Fraunhofer EMI

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

Research for a Safe Future.

Annual Report 2024/2025

Research for a Safe Future.

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Making crises manageable

Dear reader,

In engineering resilience research, there is a whole range of concepts and metrics that are used to design and optimize the resilience of complex socio-technical systems. The aim is always to minimize the probability of a disruption occurring as well as its possible consequences and ultimately to enable a rapid recovery process. For these concepts to actually work in the event of a crisis, a triad is required, which is very aptly described as "Monitoring – Communication – Governance".

As the world around us is currently either already in a crisis in many respects or is consistently moving towards one, options for grasping the situation, communicating all relevant observations and ensuring leadership are of growing importance. This applies to the rapidly changing modern battlefield as well as to coping with the symptoms of ongoing climate change and increasing violence in public spaces.

Resilience solutions for defense and civil security

Fraunhofer EMI researches technologies for the protection and effectiveness of the Bundeswehr. This includes the early detection of threats from missiles using highly sensitive small satellites such as the ERNST developed by us, as well as defense against hypersonic weapons or the safe storage of ammunition. Observing what is relevant, communicating to the right people and conducting the operation that is recognized as effective. This results in resilience on the battlefield. Our agent-based simulation helps to make major events safer, traffic models more realistic and evacuation situations more reliably coordinated. Here, the Institute's modelling and simulation expertise makes a decisive contribution to researching and realizing the resilience of complex systems, because situations are recorded and analyzed that cannot be

"As the world around us is currently either already in a crisis or is consistently moving towards one in many respects, options for grasping the situation, communicating all relevant observations and ensuring leadership are increasingly important."

identified to the same extent in exercises or from past experience with crises.

Thinking military and civil security research together

EMI's expertise in the resilience sector was also a key element of the Fraunhofer VVS conference "Future Security 2025". A core theme of this conference was the urgent need to integrate civil and military security research. A concern that is explicitly shared by the various federal government departments. And which is supported by the guiding principle of "making crises manageable". The Fraunhofer EMI is ready to play an active role in shaping this integration process.

In this annual report, we present our results together with impressive visual material. We will first focus on the three focus topics that we did not describe in last year's annual report, before moving on to the current topics in the five business units.

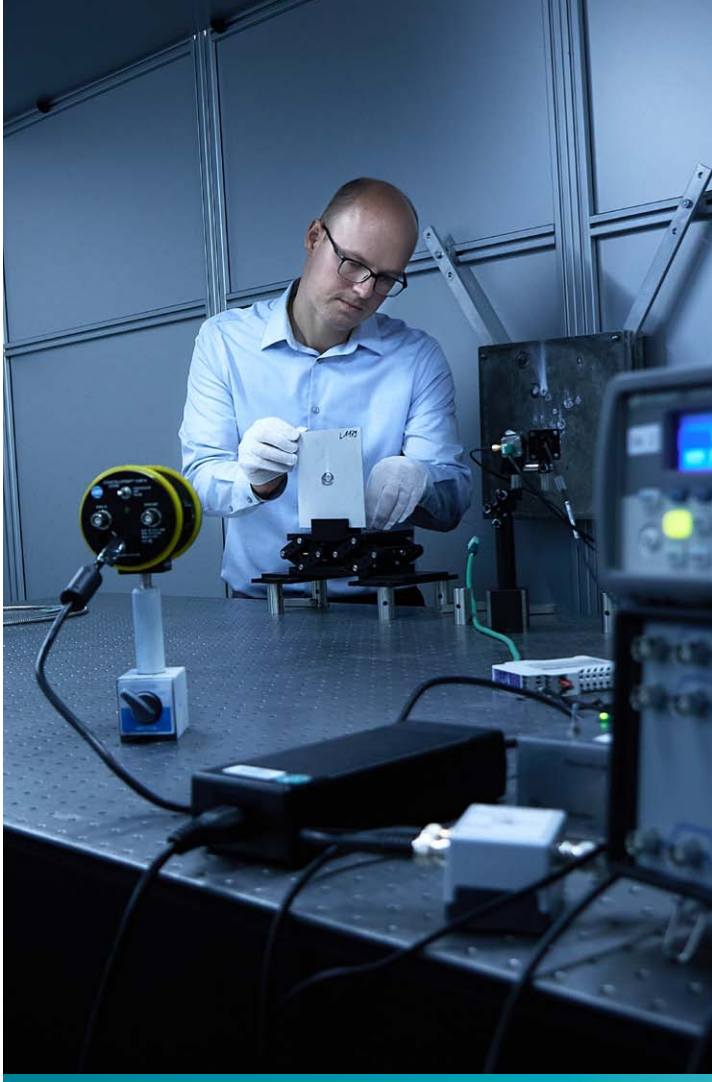
I wish you an enjoyable read and remain,
with best regards,

Prof. Dr.-Ing. habil. Stefan Hiermaier
Director Fraunhofer Institute for High-Speed Dynamics,
Ernst Mach Institute, EMI

Cover photo: Fraunhofer EMI; Foreword photo: Fraunhofer EMI

Fraunhofer EMI Annual Report 24/25

Departure into orbit: nano satellite mission ERNST launched in August. → p. 77



Cover
Battery tests at Fraunhofer EMI: The institute uses experiments and simulations in close cooperation. This allows battery systems to be efficiently understood, optimized and further developed.

→ More on battery testing: page 60

State Secretary Dr. Patrick Rapp visits Fraunhofer EMI to learn about ERNST.

→ More about ERNST on pages 38 and 77.

Focus topics

The Institute has identified six focus topics in the 2023 strategy process. Last year, **highly-dynamic X-ray**, **battery safety** and **laser-matter interaction** were presented. The other focus topics are:

Photos: SpaxeX, Fraunhofer EMI (4), Airbus

Business units

Battery crash accelerator: testing complete car batteries → p.58.

Safe integration of batteries in helicopters: Fraunhofer EMI is researching the safety of high-voltage battery systems. → p.90

The Institute in profile

Promoting young talent: At EMI, 27 people are currently doing an apprenticeship or a dual study program.

The institute

Fraunhofer EMI was founded in 1959. Its mission is to deliver high precision results and develop outstanding technologies.

The focus of the institute is: Making everything that happens quickly representable and measurable. Fraunhofer EMI researches collisions, impact phenomena and explosions and the associated safety concepts in the business fields of defense, security & resilience, automotive, aerospace and aviation.

Location Freiburg

Location Efringen-Kirchen

Location Kandern

Background photo: Research for innovative laser applications.

1959
Foundation of the institute

Fraunhofer EMI emerges from the Institute for Applied Physics at the University of Freiburg, founded in 1956.

It was incorporated into the Fraunhofer-Gesellschaft as the 6th institute.

Cold War:
Research for the Bundeswehr and its allies

In the first decades, the focus is on ballistic and fluid mechanics research.

To this end, the institute develops world-leading research approaches.

Further locations in Efringen-Kirchen and Kandern

The original quarries in Wintersweiler and Holzen are transformed into independent sites with research infrastructure.

Globally unique infrastructure in the field of high-speed dynamics

Fraunhofer EMI quickly establishes its reputation as one of the world's leading institutes in the field of high-speed dynamics. Over the years, expertise and technology are continuously developed.

395
Employees

39.3
Million euros total budget

3
Locations

Business units

Defense

Security & Resilience

Automotive

Space

Aviation

Associations

VVS Defense, Prevention and Security

MATERIALS Materials, Components

Coordinating institute of the Sustainability Center Freiburg

Alliances

Aviation & Space

Batteries

Lightweight

Simulation

Construction

Competence field Additive Manufacturing

1990s
Opening up to civilian research

After the end of the Cold War, the institute realigns itself. It opens up civilian topics such as security, automotive and structural protection:
In 1993, EMI is commissioned to reconstruct the first bomb attack on the World Trade Center.

2000s
Aerospace as new business fields

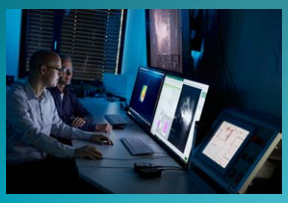
EMI transfers expertise in high-speed dynamics to the fields of aerospace.

For example, EMI conducts an investigation into the impact of meteoroids and space debris on the Columbus module of the ISS space station.

Development of crash tests with X-ray technology

For years, Fraunhofer EMI has been pursuing the goal of X-raying cars during crash tests.

Initially, only 8 X-ray images could be produced. Today, the EMI system produces 1000 X-ray images per second.



Research for a safe future

With its business units of Defense, Security, Automotive, Space and Aviation, the institute has consistently focused on increasing security in the civil and military sectors.

