauteilen und Optimierung von 3D-Druck Materialien. Internes KI-Symposium, 5.10.2022.

Hoschke, K. (2022): Sustainability-oriented topology optimization of aircraft components and best practices in LPBF-based metal additive manufacturing. Towards Sustainable Aviation Summit TSAS. Toulouse, 18.10.2022.

Huschka, M.; Dlugosch, M.; Friedmann, V.; Garcia Trelles, E.; Hoschke, K. (2022): The »AluTrace« use case: harnessing lightweight design potentials via the materials data space. TRUSTS – Trusted Secure Data Sharing Space Workshop: Data Spaces & Semantic Interoperability. Wien, 3.6.2022.

Huschka, M.; Dlugosch, M.; Friedmann, V.; Garcia Trelles, E.; Hoschke, K.; Klotz, U. et al. (2022): The »AluTrace« use case: harnessing lightweight design potentials via the materials data space. IDSA Ecosystem Building Call, 26.7.2022.

Huschka, M.; Dlugosch, M.; Friedmann, V.; Garcia Trelles, E.; Hoschke, K.; Klotz, U. et al. (2022): Harnessing lightweight potentials in LPBF-based additive manufacturing by integration of distributed materials and process data from the cross-institutional Materials Data Space®. MSE Congress, Highlight Lecture, 29.9.2022.

Imbert, M. (2022): Peeling-based recycling of thermoplastic composites: stat of the art, potential and challenges. Workshop des Lehrstuhls AWESOME. Pau, France, 25.5.2022.

Imbert, M. (2022): Review and evaluation of alternative characterization methods for the fracture resistance measurement of high toughness line pipe steels. EPRG-PRCI-APGA – Joint Technical Meeting. Edinburgh, 7.6.2022.

Jenerowicz, M. (2022): Materialcharakterisierung von Rippensurrogaten. Digitaler Workshop im Rahmen der Untersuchungen von Letalitätsgrenzen. WTD 52. Oberjettenberg, 26.1.2022.

Jenerowicz, M. (2022): Present research activities at Fraunhofer EMI« – Comparison of rib bone surrogates from additive manufacturing, cast material and PMHS data under dynamic loading. 2. Dummy.Crashtest.Konferenz. Münster, 8.9.2022.

Jenerowicz, M. (2022): Vergleich von Rippenknochen-Surrogaten aus additiver Fertigung, Gussmaterial (CTS PRIMUS breakable) und PMHS-Daten unter dynamischer Belastung. Workshop »Surrogat«. WTD 52. Oberjettenberg, 7.12.2022.

Jenerowicz, M.; Haase, T.; Linnenberg, M.; Hoschke, K.; Boljen, M.; Hiermaier, S. (2022): Comparison of rib bone surrogates

from additive manufacturing, cast material and PMHS data under dynamic loading. IRCOBI Conference. Porto, 15.9.2022.

Jenerowicz, M.; Matt, P.; Boljen, M. (2022): Verletzungsprognosen über Simulationsmethoden und anthropomorphe Messmethoden für den Schutz von Soldatinnen und Soldaten. DWT-Tagung: Angewandte Forschung für Verteidigung und Sicherheit in Deutschland. Bonn, 9.3.2022.

Jenerowicz, M.; Matt, P.; Boljen, M. (2022): Qualification of Human Body Models and Anthropomorphic Test Devices for Ballistic Injury Protection. Lightweight Armour Group for Defence and Security (LWAG). Freiburg, 15.9.2022.

Kappe, K. (2022): Finite element modeling concepts for the dynamic compression response of additively manufactured lattices structures. DYMAT 2022. Freiburg, 13.9.2022.

Köpke, C.; Walter, J.; Cazzato, E.; Linguraru, C.; Siebold, U.; Stolz, A. (2022): Methodology for resilience assessment for rail infrastructure considering cyber-physical threats. ESORICS, CPS4CIP Workshop. Kopenhagen, 30.10.2022.

Kruse, A.; Köpke, C. (2022): Warning strategies for large scale public events. Social Simulation Conference 2022. Mailand, 13.9.2022.

Martini, T. (2022): Research Outside of Academia – Scientific career at the Fraunhofer-Gesellschaft for the advancement of applied research. Retreat of the Research Training Network »Rethinking Quantum Field Theory«. Päwesin, 4.10.2022.

Matt, P.; Jenerowicz, M.; Boljen, M. (2022): Investigation of e-scooter drivers colliding with curbs – a parametric numerical study. 1. Spring Conference Series 2022 of Tech Center i-protect, Session 1 Human Body Models. Online, 27.4.2022.

Matt, P.; Jenerowicz, M.; Schweiger, T.; Heisch, F.; Lienhard, J.; Boljen, M. (2022): Investigation of e-scooter drivers colliding with curbs – a parametric numerical study. IRCOBI Conference. Porto, 16.9.2022.