Photos: Fraunhofer EMI (10), US Department of Justice, ESA

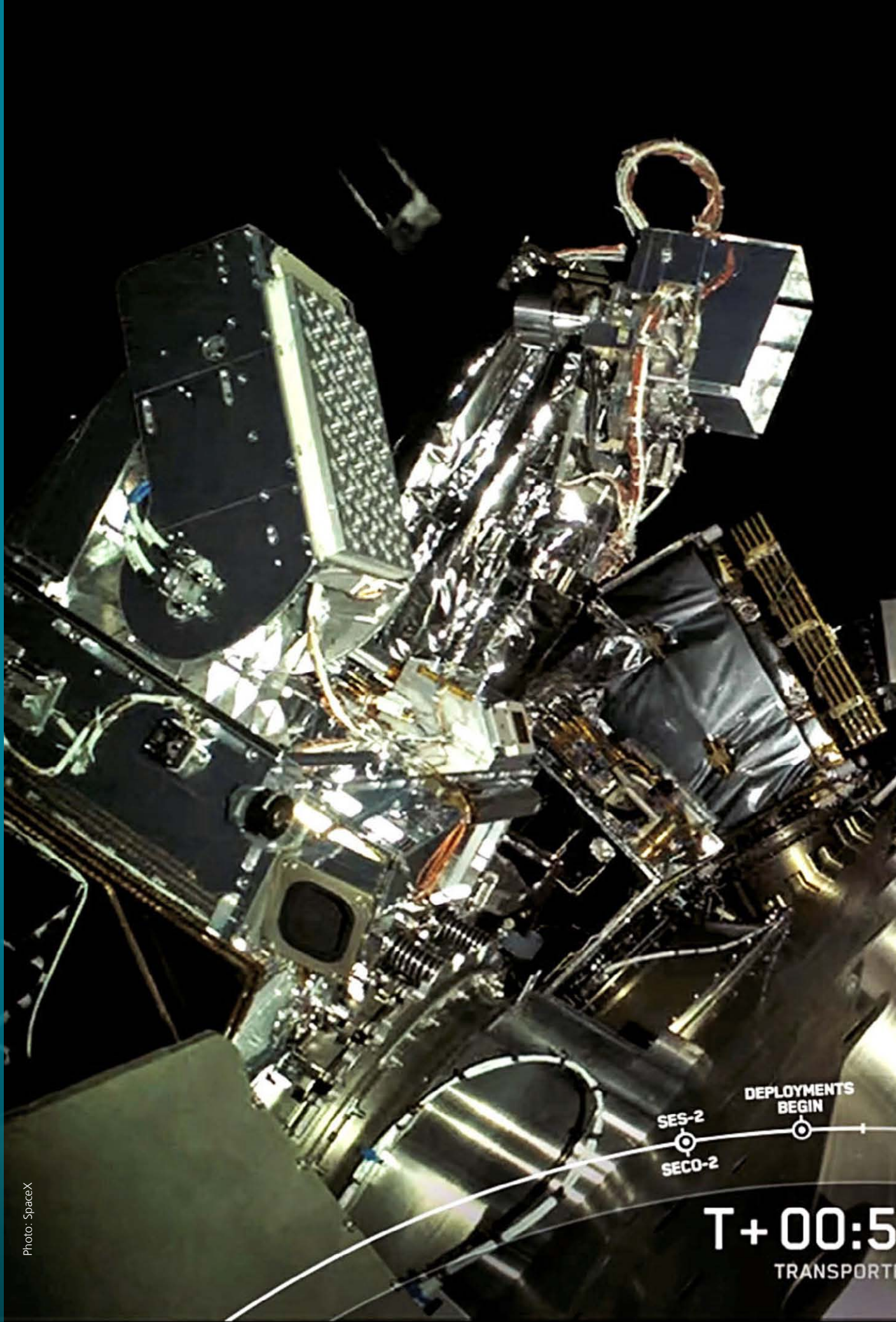


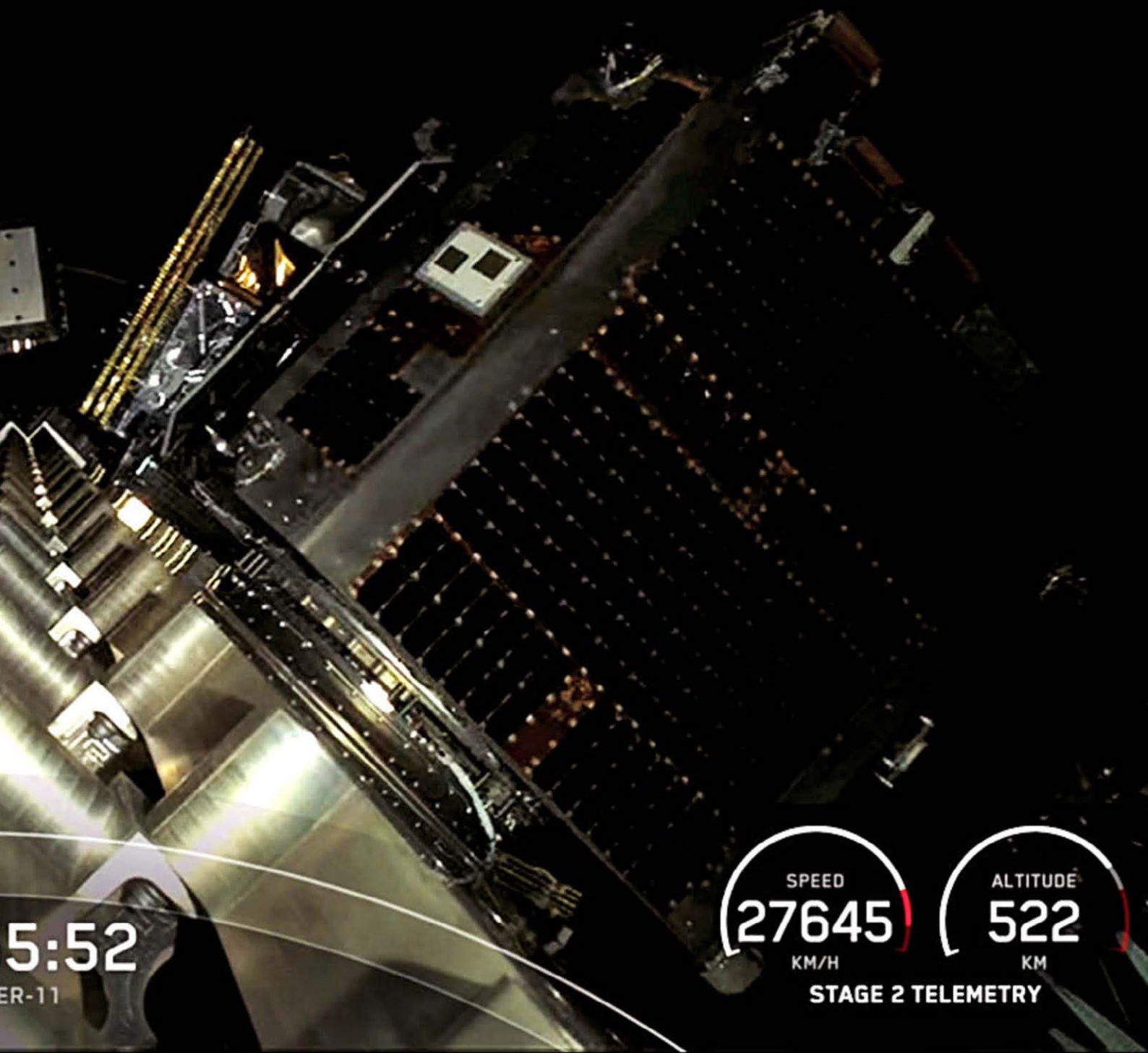
Photo: SpaceX

ERNST on its way to orbit

After several launch delays, Fraunhofer's first small satellite is in orbit: On August 16, ERNST was launched by a Falcon 9 rocket (pictured top left).

In the meantime, all systems are in operation and ERNST is ready to detect rocket launches.

The satellite was developed under the leadership of Fraunhofer EMI. Many components were developed in-house. More about ERNST on pages 38 and 77.



Focus topics

Photo: Fraunhofer EMI

Focus topics of the institute

Fraunhofer EMI has updated its institute strategy for the period 2023 to 2027. Six focus topics were defined in a joint strategy process. These topics are particularly promoted by the institute.

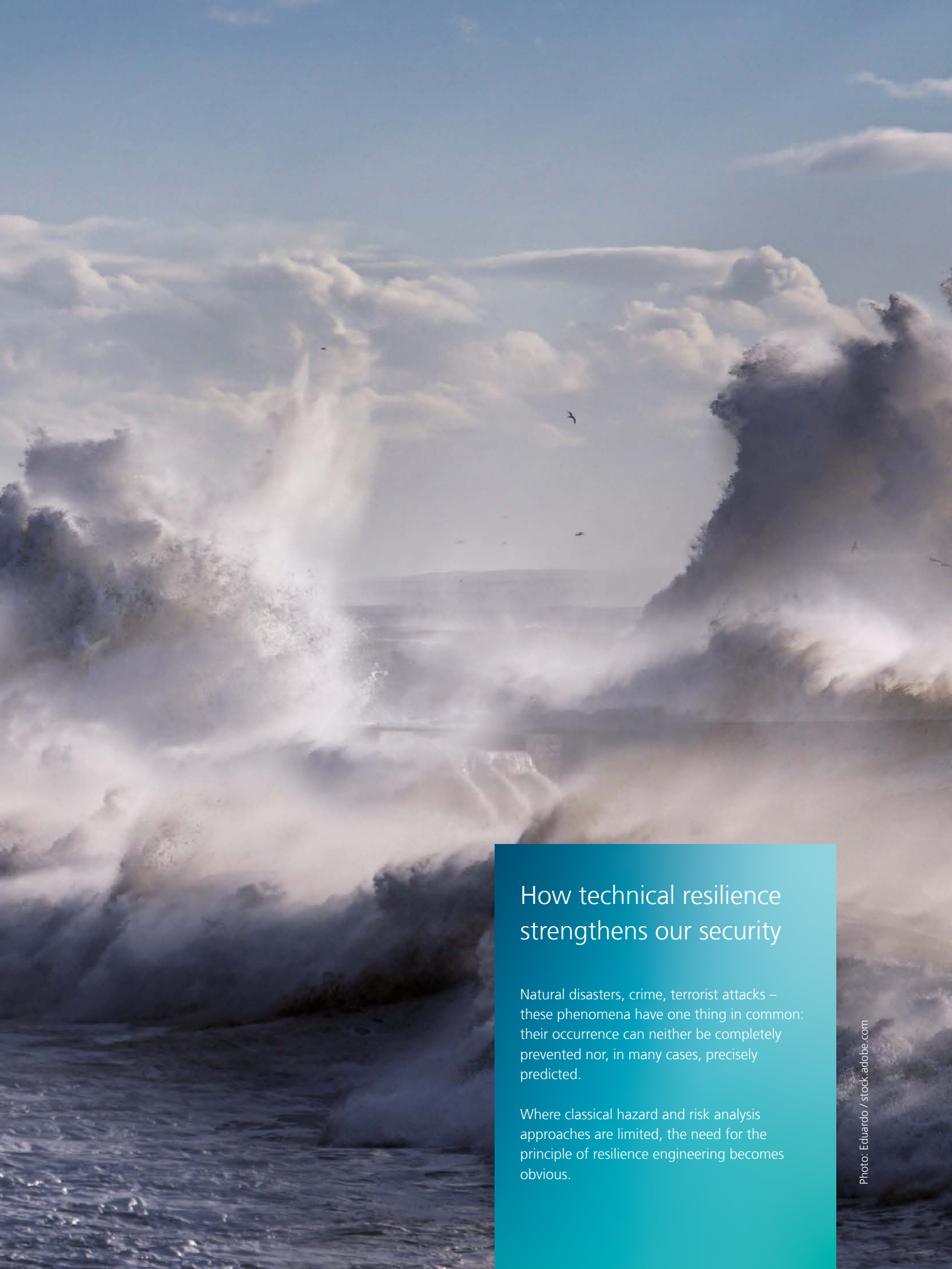
- Battery safety
- Laser-matter interaction
- Highly-dynamic X-ray
- Resilience engineering
- Satellite-based data analysis
- Realistic traffic predictions

This year's annual report presents the three remaining topics.
The first three topics are presented in the previous annual report.

← **Laser-matter interaction**
Fraunhofer EMI operates laboratories that scientifically analyze the effects of intense laser radiation using state-of-the-art high-speed measurement technology.

FOCUS TOPIC Resilience engineering

Resilience Engineering



How technical resilience strengthens our security

Natural disasters, crime, terrorist attacks – these phenomena have one thing in common: their occurrence can neither be completely prevented nor, in many cases, precisely predicted.

Where classical hazard and risk analysis approaches are limited, the need for the principle of resilience engineering becomes obvious.

Photo: Eduardo / stock.adobe.com

Recognizing and mastering crises and learning from them

Fraunhofer EMI analyzes socio-technical systems: critical infrastructures, urban spaces, industrial processes and coupled networks using different modeling approaches.
The models are implemented in software applications. The institute investigates system behavior in the event of disruptions. This enables it to identify weak points and develop solutions for measuring and increasing resilience.

Mapping, modeling and simulation of complex systems.

Models for complex socio-technical systems

How can social system components be integrated into modeling? The institute investigates the coping capacity of socio-technical systems during crises and disruptions. For example, individual processes, buildings or even entire cities and regions are analyzed. The aim is to identify all the important parts and components of the system and to understand how they work together. Technical, personnel, economic and organizational aspects are taken into account. Social system components are systematically recorded in the modeling with specific stochastic properties and included in the modeling in the same way as technical components.

Efficiency analyses of resilience measures

How effectively can individual measures increase the level of resilience? Quantitative models make it possible to characterize individual resilience phases, dimensions and properties:

Based on this multivariate concept, a wide variety of systems are analyzed at Fraunhofer EMI. Examples include buildings, urban areas, infrastructure systems and industrial processes. The comparison of different measures enables an assessment of their efficiency.

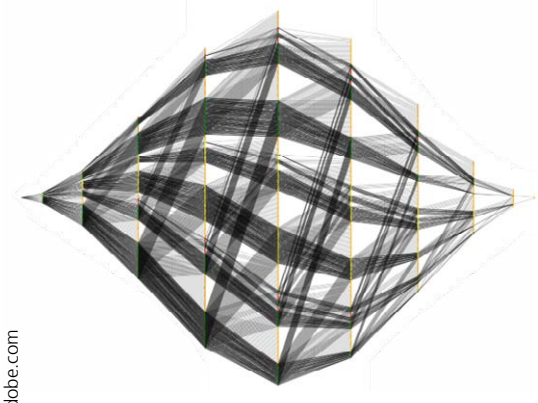
Multivariate concept

Resilience phases:
Preparation, prevention, protection, response, recovery

Resilience dimensions:
Technical, organizational, personnel, economic

Resilience properties:
Robustness, redundancy, rapidity, resources

Making materials and structures more resilient: With one of the world's largest shock tube systems, shock wave loads resulting from explosives and gas explosions can be simulated and provide a contribution to the robustness analysis of structures.



Visualization of possible states in the Markov model.

Stochastic modeling

How can stochastic modeling be used to assess the safety of autonomous driving? The evaluation of automated driving functions, taking into account all scenarios, environmental conditions and road users, is extremely challenging. Fraunhofer EMI uses statistical models to analyze failure rates. Markov modeling is used to derive reliability statements about the vehicle and its sub-functions, taking into account environmental conditions, driving situations and sensor failure rates.

Coupled network analyses

How resilient is a municipality to a power outage? Systematic recording of system components and their dependencies is achieved by representing them in a network structure. The nodes represent relevant components (e.g. personnel, machines), while the edges depict their physical and logical connections. Fraunhofer EMI uses network analysis to investigate the resilience of critical infrastructures and identify cascading effects between sectors, such as the impact of a power outage on hospitals.

Understanding the dependencies of different networks.

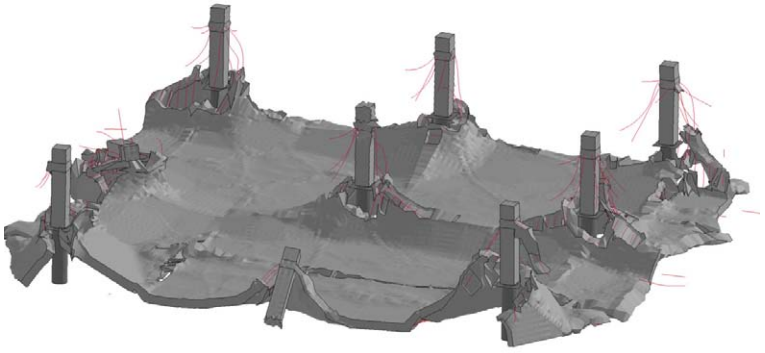
Photos: safu designe/stock.adobe.com, Fraunhofer EMI (2), panu101/stock.adobe.com

Agent-based simulations

How can the movement behavior of people or flows of people be simulated? Agent-based simulation is characterized by its ability to model the behavior of individual actors within a system and to analyze their interactions in dynamic environments.

Fraunhofer EMI integrates such behavioral aspects into socio-technical model development and uses this information to control temporal developments in network analyses. In addition, EMI has developed an agent-based simulation that simulates the movement of people in buildings and open spaces, such as at events. This allows detailed aspects of the human system components in socio-technical systems to be considered.

Simulation of movement behavior: In the run-up to the Juicy Beats Festival 2024, event security was designed using methods from Fraunhofer EMI.



Collapse behavior of a building section: numerical simulation of the failure of a load-bearing element.

Robustness analyses of buildings

How can building protection against exceptional loads be increased? Extraordinary stresses, such as explosions or extreme weather, put a strain on buildings and are often not taken into account in planning. The Safety and Resilience business unit has the expertise to characterize such loads and their effects. Engineering methods or numerical simulations, which are validated with test facilities at Fraunhofer EMI, form the basis for assessment. The hazards, possible damage and protective measures are systematically characterized. The methods form the basis for assessing robustness. Examples include the protection of properties against terrorist attacks, explosion protection on factory premises or the evaluation of protective measures against strong wind and flood events.

Photos: Juicy Beats Festival / Jonas Diener, Fraunhofer EMI (2)

Fields of application

Industry

Assessment of critical processes, status quo resilience, business resilience management

Critical infrastructures

Network analyses, cascading analyses

Municipal resilience

Identification of vulnerabilities, decision support, contribution to disaster prevention

Building safety

Assessment of exceptional stress, robustness analysis, resilience increase

Urban security

Protection of public spaces / events, people flow analysis, vehicle ramming security

Special applications

Transfer of methods to fields of application (autonomous driving, defense, satellite networks)

Current research at Fraunhofer EMI

Resilience analysis for municipalities using data room functionalities (HERAKLION)

Increasing the resilience of the state and administration through continuous improvement (RESKON)

Resilience management for cities (FR Resist)

Resilience as a contribution to cyber security and business continuity management (DYNAMO)

Resilient power supply for the energy transition (Resist)

Sustainable contributions to increasing resilience (NBS Infra)

Sustainability and resilience of critical infrastructures and logistics chains (SARIL)

Robust assessment of possible states in the field of autonomous driving (RDV)

Focus topic: Resilience engineering

Dr. Kai Fischer
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Satellite-based data analysis

Research for innovative satellite applications

Fraunhofer EMI develops technologies and methods for small satellites, addressing payload development, mission implementation, and data products. New approaches for mission concepts in Earth Observation and science are being developed at the interface between New Space and established space.

In the picture: Engineering of a "Flatsat" for system testing of an optical payload for small satellites.

Focusing on the planet – for a sustainable and secure future

Earth observation provides significant contributions to solving global problems in the areas of security, environmental protection, climate change impacts, and enable new approaches for agriculture, urban development, disaster management, logistics and defense.

Fraunhofer EMI focuses on research and technology development for the acquisition and real-time processing of Earth observation data through satellites.

Engineering qualification model of the 12U CubeSat ERNST.

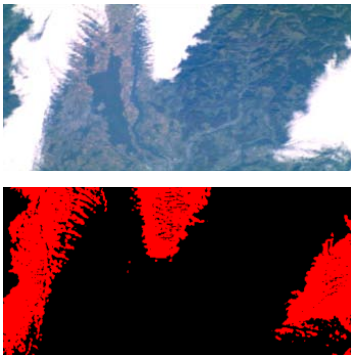
Scientific camera payloads for infrared imaging

How do small satellites enable new business models in Earth observation? Fraunhofer EMI is developing infrared cameras for small satellites using the New Space approach. Under the motto "validation instead of certification", cost-efficient payloads with commercial components are being developed. These are intended to deliver precise infrared data with a high repetition rate in small satellite constellations. Based on a pilot mission with a thermal infrared imager on the ISS, the EMI spin-off constellr is building its own small satellite constellation whose surface temperature data is intended to solve urgent problems such as water management in agriculture.

Various space applications: Installation of a compact thermal infrared payload for operation on board the ISS

Data processing systems based on high-performance FPGAs

What difference do commercial FPGA modules make to onboard data processing? Fraunhofer EMI integrates commercial FPGA SoC hardware into system-on-module concepts for high-performance onboard data processing. Modern FPGAs minimize bottlenecks in downlink capacity and enable the analysis of payload data already on board, for example through artificial intelligence. The systems adapt to the specific needs of the payload and meet reliability requirements through redundant design.



Recognizing clouds with AI: real image captured by small satellite ERNST.