Matura, P.; Signetti, S.; Moser, S.; Sandoval Murillo, J.-L.; Durr, N.; Watson, E. et al. (2022): Modelling and simulation of the pellet shattering process related to the SPI technology for the ITER DMS. Second Technical Meeting on Plasma Disruptions and their Mitigation. ITER Headquarters. France, 19.7.2022.

May, M.; Jung, M.; Pfaff, J.; Schopferer, S.; Schaufelberger, B.; Matura, P.; Imbert, M. (2022): Vulnerability of aerostructures to drone impact – characterization of critical drone components. AIAA-SciTech-Forum. Online, 4.1.2022.

Niklas, W.; Ramin, M. von (2022): Softwaregestützte Sicherheitsanalysen von Freifeldszenarien mit Hochenergie-Laserstrahlung. Symposium Lasertechnologie in der Wehrtechnik. WTD 91, Meppen, 1.6.2022.

Patil, S. (2022): Towards programming the strain rate dependency into mechanical metamaterials. DYMAT 2022, 13.9.2022.

Pfaff, A.: Thermal history and phase analysis of functionally graded steel microstructures by L-PBF. Alloys for Additive Manufacturing Symposium.

Ramin, M. von (2022): Auslegung von Bauteilen gegen dynamische Belastung aus Störlichtbogenereignissen. Forschungsgemeinschaft für Elektrische Anlagen und Stromwirtschaft e.V. (FGH), Online-Workshop »Störlichtbögen«, 5.4.2022.

Ramin, M. von (2022): Aktuelles aus der Forschung. 9. Workshop Bau-Protect: Schutz der baulichen Infrastruktur vor außergewöhnlichen Einwirkungen. Neubiberg, 22.11.2022.

Ramin, M. von; Hupfauf, M. (2022): Strukturverhalten im hochdynamischen Bereich. 9. Workshop Bau-Protect: Schutz der baulichen Infrastruktur vor außergewöhnlichen Einwirkungen. Neubiberg, 22.11.2022.

Reich, S. (2022): Untersuchungen zur Hochenergie-Laserwirkung auf metallische Materialien. Lasersymposium. Meppen, 1.6.2022.

Reich, S. (2022): Metal penetration with 120 kw high-power fiber laser. Optica Laser Congress and Exhibition, Laser Applications Conference, Defense Applications Session. Barcelona, 11.12.2022.

Rietkerk, R.; Früh, P.; Riedel, W.; Heine, A. (2022): Machine learning as an alternative approach to quantify the thermal softening of HHA and UHA armor steels. Lightweight Armour Group for Defence and Security (LWAG). Freiburg, 15.9.2022.

Rietkerk, R.; Heine, A.; Riedel, W. (2022): Maschinelles Lernen für Schutz und Wirkung – Modellierung des hochdynamischen Verhaltens von Werkstoffen unter Beschuss. Angewandte Forschung für Verteidigung und Sicherheit in Deutschland. Bonn, 8.3.2022.

Rietkerk, R.; Heine, A.; Riedel, W. (2022): Anwendung von maschinellem Lernen für Analysen zu Endballistik und zu endballistischem Werkstoffverhalten. KI-Kolloquium. Freiburg, 14.9.2022.

Rosin, J. (2022): Stability of steel tanks with unintentional pre-deformation due to installation. Conference on Flat Bottom Storage Tanks. München, 19.10.2022.

Sauer, M.; Dörfler, M.; Klomfass, A. (2022): Simulation von Fragmentierungsvorgängen bei Impakt. Reactive Materials Workshop. WTD 91. Meppen, 31.5.2022.

Schaufelberger, B.; Trondl, A. (2022): Detailliertes FE-Modell und Ersatzmodellierung zur Bewertung der Crash-Sicherheit einer Li-Ionen Zelle. Spring Conference Series #4 (Battery Safety) des Tech Center i-protect. Online, 12.7.2022.

Schimmerohn, M. (2022): Ballistic limit equations – history, limits and need for future development. 2nd European Hypervelocity Impact Risk Assessment Forum. Cranfield University, 22.11.2022.

Signetti, S.; Heine, A. (2022): Transition regime between high-velocity and hypervelocity impact and related energy partition in metals: state-of-the-art review, characterization, and modeling. 16th Hypervelocity Impact Symposium. Alexandria, Virginia, USA, 21.9.2022.

Srivastava, K.; Köpke, C.; Walter, J.; Faist, K.; Berry, J.; Porretti, C.; Stolz, A. (2022): Modelling and simulation of railway networks for resilience analysis. ESORICS, CPS4CIP Workshop. Kopenhagen, 30.10.2022.

Stolz, A. (2022): Engineering resilience against natural and man-made disasters. TexXPlore (TXP) Day, Home Team HTX. Singapore, 29.11.2022.

Strassburger, E.; Bauer, S. (2022): Transparente Panzerung mit erhöhter Effizienz. 24. Tagung »Schutz gegen IED und ballistische Bedrohung«. WTD 91. Meppen, 18.10.2022.

Strassburger, E.; Bauer, S.; Amlung, E. (2022): Einfluss von Störplatten auf Projektile mit Wolframcarbidkern. 24. Tagung »Schutz gegen IED und ballistische Bedrohung«. WTD 91. Meppen, 18.10.2022.

Strobl, M.; Aurich, H. (2022): Characterization of progressive damage evolution in polymer bonded explosives. 51st International Annual Conference of the Fraunhofer ICT. Karlsruhe, 29.6.2022.

Watson, E.; Durr, N.; Büttner, M.; Matura, P.; Schimmerohn, M. (2022): DEM-O II. Final Presentation Meeting. Freiburg, 7.11.2022.

Seminar lectures at EMI

Goesmann, M. (2022): Numerische Simulation der Laser-Materie-Wechselwirkung. EMI-Doktorandenseminar, 21.10.2022.

Holz, S. (2022): Analyse und Simulation der Aerosolausbreitung, Aspekte des Projekts »AVATOR« (Anti-Virus-Aerosol: Testing, Operation, Reduction). EMI-Hausseminar. Freiburg, 17.2.2022.

Jäcklein, M. (2022): Entwicklung von Metall-Matrix-Verbundwerkstoffen im LPBF-Verfahren. EMI-Doktorandenseminar, 3.6.2022.

Jenerowicz, M. (2022): Meso-mechanical simulation methods for predictive analysis of bone structures under dynamic loads. EMI-Doktorandenseminar. EMI Freiburg, 16.12.2022.

Jenerowicz, M.; Haase, T.; Linnenberg, M.; Hoschke, K. (2022): EMIdee »SAMBIT« Surrogates from Additive Manufacturing for Ballistic Impact Tests. EMI-Hausseminar. EMI Freiburg, 30.6.2022.

Kappe, K. (2022): Optimierungsmethoden für additiv gefertigte zelluläre Gitterstrukturen unter dynamischer Belastung. EMI-Doktorandenseminar, 25.11.2022.

Köpke, C. (2022): Vorstellung des Projektes »SATIE (Security of Air Transport Infrastructure of Europe)«. EMI-Hausseminar, 17.3.2022.

Mert, D. (2022): Untersuchung des Ausatemvorgangs mittels Schlierentechnik, Aspekte des Projekts »AVATOR« (Anti-Virus-Aerosol: Testing, Operation, Reduction). EMI-Hausseminar. Freiburg, 17.2.2022.

Patil, S. (2022): The auxetic friction cell – towards programming the strain rate dependency into lattice structures. EMI-Doktorandenseminar, 14.6.2022.

Pfaff, A. (2022): Functionally graded lattice structures. EMI-Doktorandenseminar, 21.10.2022.

Reich, S. (2022): Challenge accepted: Was bekommt der 120-kW-Laser als Erstes durchbohrt? EMI-Hausseminar. EMI Freiburg, 21.7.2022.

Rosin, J. (2022): Überblick über das Projekt »ResCentric« – Climate Risk Analyses. EMI-Hausseminar, 21.7.2022.

Sauer, M.; Bagusat, F.; Rüthnick, P.; Pfändler, S.; Maurer, M.; Günther, W. et al. (2022): Bestimmung hochdynamischer Materialeigenschaften mit »Taylor-Tests«. EMI-Hausseminar, 8.12.2022.

Soot, T. (2022): »Grey Box Processing«. Integrales Validierungsverfahren für Struktursimulationen in der Fahrzeugsicherheit. EMI-Doktorandenseminar. EMI Freiburg, 3.6.2022.

Courses of the Carl-Cranz-Gesellschaft

Heine, A. (2022): Verhalten von Bauwerkstoffen bei Projektilimpakt. Seminar VS 1.42 »Ballistik und Effektivität moderner Hochleistungsgeschosse«. Oberpfaffenhofen, 13.10.2022.

Heine, A. (2022): Wissenschaftliche Untersuchungemethoden für die Geschosswirkung. Seminar VS 1.42 »Ballistik und Effektivität moderner Hochleistungsgeschosse«. Oberpfaffenhofen, 13.10.2022.

Signetti, S. (2022): Simulationsmodelle der Innenballistik. Seminar »Innenballistik von Rohrwaffen«. EMI Efringen-Kirchen, 27.9.2022.