AI methods for onboard data analysis and automated anomaly detection

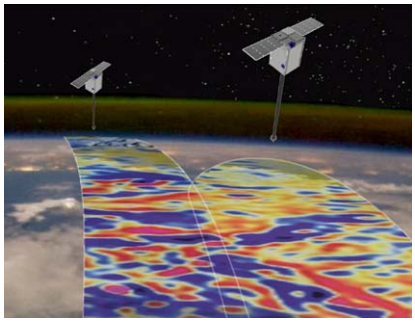
How can artificial intelligence make on-board data acquisition more efficient? Machine learning enables the analysis of relevant Earth observation targets directly on board. More and more satellites and powerful payloads are generating a growing amount of raw data that is transmitted via ground stations. Fast, automated analysis on board allows relevant targets to be identified and irrelevant data, such as cloud cover, to be sorted out. This reduces the amount of data for the downlink and makes Earth observation tasks more efficient.

Photos: Fraunhofer EMI (5)

Superresolution for thermal infrared images

How can the resolution of Earth observation images be increased despite physical limitations? Superresolution reconstructs images of higher quality from low-resolution images. To do this, several images are combined or deep learning models are used. The latter use additional training data for feature detection and extraction to determine suitable parameters for resampling. Fraunhofer EMI is investigating super-resolution methods specifically for combining Earth observation data from different satellites with different resolutions.

Increase resolution: Application of super-resolution methods using the example of agricultural land.



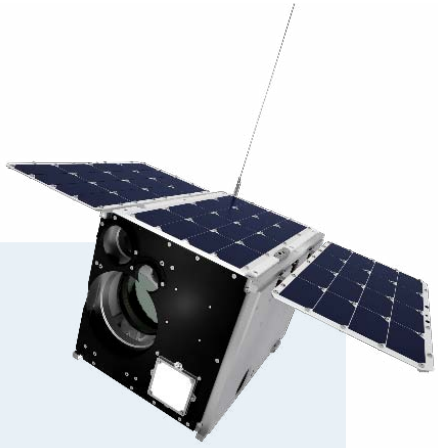
Small satellites enable cost-efficient technology demonstrations: Fraunhofer EMI accompanies the entire development and implementation process.

Earth observation missions with small satellites

How can new technology and mission concepts be tested quickly in orbit? Thanks to their rapid and cost-efficient implementation, small satellite missions are key to demonstrating new technologies in orbit. They create new application possibilities for which the cost threshold of established systems is too high. Rapid market growth and high innovation potential in the field of small satellite constellations are driving the pace forward. Fraunhofer EMI is available as a partner to implement new concepts from sketch to design, implementation and testing to operation.

ERNST: The first satellite mission developed entirely by Fraunhofer

ERNST is a 12U CubeSat. It is the first satellite mission developed entirely by Fraunhofer and also the first small satellite for the German Armed Forces. ERNST is intended to demonstrate the potential of low-cost small satellites for defense tasks. It tests technologies for missile early warning from Low Earth Orbit. Its design highlights include a cryo-cooled infrared camera, a generatively designed optical bench and a drag sail for space debris mitigation.



ERNST small satellite: The 12-unit CubeSat ERNST started its mission in August 2024 in a sun-synchronous orbit with a multispectral infrared camera system.

Current research at Fraunhofer EMI

Satellite operations
Operation of the ERNST satellite and acquisition of data for early warning from Low Earth Orbit

Data processing units
Continuous development for diverse satellites, including those of ConstellR

Demonstrators for low orbit
Development of system demonstrators for Very Low Earth Orbit (VLEO)

NeT Pioneer
Test methods and procedures for New Space

Focus topic: Satellite-based data analysis

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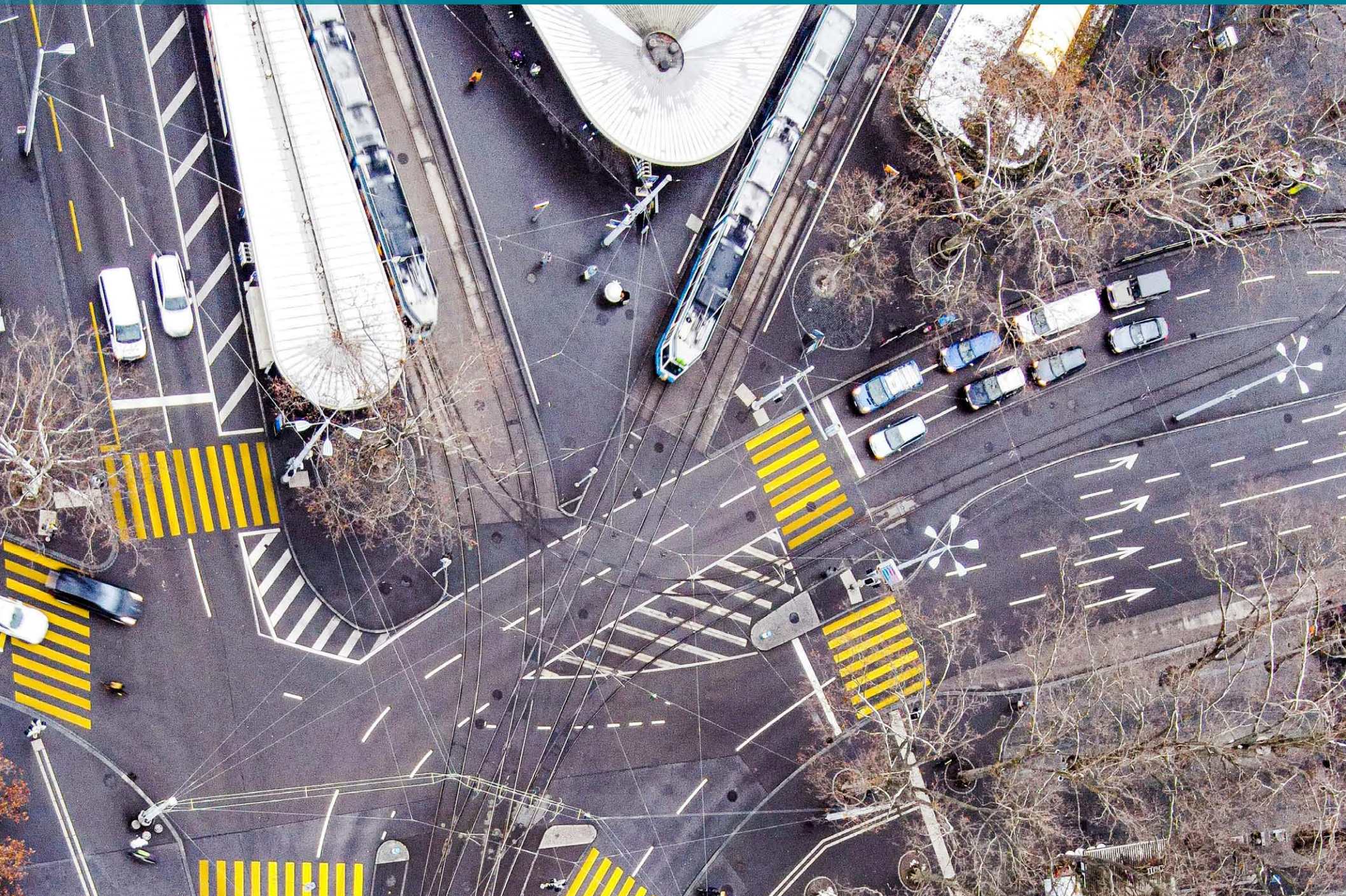
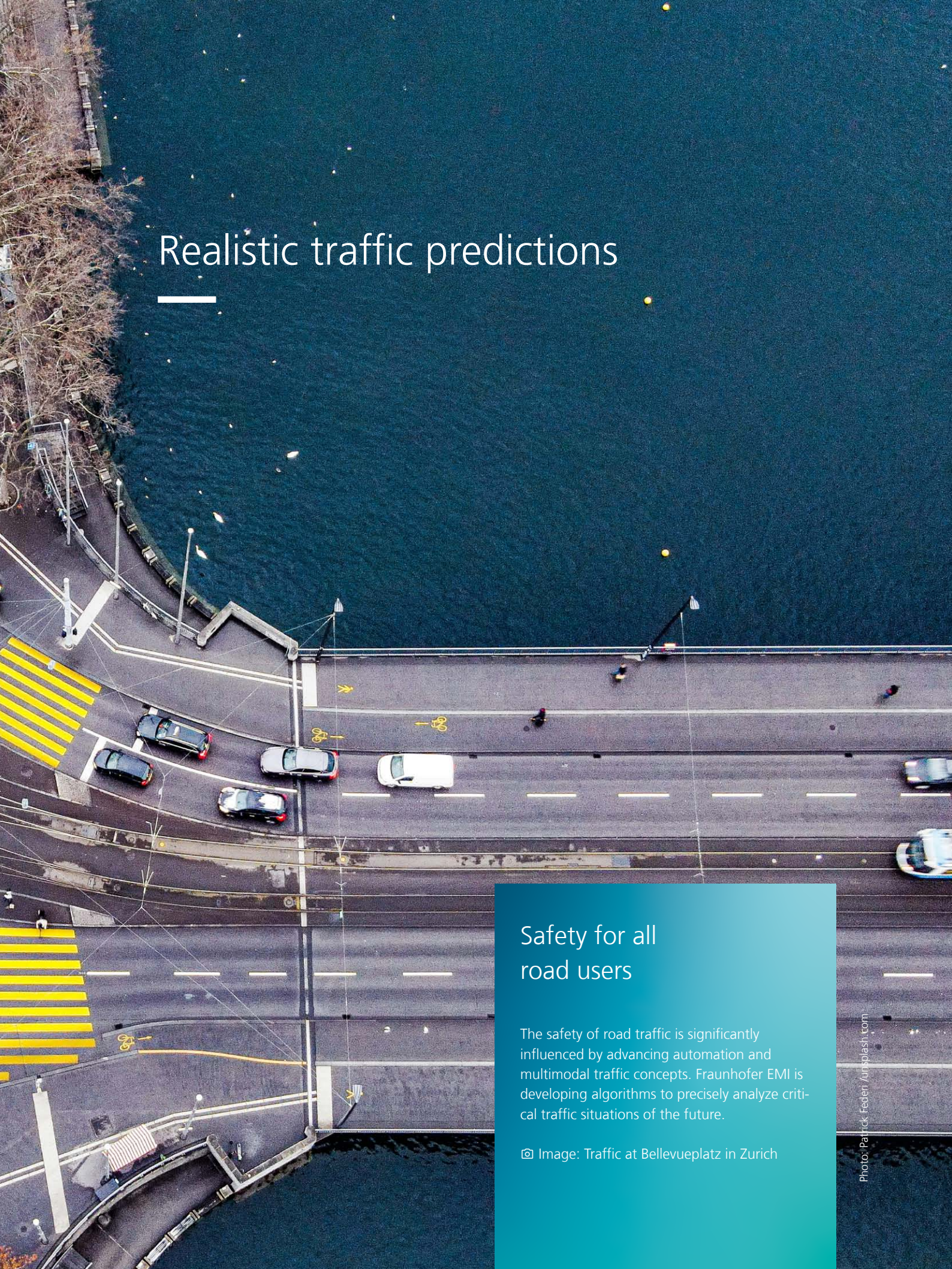
Photos: Fraunhofer EMI (5)



Realistic traffic predictions



Safety for all road users

The safety of road traffic is significantly influenced by advancing automation and multimodal traffic concepts. Fraunhofer EMI is developing algorithms to precisely analyze critical traffic situations of the future.