Strassburger, E. (2022): Endballistik kleinkalibriger Geschosse – Keramik für den ballistischen Schutz. Seminar VS 1.43 »Endballistik – Grundlagen und Anwendungen«. ISL. Saint-Louis, 21.6.2022.

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

Boljen, M.; Jenerowicz, M.; Matt, P.: Qualifikation numerischer und experimenteller Methoden zur Prognose und zum Schutz vor ballistischer Wirkung auf den menschlichen Körper. Ballistik in Forschung und Technologie. BiZBw Mannheim.

Früh, P.; Heine, A.; Wickert, M. (2022): Reaktivschutz für schwere Landsysteme – Potenzial zur Abwehr von KE-Penetratoren. Symposium Ballistik in Forschung und Technologie 2022. BiZBw Mannheim, 20.9.2022.

Rietkerk, R.; Heine, A.; Riedel, W. (2022): Anwendung von maschinellem Lernen für Analysen zu Endballistik und zu endballistischem Werkstoffverhalten. Symposium Ballistik in Forschung und Technologie 2022. Mannheim, 21.9.2022.

Sauer, C.; Bagusat, F.; Ruiz-Ripoll, M.-L.; Roller, C.; Sauer, M.; Heine, A.; Riedel, W. (2022): Untersuchung von Stoßwellen-eigenschaften eines ultrahochfesten Faserbetons durch Kombination von Experiment und Simulation. Symposium Ballistik in Forschung und Technologie 2022. Mannheim, 21.9.2022.

Strassburger, E. (2022): Transparente Panzerungen mit erhöhter Effizienz gegen Geschosse mit Hartmetallkern. Symposium Ballistik in Forschung und Technologie (BFT). BiZBw Mannheim, 19.9.2022.

Thoma, O. (2022): Mündungssignatur und Funkenbildung bei Handwaffen. Symposium Ballistik in Forschung und Technologie 2022. BiZBw Mannheim, 20.9.2022.

Thoma, O. (2022): Untersuchungen zur Abgangsballistik von Unterkalibergeschossen. Symposium Ballistik in Forschung und Technologie 2022. BiZBw Mannheim, 20.9.2022.

Lectures

Balle, F. (Wintersemester 2021/2022): Lightweight Design and Materials. Vorlesung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Balle, F. (Wintersemester 2021/2022): Materials Selection and Sustainable Development for Mechanical Engineering. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Balle, F. (Wintersemester 2021/2022): Sustainable Materials – Functional Materials: Einführung. Vorlesung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Balle, F. (Wintersemester 2021/2022): Sustainable Systems Engineering: Studienprojekt. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Balle, F. (Wintersemester 2021/2022): Werkstofftechnik und -prozesse. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Balle, F. (Sommersemester 2022): Lab Course Engineering Materials and Testing Methods. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

Balle, F. (Sommersemester 2022): Methodenpraktikum Master Sustainable Materials – Functional Materials. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

Balle, F. (Sommersemester 2022): Nachhaltige Materialien. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

Balle, F. (Sommersemester 2022): Ringvorlesung Methoden der Materialwissenschaften. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

Balle, F. (Sommersemester 2022): Technische Funktionswerkstoffe. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

Balle, F.; Kilchert, S.; Hiermaier, S. (Sommersemester 2022): SSE-Studienseminar. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

Busch, S. (Wintersemester 2021/2022): Cansat Design Lab. Julius-Maximilians-Universität Würzburg, Wintersemester 2021/2022.

Busch, S. (Wintersemester 2021/2022): New Space. Seminar, Wintersemester 2021/2022.

Busch, S. (Wintersemester 2021/2022): Spacecraft System Analysis. Vorlesung. Julius-Maximilians-Universität Würzburg, Wintersemester 2021/2022.

Busch, S. (Sommersemester 2022): Spacecraft System Analysis Repetitorium. Vorlesung. Julius-Maximilians-Universität Würzburg, Sommersemester 2022.

Ganzenmüller, G.; Hiermaier, S. (Wintersemester 2021/2022): Fundamentals of Resilience. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Ganzenmüller, G.; Hiermaier, S. (Wintersemester 2021/2022): Grundlagen der mechanischen Werkstoffcharakterisierung/ Basics of mechancial testing. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Ganzenmüller, G.; Hiermaier, S. (Wintersemester 2021/2022): Physics of Failure. Vorlesung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Ganzenmüller, G.; Hiermaier, S. (Sommersemester 2022): Angewandte Finite Elemente für die Strukturmechanik. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

Ganzenmüller, G.; Hiermaier, S. (Sommersemester 2022): Werkstoffdynamik: Werkstoffcharakterisierung / Dynamics of Materials: Material Characterization. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

Häring, I. (Wintersemester 2021/2022): Quantitative Risikoanalyse. Vorlesung. Hochschule Furtwangen, Wintersemester 2021/2022.

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

Häring, I. (Sommersemester 2022): Funktionale Sicherheit – Aktive Resilienz / Functional Safety: Active Resilience. Vorlesung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

Harwick, W. (Wintersemester 2022/2023): Werkstoffkunde. Vorlesung. DBHW Lörrach, Wintersemester 2022/2023.

Hiermaier, S. (Sommersemester 2022): Climate Change. Vorlesung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

Hiermaier, S. (Sommersemester 2022): Grundlagen resilienter Systeme. Vorlesung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

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

Kilchert, S.; Hiermaier, S. (Sommersemester 2022): Material Flow Analysis. Vorlesung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

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

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

Matura, P. (Wintersemester 2022/2023): Numerische Methoden in der Mathematik. Vorlesung. DBHW Lörrach, Wintersemester 2022/2023.

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

Matura, P.; Hiermaier, S. (Wintersemester 2022/2023): Kontinuumsmechanik. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2022/2023.

May, M.; Imbert, M.: Composite Materials. Vorlesung. Wintersemester 2022/2023. Albert-Ludwigs-Universität Freiburg.

Osterholz, J. (Sommersemester 2022): High-Energy-Density Physics. Vorlesung. Heinrich-Heine-Universität Düsseldorf, Sommersemester 2022.

Ramin, M. von (Sommersemester 2022): Lehrbeauftrager im Masterstudiengang »Katastrophenvorsorge und Katastrophenmanagement«, Unterrichtseinheit 3 »Bauliche Prävention im Bevölkerungsschutz« im Modul »Ausgewählte Konzepte und Maßnahmen der Katastrophenvorsorge«. Rheinische Friedrich-Wilhelms-Universität Bonn, Sommersemester 2022.

Riedel, W.: Schutz baulicher Infrastrukuturen. Vorlesung. Wintersemester 2021/2022 und 2022/2023. Hochschule Furtwangen.

Sauer, M. (Wintertrimester 2022): Laborpraktikum. Universität der Bundeswehr München, Wintertrimester 2022.

Sauer, M. (Wintertrimester 2022): Numerische Simulationsverfahren. Vorlesung. Universität der Bundeswehr München, Wintertrimester 2022.

Sauer, M. (Wintertrimester 2022): Werkstoffcharakterisierung. Vorlesung. Universität der Bundeswehr München, Wintertrimester 2022.

Schäfer, F. (Wintersemester 2021/2022): Charakterisierung von Geomaterialien unter Stoßbelastung I, Characterization of Geomaterials under Shock Loads I. Vorlesung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Schäfer, F. (Wintersemester 2021/2022): Shock Waves in Rocks I. Vorlesung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2021/2022.

Schäfer, F. (Sommersemester 2022): Charakterisierung von Geomaterialien unter Stoßbelastung II, Characterization of Geomaterials under Shock Loads II. Vorlesung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

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

Stolz, A. (Sommersemester 2022): Design and Monitoring of Large Urban Infrastructures. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

Stolz, A. (Wintersemester 2022/2023): Structural Robustness: Resilient Designs. Vorlesung. Albert-Ludwigs-Universität Freiburg, Wintersemester 2022/2023.

Stolz, A.; Lickert, B. (Sommersemester 2022): Resilience of Supply Networks. Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg, Sommersemester 2022.

Visiting scientists at EMI

Fischer, Frank, 18.10.2021–17.10.2022.

Fransson, Matilda, 7.10.2022–21.10.2022.

Gonzalez Virgen, Georgina, 1.12.2021–30.3.2022.

Jain, Atin, 16.11.2020–31.8.2023.

Nasr, Engy, 1.3.2021–28.2.2022.

Plappert, David, 15.5.2021–30.4.2023.

Resende Oliveira, Pablo, Stipendiat, 1.6.2018–31.5.2022.

Rey de Pedraza, Victor, 1.4.2022–30.6.2022.

Roth, Antonina, 16.1.2019–30.6.2024.

Schalm, Tobias, 1.1.2022–31.7.2022.

PhD

Becker, M. (2022): Arlequin-coupling of 2-D peridynamic finite elements with an analytical Jacobian matrix. Dissertation. TU München, München.

Becker, M. (2022): Energieeffizientes Punktschweißen von Aluminium/Stahl-Strukturen durch Leistungsultraschall. Dissertation. Albert-Ludwigs-Universität Freiburg, Freiburg.

Benz, M. (2022): Automatisierbare direkte Kalibrierung von Materialmodellen auf Basis digitaler Bildkorrelation. Dissertation. Universität Stuttgart, Stuttgart.

D'haen, J. (2022): On the behavior of compression loaded multidirectional carbon fiber laminates after first ply failure. Dissertation. Albert-Ludwigs-Universität Freiburg, Freiburg.