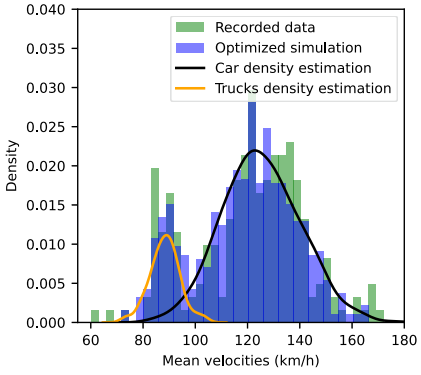
Image: Traffic at Bellevueplatz in Zurich

Photo: Patrick Federi / unsplash.com

Understanding and predicting traffic

Automation and multimodal concepts are revolutionizing road traffic. This makes the development and testing of new functions increasingly challenging.

Fraunhofer EMI therefore relies on agent-based simulations that reproduce realistic traffic situations. The focus here is on the detailed simulation of critical traffic scenarios.



Optimized speed distributions from aerial photographs taken by Fraunhofer IOSB.

Data-based optimization of behavioural models

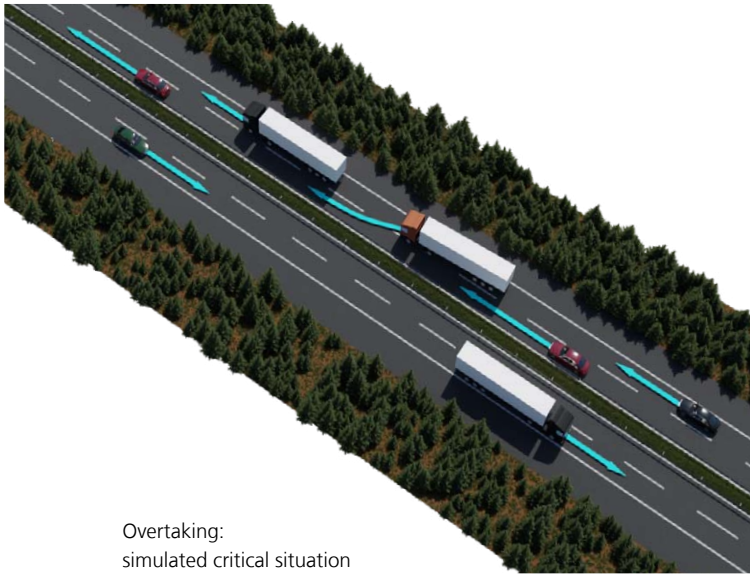
How to generate more realistic traffic simulations?
Agent-based models are often used for microscopic traffic flow simulation, in which vehicles are divided into agent classes such as cars or trucks. Each vehicle is assigned behavioral parameters that are drawn from statistical distributions of the respective agent class. The parameter values of these distributions must be defined before the simulation.
EMI has developed a method to determine optimal parameter values of the behavioural models through numerical optimization based on traffic data. The aim is a realistic simulation that maps statistical traffic variables.

Photos: Fraunhofer EMI (3)

Analyzing complex traffic situations: Fraunhofer EMI develops algorithms to detect critical traffic situations.

Identifying critical traffic situations

How to recognize critical situations in road traffic?
A key feature of realistic traffic flow simulation is the ability to depict critical situations using the integrated behavior models – from potentially dangerous situations to actual accidents – in a statistically comparable way to real traffic. In order to take these aspects into account in the simulation, the behavior models used must be able to depict critical situations. It is also necessary to have sufficient data on critical situations in road traffic. The analysis and evaluation of the criticality of driving scenarios in existing and future data therefore represent central challenges in the implementation of realistic simulations. Fraunhofer EMI is tackling these challenges and developing evaluation algorithms for the automated identification of critical driving scenarios in traffic environments of varying complexity.



Overtaking:
simulated critical situation

Major events: Keeping an overview with data analysis and simulations

How to better analyze and manage crowd flow during major events?

Fraunhofer EMI accompanied the 2024 Juicy Beats Festival, working alongside Fraunhofer IOSB to create a 3D reconstruction of the site.

Utilizing this model, they conducted visibility analyses and simulated crowd flow based on video recordings of visitors and influx data provided by the event organizers.

Fraunhofer EMI and IOSB accompanied the Juicy Beats Festival 2024 in Dortmund's Westfalenpark

Fraunhofer EMI uses AI methods such as reinforcement learning to develop behavioral models for vulnerable road users.

Behavioral models for pedestrians and cyclists

How can behavioral models improve the safety of pedestrians and cyclists in traffic simulations?

Pedestrians and cyclists are among the vulnerable road users who are insufficiently considered in current traffic simulations. Fraunhofer EMI is developing behavioral models for this group based on simulations of the flow of people at major events. AI methods such as reinforcement learning are used to teach virtual pedestrians how to cross roads safely.

Algorithms for realistic risk assessments:
In order to avoid accidents and improve autonomous driving, researchers are simulating pedestrian behavior. Fraunhofer EMI has developed an extended algorithm for this purpose. It includes risk areas at intersections. This allows for more realistic traffic predictions.

Current research on this at EMI

VRU behavior models

Behavior of Vulnerable Road Users (VRU) in normal but also critical situations.

Data generation

Concepts for capturing critical scenarios in inner-city traffic

New simulation methods

Extension of classic simulation implementations with generative approaches, for example reinforcement learning

Focus topic: Realistic traffic predictions

Dr. Mirjam Fehling-Kaschek
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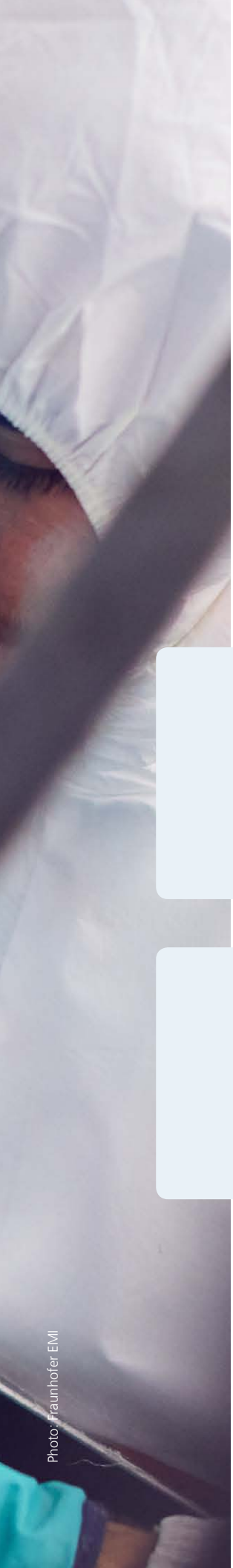


Photo: Fraunhofer EMI

Business units at Fraunhofer EMI

Defense

Security & Resilience

Automotive

Space

Aviation

← **Increasing the security of battery systems**
Extensive battery testing can be carried out at the Efringen-Kirchen location. The testing is closely linked to accompanying simulations.

BUSINESS UNIT Defense

Business unit Defense

Armor and anti-armor for the Bundeswehr

The German Armed Forces need future-proof systems for land, air, sea and cyberspace. Fraunhofer EMI is therefore researching scientific and technological issues in the areas of armor and anti-armor as well as in defense and security related systems.

In the marine sector, Fraunhofer EMI is currently focussing on underwater detonations. To this end, the institute is developing algorithms and simulations to better protect critical maritime infrastructure.

Pictured: The task force provider "Frankfurt am Main" and the frigate "Baden-Württemberg" as part of the Indo-Pacific Deployment 2024.

Photo: Bundeswehr / Nico Theska

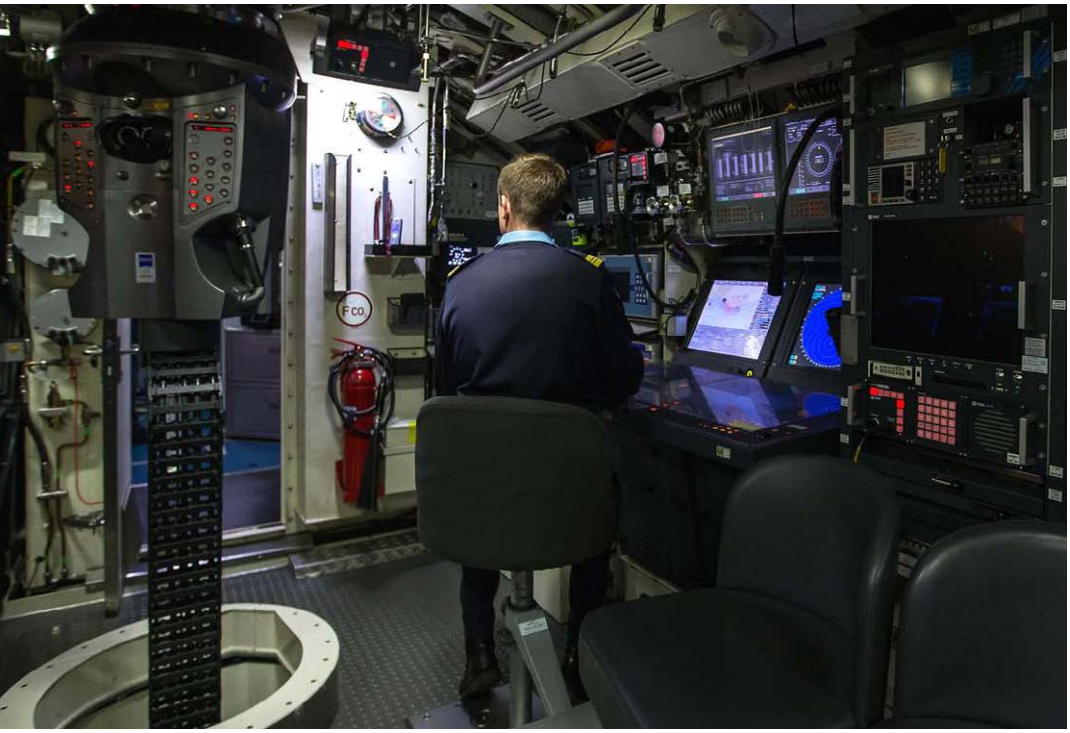
Joining forces to defend Europe

Refocusing the Bundeswehr on national and alliance defense: In close cooperation with EU armies and NATO alliance partners, the exchange of specialist knowledge results in innovative solutions that sustainably strengthen European defense capabilities. Pictured: Bundeswehr at the NATO maneuver "Quadriga 2024" in Lithuania.

Europe's security challenges have changed dramatically in recent years – and so has the importance of joint defense research. The European Defence Fund (EDF) plays a central role in this.

But how will this funding instrument develop in the future? Which opportunities does it offer for Germany and Europe? And where do the obstacles lie?

Prof. Dr. Werner Riedel, Chief Scientist Defense at EMI and an expert on civil security research at EU level, talks about the future of the EDF, international cooperation and the challenges for research and industry.



Control center of a class 212A submarine. The popular and efficient submarine class is an example of successful cooperation at EU level.

Prof. Riedel, you have been involved in civil security research at EU level for over 15 years. In your opinion, how will the European Defense Fund (EDF) develop?

I am certain that the EDF will remain. Although its extension is currently being discussed, its necessity is beyond question. I expect it to be continued not just in the medium term, but in the long term. The balance between European and national defense research will take years to establish – that is a lengthy process.
However, one thing is clear: those who rely solely on national research structures will find it increasingly difficult. Those who do not take advantage of the opportunities offered by the EDF and do not network internationally will lose valuable potential. Europe can only survive in the defense sector if innovations also arise from joint programs and if each country does not just develop its own systems.

Can you give an example?

One impressive example is the class 212A submarines that ThyssenKrupp Marine Systems (TKMS) and Fincantieri have been developing and building together for over 20 years. These boats enjoy a high reputation worldwide and are extremely competitive.

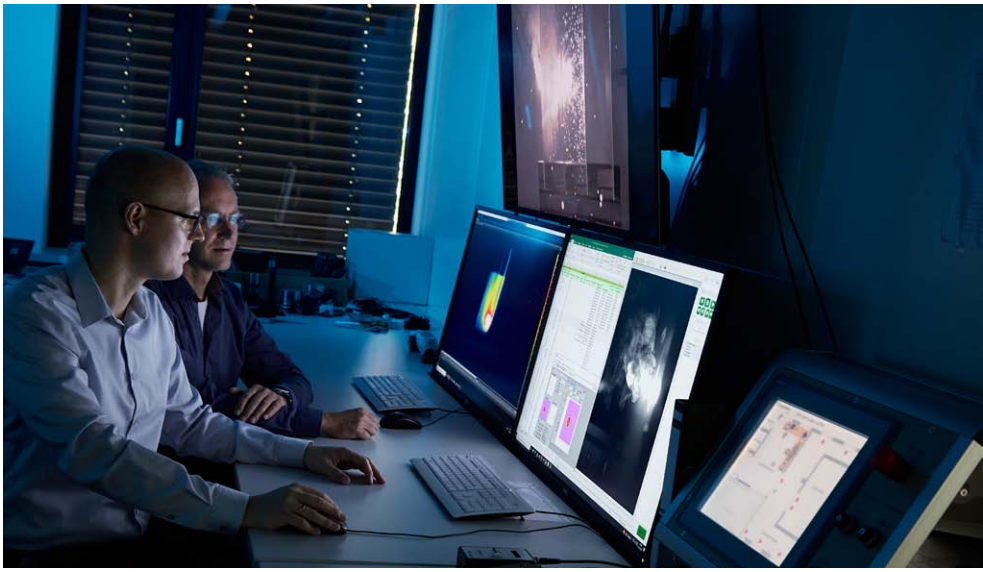
Another example is Airbus Defense and Space. While Airbus is established as the European market leader in the civil aviation sector, there is still some catching up to do in the military sector. With the support of EDF, new European success stories could emerge here, including for smaller-scale innovations.

In addition to the positive aspects, there is also criticism of EU research programs, for example because of the high bureaucratic effort involved and the low success rate for funding applications.

Yes, this criticism is justified. The problem has been particularly evident in security research for years. Funding ratios of up to 1:40 are not uncommon – in other words, 39 out of 40 applications are rejected. In view of the enormous effort that goes into each application, the question arises as to whether this can still be called funding. This system often prevents research because the time would be better invested in productive scientific work. There is no simple solution – the problem lies in the structure of European research funding and urgently needs to be reconsidered.

In the civilian sector, the German government has set up contact points to support applicants. Does this also exist in the defense sector?

Photos: Bundeswehr / Marco Dorow, Bundeswehr / Jane Schmidt



Military research for new applications: The Fraunhofer EMI has laboratories in which intense laser radiation is scientifically analyzed using the latest high-speed measurement technology. This allows laser applications of the future to be developed.

Yes, and our experience with the national contact point for the EDF has been excellent. It is easy to reach, highly competent and offers effective support. I regularly recommend that our scientists go there, especially for special questions.

Cooperation with European partners is a central component of EU programs. Doesn't this often lead to conflicts of confidentiality? Does it work equally well with all countries?

I wouldn't pin this down to individual countries. Industry and politics have to decide for themselves how far they want to go in their cooperation. I know from security research at Fraunhofer that the problems are often smaller than you might think. Each partner makes specific partial contributions to a large overall project, the scope and use of which they negotiate contractually. In return, you gain valuable insights that would often not be available nationally.
One example is the cooperation with Eastern European partners in the EDF. Countries such as Poland and the Baltic states have a deep understanding of Russian military technology. The exchange with them opens up insights that purely national research at working level could not offer so easily.

"Europe can only survive in the area of defense if innovations also arise from joint programs and if not every country only develops its own systems."

Prof. Dr. Werner Riedel, Fraunhofer EMI

For a long time, German companies have hardly been involved in civil security research. Southern European players dominate the field. What about Germany's participation in the EDF?

Unfortunately, I still see major deficits here. Southern European and smaller countries were early to make strategic use of the EDF and its precedent programs, while Germany got in late. One reason for this is our complex structure: there are many players, from the ministry to the Bundeswehr, BAAINBw, defense technology agencies, industry and research. The flow of information between them is often too indirect and slow.
In the Fraunhofer Defense, Prevention and Security Division (VVS), we are actively working to compensate for this disadvantage. We are specifically seeking contact with the official side in order to be better positioned strategically. We

Photos: Fraunhofer EMI (2)

are also seeing strong efforts from there to become better as a country.

Another pressing issue is the shortage of skilled workers in engineering. Does this also affect defense research?

Yes, absolutely. I see many highly qualified specialists from the EU who are very interested in working at institutes such as the Fraunhofer EMI or in the VVS service area. Our institutes are internationally attractive, and this is reflected in our teams – they are much more international today than they were in the 1990s when I started here. I have also worked with top European talents worldwide who work at renowned scientific institutions. This gives me confidence that Germany will continue to attract specialists as a location for science and innovation and that we will be able to compensate for an ageing society to a large extent.

In Germany, many universities have civilian clauses that restrict defense-related research. Does this inhibit innovation?

The civilian clauses are already crumbling in many places. At networking events, I often meet researchers who used to stay away from defense research but now want to become active. The changed security policy situation has reduced inhibitions here. I therefore do not see any serious restriction on innovative strength. Graduates in physics, electrical engineering or mechanical engineering come to us with an excellent education – regardless of whether their university has a civilian clause or not. They have the necessary basic knowledge and can quickly familiarize themselves with defence research.

The interview was conducted by Daniel Hiller, head of Business unit Defense at Fraunhofer EMI

European Defense Fund (EDF)

Founded: 2017
Initiator: European Commission
Objective: To promote cooperation in the field of defense research and development within the EU
Budget: 8 billion euros for the period 2021-2027

"Those who rely solely on national research structures will find it increasingly difficult. Those who do not take advantage of the opportunities offered by the EDF and do not network internationally will lose valuable potential."