Heunoske, D. (2022): Zeitaufgelöste Untersuchungen von Plasmaeffekten bei der Wirkung intensiver Laserstrahlung auf Metalle. Dissertation. Heinrich-Heine-Universität, Düsseldorf.

Rehra, J. (2022): Beitrag zur Beschreibung des mechanischen Materialverhalten von Metall-Faser- Hybrid-Verbund-Werkstoffen am Beispiel von stahl- und kohlenstofffaserverstärktem Epoxidharz. Dissertation. TU Kaiserslautern, Kaiserslautern.

Resende Oliveira, P. (2022): Eco-mechanical characterization of sandwich panels based on an environmentally-friendly honeycomb core with upcycled plastic caps. Dissertation. Albert-Ludwigs-Universität Freiburg, Freiburg.

Schlamp, M. (2022): Der Einfluss eliptischer Krümmung auf das Verformungs- und Schädigungsverhalten glasfaserverstärkter Kunststoffstrukturen. Dissertation. Albert-Ludwigs-Universität Freiburg, Freiburg.

Staab, F. (2022): Verbundeigenschaften, Mikrostruktur und Prozessanalyse ultraschall-geschweißter Leichtmetall/CFK-Verbunde. Dissertation. Albert-Ludwigs-Universität Freiburg, Freiburg.

Watson, E. (2022): Fragment tracking in hypervelocity impact experiments. Dissertation. Albert-Ludwigs-Universität Freiburg, Freiburg.

Bachelor, master and diploma theses

Arikan, E. (2022): A Comparative Study on Graph-based Path Planning Algorithms. Master's Thesis. EMI-Report A 01/22. Albert-Ludwigs-Universität Freiburg.

Biernacki, J.-B. (2022): Room impulse response filtering for application in an indoor sonar system. Master 's Thesis. EMI-Report A 13/22. Albert-Ludwigs-Universität Freiburg.

Burtsche, J. (2022): Auswertung quantitativer Schädigungsinformationen an Betonelementen nach lokaler, hochdynamischer Belastung. Bachelorarbeit. EMI-Bericht A 24/22. DHBW Lörrach.

Feix, W.: Smart Coating – Materialcharakterisierung von Polyurea als Beschichtung zum Explosionsschutz. Bachelorarbeit.

Giebfried, R. (2022): Entwicklung einer Generative Engineering Implementierung zur Topologieoptimierung eines wehrtechnischen Bauteils unter dynamischer Last für den metallischen 3D-Druck. Bachelorarbeit. DBHW Lörrach.

Grau, P. (2022): Sicherheitsbezogene Betrachtungen zu einem Leichtgasbeschleuniger. Bachelorarbeit. EMI-Bericht A 03/22. Hochschule Furtwangen.

Grenier, R. (2022): Innovativer Recyclingansatz für thermoplastische Composites: Einfluss der Temperatur und der mechanischen Belastungsbedingungen auf das Lagetrennverhalten. Masterarbeit. EMI-Bericht A 41/22. RWTH Aachen.

Hardt, L. (2022): Optimierung einer Messeinrichtung zur Untersuchung abgangsballistischer Vorgänge mit Röntgenstrahlung. Bachelorarbeit. EMI-Bericht A 42/22. DHBW Mannheim.

Kim, J. (2022): Methodology for integration of life cycle assessment into a generative design process of 3D-printed products. Master's Thesis. EMI-Bericht A 39/22. Albert-Ludwigs-Universität Freiburg.

König, L. (2022): Sichtbarkeits- und Hörbarkeitsberechnungen unter Ausnutzung von Grafikprozessoren. Bachelorarbeit. EMI-Bericht A 21/22. DHBW Lörrach.

Labusch, C. (2022): Numerische Strömungssimulation zur Untersuchung hybrider Lüftungskonzepte in Klassenräumen im Hinblick auf exhalierte Aerosole. Masterarbeit. FH Münster.

Maura Aláez, V. (2022): Sun simulation for a thermal-vacuum test facility for small satellite and payload testing. Master's Thesis. EMI Report A 05/22. University of the Basque Country.

Pätzold, Q. (2022): Studie über ein strahlungstolerantes Überwachungssystem für die Nutzlast eines Kleinsatelliten. Bachelorarbeit. EMI-Bericht A 19/22. Albert-Ludwigs-Universität Freiburg.

Ronge, F. (2022): (Energie-)Effizienz und Resilienz von Gebäudebegrünungen im Hinblick auf zukünftige Klimaszenarien – Simulativer Vergleich von verschiedenen Begrünungssystemen, Pflanzenarten und Flächenbedeckungskonfigurationen sowie Ermittlung und Optimierung von deren Einfluss auf die Innentemperatur und den Energiehaushalt eines mitteleuropäischen Referenzgebäudes. Bachelorarbeit. EMI-Bericht A 12/22. Albert-Ludwigs-Universität Freiburg.