Service portfolio

Design and analysis of protection mechanisms

Numerical simulation of impact and shock wave events

Material characterization and failure analysis

Sensors and electronics for extreme conditions, high-speed measurement technology

Analyses of safety and reliability of defence systems

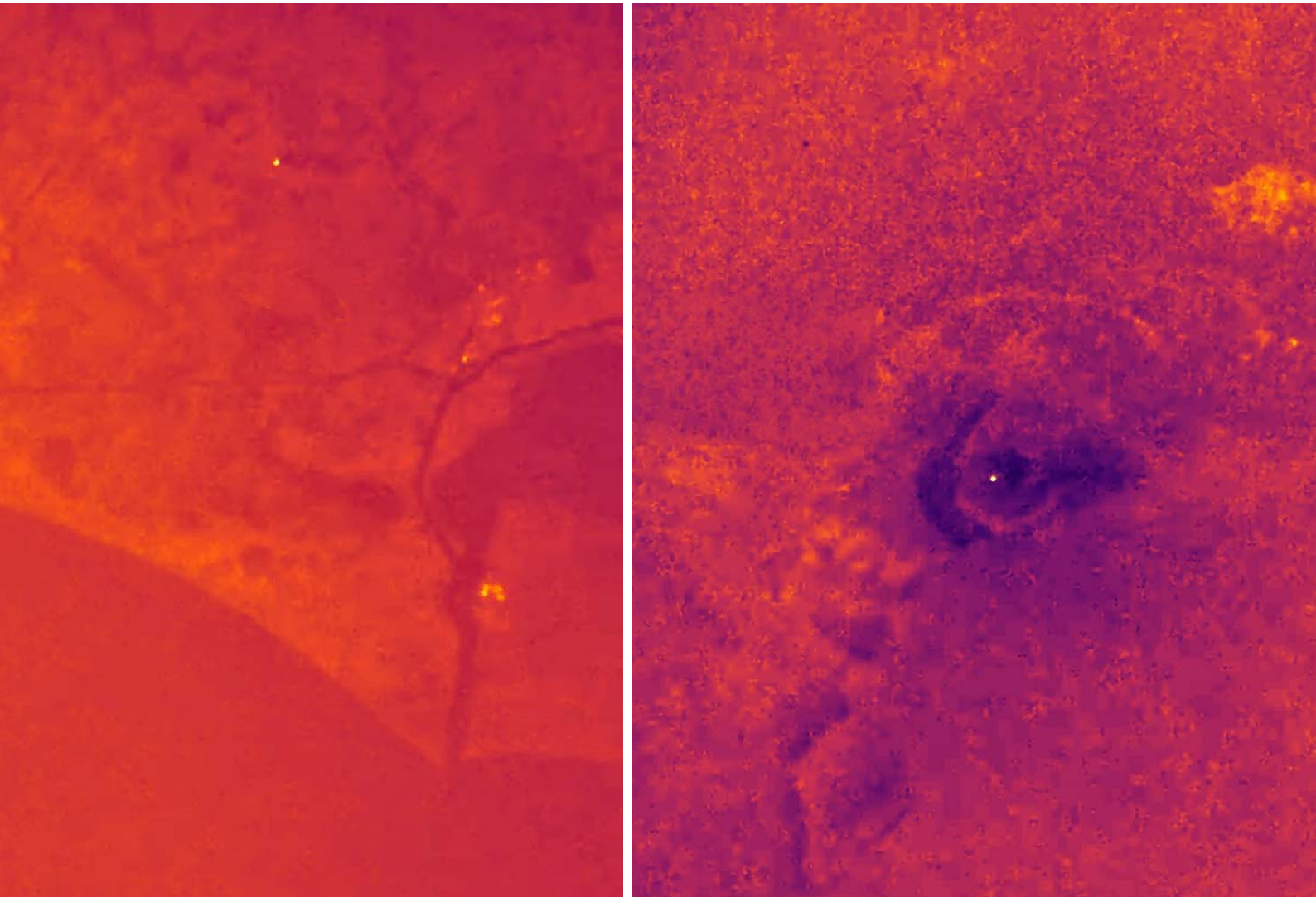
Small satellite ERNST: First image data from the thermal infrared camera

ERNST demonstrates the potential of small satellites for military applications. Using innovative infrared technology, it improves missile early warning and provides important infrared data for the national security strategy.

On August 16, 2024, the active phase of demonstrating small satellite technology for military purposes began for the German Armed Forces with the launch of the ERNST research satellite. Developed by Fraunhofer EMI, the 12U CubeSat platform demonstrates the potential of this satellite class, which, in addition to the obvious feature of its smaller size, is characterized above all by cost- and time-efficient implementation. This allows a greater willingness to take risks in development and operation, as the cost threshold of small satellites is much lower and the development time much shorter than that of traditional, large satellite systems. New technologies are brought to initial operational readiness more quickly and can be optimized in short cycles based on practical experience. Small satellites therefore meet one of the urgent needs of a dynamically changing security situation. In this context, ERNST is pursuing two overarching goals. The first is to demonstrate the 12U CubeSat platform technologies, especially their reliability and performance. Secondly, the focus is on demonstrating the technology for detecting missile launches from Low Earth Orbit. Missile defense systems rely on the early detection of military missiles. This information is used to instruct the target radars for countermeasures. Reliable and correct orbit prediction is the key to the success of these countermeasures. Germany has relevant national expertise in this area. Fraunhofer IOSB is contributing its detection expertise to the ERNST mission. Nevertheless, neither in Germany nor in Europe are measurement data from orbit available in the appropriate wavelength ranges. The infrared signatures of intercontinental ballistic missiles or hypersonic gliders and their changes over the duration of their mission, from the initial boost phase through the midcourse phase to the final approach, have not yet been recorded in practical measurements. Understanding these signals is crucial for the development of our own early warning capabilities.

ERNST carries an infrared camera on board for this purpose, which will be used to investigate how targets can be detected and tracked in the short-wave and medium-wave infrared range, both in front of the Earth's background and above the horizon against the cold space background. The heart of the payload is a detector module that is cooled down to the required temperatures using a cryo-cooler. To our knowledge, this is the first CubeSat with a cryo-cooled infrared payload with

ERNST on its way into orbit:
The small satellite was launched on August 16 from Vandenberg / California and was released into orbit around 56 minutes after its launch.



Infrared signatures of gas flares from natural gas and chemical plants in Texas (left) and the lava lake of Mt. Erebus in Antarctica.

this capacity. A filter wheel is used to change the wavelength range. After the rocket launch and the completion of the commissioning of ERNST, the experimental operation of the infrared payload was started and the recording of various areas of interest began. As an example, we show midwave-infrared images. The detection potential is already clearly evident in terms of resolution, signal-to-noise ratio and the ability to distinguish the hot sources against the Earth's background. Optimization of the operation for the demonstration of the technology and the generation of the ERNST image data is progressing. The detection of the first rocket launch by ERNST is only a matter of time.

Below: ERNST creates high-resolution images with a cryo-cooled infrared camera.

ERNST and Missile Early Warning from Low Earth Orbit

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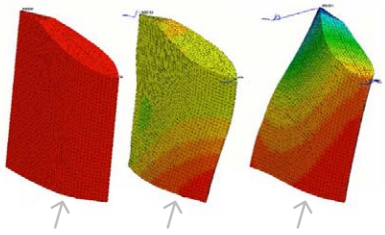
Photos: SpaceX, Fraunhofer EMI (3)

Simulation of underwater detonations

How Fraunhofer EMI uses algorithms and simulations to better protect critical maritime infrastructure.



Rudder deformation (false color representation): Structural response after passage of a shock wave.

Energy supply, communication and seaports as hubs for global trade define the "critical maritime infrastructure" in Germany and Europe. They are increasingly the target of acts of sabotage, terrorist attacks or hostile intelligence services. Protecting them poses an enormous challenge.

How do you reliably assess the damage to complex protective structures caused by dynamic loads, such as the detonation of a sea mine? In water, an incompressible medium, such questions are challenging and highly complex.

Fraunhofer EMI has been researching high-speed dynamics in water for over ten years. The simulation of fluid-structure coupled systems under loads, such as those occurring in underwater explosions (UNDEX), poses a particular challenge. Near-field effects such as cavitation and the afterflow from the gas bubble of the combustion products also have a considerable influence on the load curves. An example of fluid-structure coupled systems is the interaction of an underwater shock wave with a generic rudder unit of a ship. The simulation of this interaction makes it possible to analyze the structural response. The entire layer structure up to the entangled fibers is taken into account, which makes the evaluation of damaged areas complex. Proven methods such as fiber breakage criteria according to Puck are used.

Fraunhofer EMI uses both commercial and self-developed fluid and structural codes to simulate and evaluate load applications after UNDEX events. The CFD tool Apollo Blastsimulator, originally developed for air, has been expanded to include an algorithm for underwater detonations. Together with industrial partners, we are looking for the best solutions to emerging problems.

Underwater simulation
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Hypersonic defense

Using light-gas guns to research defense mechanisms against new types of hypersonic threats.

Innovative hypersonic tests are carried out at the Fraunhofer EMI using two-stage light-gas guns. These laboratory accelerators catapult projectiles to speeds of up to eight kilometers per second.

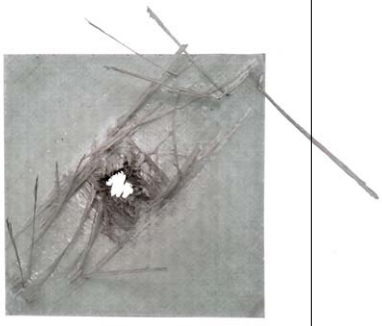
Air defence in transition
For over 20 years, Fraunhofer EMI has been researching how interceptor missiles can neutralize ballistic missiles with direct hits. In the face of new threats from hypersonic weapons, however, it is becoming clear that air defense needs additional defense mechanisms. The Institute uses unique special laboratories with light-gas guns to research hypersonic weapons.

Established missile defense relies on the kinetic energy released by an interceptor missile in a direct hit to destroy warheads and warfare agents. Fraunhofer EMI has been investigating such interactions for years in scaled laboratory tests. This knowledge forms the basis for further developing air defense technologies, evaluating their effectiveness and validating simulation models. New types of hypersonic weapons are forcing us to rethink and adapt the defense mechanisms of air defense.

Light-gas guns for new types of experiments
We must also adapt the scientific research instruments accordingly.

On the one hand, it must be possible to examine new types of interceptor missile models in laboratory tests. Fragmentation effects are also gaining in importance if a direct hit cannot be guaranteed with hypersonic glide vehicles due to their unpredictable trajectory. Shrapnel must be so effective that they completely neutralize warheads even with just a few hits.

Research is therefore being carried out on how the effectiveness of splitters can be increased. Novel material compositions in combination with modified geometric designs are being considered for this purpose. Their behavior on impact with typical missile structures and warhead models is particularly relevant. Fraunhofer EMI's light-gas guns are the central tool for these experiments. These systems are unique in Germany, and only a few defense technology institutes in the world have such test facilities. They form an essential basis for research in air defense.



Testing splinter effects: Impact of a hypervelocity splitter on a typical aviation structure in a laboratory test.

Hypersonic defense
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Photos: US Navy, Fraunhofer EMI (3)

How can ammunition be stored safely? With ASASP, Fraunhofer EMI is developing a software tool for the strategic planning of ammunition storage facilities.