Sakhala, S. (2022): Numerical simulation of gas explosions considering turbulent flame propagation. Masterarbeit. EMI-Bericht A 40/22. Universität Paderborn.

Sasi, S. K. (2022): FEM simulation of the mechanical loading on solid fuels. Master's Thesis. EMI-Bericht A 37/22. Universität Duisburg Essen.

Schlegel, N. (2022): Numerische Simulation der Laser-Materie-Wechselwirkung. Bachelorarbeit. EMI-Bericht A 26/22. DHBW Lörrach.

Schneider, N. (2022): Modellierung und Impaktsimulation ausgewählter Drohnenkomponenten Modeling and Impact Simulation of Selected Drone Components. Master's Thesis. EMI Report A 16/22. Berliner Hochschule für Technik.

Schütz, B. (2022): Charakterisierung von Berstmembranen für Crashanwendungen. Bachelorarbeit. EMI-Bericht A 27/22. DHBW Lörrach.

Siebert, A. (2022): Fusionsalgorithmen für eine MEMS-IMU basierte Orientierungsbestimmung bei transienter Überlast. Masterarbeit. EMI-Bericht A 18/22. Albert-Ludwigs-Universität Freiburg.

Speck, R. (2022): Aufbau und Umsetzung eines Konzepts zur Steuerung einer optischen Nutzlast zum Einsatz auf der ISS. Bachelorarbeit. EMI-Bericht A 15/22. FH Aachen.

Steiert, M. (2022): In-Situ-Wärmebehandlung von Gitterstrukturen im L-PBF-Verfahren. Bachelorarbeit. EMI-Bericht A 32/22. Hochschule Offenburg.

Strahringer, S. (2022): Eco-mechanical characterization of sandwich panels based on an environmentally-friendly honeycomb core with upcycled plastic caps. Bachelorarbeit. EMI-Bericht A 25/22. Albert-Ludwigs-Universität Freiburg.

Thalwaththe Gedara, M. (2022): Lithium-ion battery thermal runaway investigation using conventional computed tomography (CT) and energy resolved CT with the Medipix3RX detector. Master's Thesis. EMI-Bericht A 04/22. Albert-Ludwigs-Universität Freiburg.

Thiedecke, N. (2022): System concept for evaluation of planar sparse microphone array geometries regarding sound source localization performance. Master's Thesis. EMI Report A 14/22. Albert-Ludwigs-Universität Freiburg.

Tisha, L. S. (2022): Development of Ta-W Composite Using Laser Powder Bed Fusion. Master's Thesis. EMI Report A 22/22. TU Chemnitz.

Tsao, Y. H. (2022): Behavior of granular material soil under high speed flood events. Master's Thesis. EMI Report A 23/22. Albert-Ludwigs-Universität Freiburg.

Wandel, L. (2022): Entwicklung von Reflexionsmessungen zur Verbesserung des Verständnisses von Hochleistungslaserprozessen. Bachelorarbeit. EMI-Bericht A 29/22. Hochschule Furtwangen.

Welp, P. (2022): Empirische Optimierung von L-PBF-Parametern zur Verarbeitung von Rein-Kupfer. Bachelorarbeit. EMI-Bericht A 31/22. DBHW Lörrach.

Patents

Hoschke, K.; Gutmann, F.: Method for producing a bone replacement element. Anmeldenummer: EP22191063.1.

Imbert, M.: Method and apparatus for detaching a fiber layer from a multilayer fiber composite material. Anmeldenummer: EP22181631.7.

Pfaff, A.: Method for post-treating additively manufactured structures by means of ultrasound. Anmeldenummer: EP22214871.0.

Pfaff, A.: Reduction of oxygen content in a process chamber. Anmeldenummer: EP22181901.4.

Rosin, J.; Delleske, C.; Lüttner, F.: Method and apparatus for indicating the presence of a buried person in a building after a collapse of the building. Anmeldenummer: Europäische Patentanmeldung: 21 154 793.0.

Rosin, J.; Delleske, C.; Lüttner, F.: Multifunktionale Sensoreinheit zur automatisierten und schnellen Detektion verschütteter Personen. Anmeldenummer: US-amerikanische Patentanmeldung: 17/585,941.

Workshops and events

9. Workshop Bau-Protect. Fachliche Leitung seitens Fraunhofer EMI. Neubiberg.

Doktoranden Summer School, Fraunhofer EMI + INATECH-SSE (Sustainable Systems Engineering). Naturfreundehaus Breitnau.

Workshop ASASP. 8.–10.11.2022. EMI Efringen-Kirchen.

Haase, T. (2022): 5. Gesamtprojekttreffen »AIMM«. EMI Freiburg, 6.10.2022.

Hoschke, K.: Formnext 2022 (15.-18.11.2022): Standbetreuung für Fraunhofer Kompetenzfeld Additive Fertigung und Ausstellung mehrerer Exponate; Nennung des Fraunhofer EMI in Pressemitteilung des Fraunhofer Kompetenzfeld (1.11.22).

Hoschke, K.: Rapid.Tech 2022 (17.–19.6.2022): Standbetreuung für Fraunhofer Kompetenzfeld Additive Fertigung und Ausstellung mehrerer Exponate; Nennung des Fraunhofer EMI in Pressemitteilung des Fraunhofer Kompetenzfeld.

Matt, P.; Léost, Y.; Kurfiß, M.; Schweiger, T.; Lienhard, J.; Boljen, M. (2022): E-Scooter-Unfälle an Bordsteinkanten – Dummys und Menschmodelle im Einsatz. Freiburger Dialog, 26.10.2022.

Pfaff, A.: auf ICoNSOM 2022 (13.–16.6.2022): Organization und Durchführung des Mini-Symposiums »Additive Manufacturing and characterization of metamaterials« International Conference on Nonlinear Solid Mechanics, Alghero, Italien.

Participation in professional boards, associations and program committees

Heine, A.: Organizing Committee, 4th International Conference on Impact Loading of Structures and Materials (ICILSM 2024).

Heine, A.: Scientific Committee, Light-Weight Armour Group (LWAG).

Heine, A.; Strassburger, E.: Co-Chairs of the LWAG 2022 Light-Weight Armour for Defence and Security.

Hoschke, K.: Kompetenzfeld Additive Fertigung.

Köpke, C.: Mitglied Programm Committee des CPS4CIP 2022 Workshops.

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

May, M.: Editorial Board »Journal of Dynamic Behavior of Materials«.

May, M.: Editorial Board »Unizik, Journal of Technology, Production and Mechanical Systems« (UJTPMS), Nnamdi Azikiwe University Awka, Nigeria.

May, M.: Member International Honors and Awards Development Committee, AIAA, USA.

May, M.: Mitglied der Fraunhofer VINTAGE Class seit Januar 2022.

May, M.: Project Management Committee Vertreter der Fraunhofer-Gesellschaft in Clean Sky 2 AIRFRAME.

May, M.: Scientific Committee 2nd European Conference on Crashworthiness of Composite Structures ECCCS2, Toulouse, 14.–16.11.2022.

May, M.: Stellv. POC des Fraunhofer VVS für den FCAS-Masterplan.

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

May, M.: Working Group Member International Activites Advisory Committee, AIAA, USA.

Putzar, R.: Repräsentant des Ernst-Mach-Instituts in der Aeroballistic Range Association (ARA). Bis 2022-08: Past Chairman der Aeroballistic Range Association (ARA).

Ramin, M. von: Deutscher Delegierter für die NATO PFP(AC/326-SG/C) AASTP-4 Custodian Working Group.

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

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

Ramin, M. von: Mitglied in der »European Commission expert group 'Fighting Crime and Terrorism, including Resilient Infrastructure' for the Community for European Research and Innovation for Security (CERIS)«.

Rosin, J.: Mitglied der DGEB – Deutsche Gesellschaft für Erdbebeningenieurwesen und Baudynamik e.V.

Rosin, J.: Mitglied im Normenausschuss NA 104 DIN Standards Committee Tank Installations (NATank) Deutscher Spiegelausschuss CEN/TC 265/WG 10.

Rosin, J.: Projektleitung im Normenausschuss, CEN/TC 265/ WG 10 – Revision of EN 14620 Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C.

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

Signetti, S.: Organizing Committee, 4th International Conference on Impact Loading of Structures and Materials (ICILSM 2024), 13.–17.5.2024, Freiburg, Germany.

Scientific prizes and awards

Burtsche, J.: Förderpreis 2022 der Gisela und Erwin Sick Stiftung in der Fakultät Technik der DHBW Lörrach für herausragende wissenschaftliche Leistungen in der Bachelorarbeit.

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

BMBF-Verbundvorhaben »Handwaffen mit selbstgedruckten Teilen – eine Risikoabschätzung (HamsTeR)«, Förderkennzeichen 13N16030.

Kooperationspartner im BMBF SifoLIFE-Projekt »Ganzheitliche zivile Sicherheitslösungen für die Stadt Wilhelmshaven als Bundeswehr- und maritimer Standort an der Schnittstelle städtischer Lebensräume (ZisSch)«.

Publishing notes

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Deborah Kabel, Sonja Weber

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