Storing ammunition safely and efficiently

A software tool developed at Fraunhofer EMI optimizes safety distances, storage capacities and cost planning for the German Armed Forces.

The "Ammunition Storage And Site Planning" (ASASP) software tool supports the German Armed Forces in the strategic planning of ammunition storage facilities – both at home and during deployments abroad. In a guided and automated process, it calculates the protection and safety distances resulting from the quantities of explosives to be stored, thereby increasing the safety of personnel and the population. The tool also optimizes the storage of ammunition in existing warehouses. To do this, it uses specially developed packing and distribution algorithms that automatically ensure compliance with all safety regulations.

ASASP also offers a unique analysis tool that calculates the storage capacities of all ammunition depots throughout Germany, taking into account all procurement scenarios and regulations. It precisely determines the need for new warehouses in the context of current procurement scenarios. This data prevents the undersizing of storage capacities and at the same time avoids oversized new buildings, which would cause unnecessary construction costs. The tool thus makes a decisive contribution to efficient planning and cost control.

Structural protection of military infrastructures

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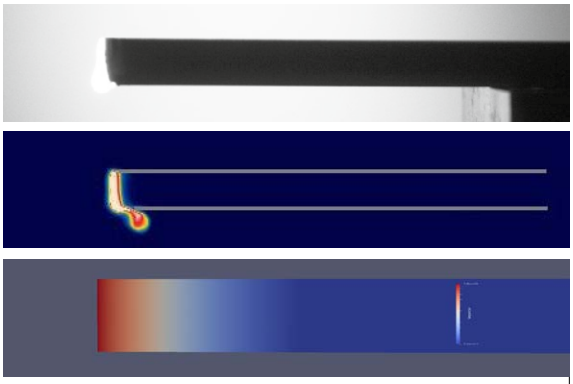
Laser simulation for military applications

Fraunhofer EMI is developing powerful software that simulates complex laser-matter interactions and evaluates the effects of laser weapons.



Removal of an iron bar by laser
Top: high-speed image
Middle: thermographic image
Bottom: numerical model of the process

The software enables the coupled simulation of heat conduction processes and material removal.

Fraunhofer EMI is developing innovative software that simulates complex laser-matter interactions for defense applications and evaluates the effects of laser weapons. It also offers potential for other areas of application. The researchers use state-of-the-art mathematical methods to master the challenges. When objects are irradiated with high-energy lasers with a power of over 100 kW and beam radii in the millimeter to centimeter range, numerous physical effects occur. These include heat conduction in solids, fluid dynamic effects after phase transitions and chemical reactions such as oxidation processes that are caused by the thermal effect of the laser. The complexity of these coupled processes overwhelms currently available software solutions, so that adequate and high-performance simulation is only possible to a limited extent. To overcome these challenges, Fraunhofer EMI is developing problem-oriented, modular modeling approaches. These weight the model equations based on the dominant sub-processes, while ignoring less relevant effects. To implement this idea, a software environment was developed that enables the implementation of physical-mathematical models as partial differential equations on dynamic computing domains. The numerical infrastructure is based on the discontinuous Galerkin method, which combines concepts of finite volume and finite element methods. This method enables efficient simulations through adaptive resolution adjustment and is characterized by high parallelizability. The newly developed software has an impressive modular structure and already fulfills other defence technology purposes. In addition to laser-matter interaction, it simulates the propagation of thermal radiation through the near-Earth atmosphere, for example.

Lasers are a cheap and efficient weapon for drone defense. The "ammunition costs" are just a few euros per shot.

Numerical simulation of laser-matter interaction
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Concrete debris

A new method makes it possible to precisely calculate the damage to concrete under heavy loads, including breakage and debris formation. It analyzes individual pieces of debris and precisely determines their trajectories.

Until now, risk analyses that assessed the dangers of concrete debris were based on statistical estimates based on a few large-scale tests. An accurate and reliable numerical prediction tool was not previously available.

Fraunhofer EMI has now developed a method that can accurately simulate the damage, crack growth process and debris formation in concrete. The heterogeneous structure of the concrete is modeled in detail. This allows the formation of the debris to be accurately mapped and compared with real measurement data. In addition, the shape and flight characteristics of the debris can now also be determined, which leads to more accurate calculations of their trajectories.

This new method is particularly important when it comes to safety planning for ammunition depots. In the past, protective distances were often conservatively calculated and the available space may not have been optimally utilized. With the new method, these distances can now be calculated more precisely.

The method can also help to more accurately identify hazardous areas when explosions occur in or around buildings, helping to minimize the risk to people and equipment. It can also be used in other areas such as the assessment of security risks in the event of accidents involving explosives or terrorist threats.

As the calculations require a lot of computing power, the method has so far been used as a prototype. However, with suitable hardware, it could also be used in the future in the real planning of ammunition depots and other security-relevant areas.

Debris thrown from concrete

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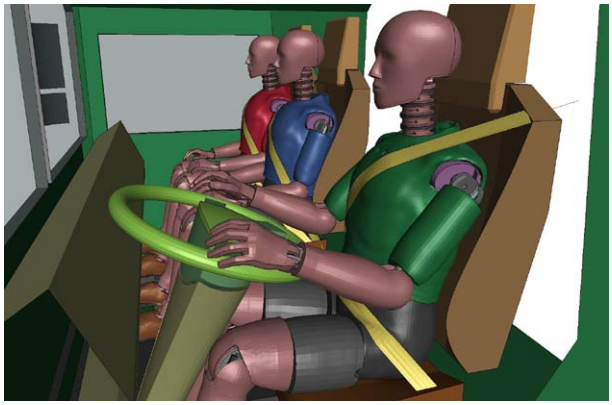
Occupant safety for military vehicles

Fraunhofer EMI is researching how occupant restraint systems work in military vehicles. The researchers are particularly interested in the effects of equipment worn on the body, the challenges of driving off-road, poor visibility and the danger posed by weapons.

EMI has developed a calculation model for the driver's cab of a heavy transport vehicle, equipped with dummy models. This allows specific variations to be introduced and analyzed.



Finite element model of a fully occupied driver's cab of a heavy transport vehicle of the German Armed Forces to analyze the efficiency of occupant restraint systems under crash loads. (Above: symbolic image)

Occupant protection for emergency vehicles
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Future Security: Protection of critical infrastructures

From April 2 to 3, 2025, Future Security took place at the Fraunhofer Forum Berlin under the theme "Protection of critical infrastructures against civil and military threats". The first day offered exciting plenary presentations by high-ranking representatives from ministries and authorities as well as insights from industry and the Fraunhofer Defense, Prevention and Security Division (VVS). On the second day, EMI and Fraunhofer ICT jointly hosted the specialist session on physical protection.

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Photos: Fraunhofer EMI (using Midjourney) (2), Fraunhofer EMI (2)

BUSINESS UNIT Security & Resilience

Business unit Security & Resilience

Resilient and sustainable logistics

Global crises such as the Covid-19 pandemic, geopolitical conflicts and extreme weather events have exposed the vulnerability of international supply chains. In the EU-funded SARIL project, Fraunhofer EMI is developing innovative decision support systems to make transportation and logistics networks more resilient and sustainable.

Pictured: Port of Hamburg. It is one of the 25 largest ports in the world in terms of container throughput.

Photo: TimSiegert-bildcam / stock.adobe.com

Research for a resilient future

Global crises, extreme weather, cyberattacks and disrupted supply chains reveal the vulnerability of modern societies.

Critical infrastructure must become more resilient to both known and unexpected disruptions – whether in the energy sector, logistics or disaster management.

By **Daniel Hiller**

Stress test for resilient infrastructures: extreme weather events such as the flooding in Valencia show how vulnerable networked systems are to natural disasters. Resilient structures and intelligent adaptation strategies are crucial to overcome such challenges and quickly restore critical processes.

Security & resilience in an interconnected world

Our world relies on interconnected systems – from energy and communication networks to global supply chains and digital infrastructures. However, this interconnectedness harbors risks: Natural disasters, cyber attacks, geopolitical tensions or pandemics can disrupt critical processes and plunge societies into crises. Resilience is becoming a key competence and characteristic for security, the economy and sustainability.

Resilience means that systems not only fend off threats, but also adapt quickly to changes and restore their function after disruptions. This requires a deep understanding of the risks, robust protection mechanisms and intelligent adaptation strategies. This is where research at Fraunhofer EMI comes in.

The institute develops methods to measure risks, analyze weak points and create resilient structures and technical systems. The institute uses state-of-the-art technologies such as numerical simulations, artificial intelligence (AI), experimental tests and data-driven decision-making systems. The following examples show how current research projects at EMI are helping to strengthen security and resilience.

Danger from unexploded ordnance: safer explosive ordnance disposal

Unexploded ordnance poses a significant threat to people and infrastructure around the world. One major problem is accurately predicting the effects of a possible detonation. The BMBF's project Shockanalyst is improving simulation models in order to calculate the pressure waves and fragmentation effects of explosions in the ground more realistically. These findings help emergency services to optimize protective measures and reduce risks.

Supply chains under pressure: solutions for resilient goods transportation

Global crises such as pandemics and natural disasters have shown how vulnerable supply chains are. To make transportation and logistics networks more resilient, the EU project SARIL is developing decision support systems. These systems help to quickly identify alternative transport routes and avoid supply bottlenecks. By combining real-time data and simulations, robust and sustainable supply strategies can be developed.

Photo: gonzagon / stock.adobe.com

Where there used to be a carefree Christmas atmosphere, there are now concrete bollards – a visible reminder of the increased threat of terrorist attacks. Since the attack on Berlin's Breitscheidplatz in 2016 and most recently the attack in Magdeburg in December 2024, these barriers have become standard. They protect, but they also make it clear that public safety can no longer be taken for granted.

Hydrogen economy: safe transport and storage

Hydrogen is becoming increasingly important as a sustainable energy source, but its transport and storage pose risks. To ensure the resilience of hydrogen networks, EMI is investigating possible incidents such as leaks or acts of sabotage. Numerical simulations help to develop effective countermeasures and create a secure infrastructure for the energy transition.

Monitoring the flow of goods: new technology for secure logistics

In logistics, the traceability of goods is crucial. However, metal containers make conventional radio transmissions difficult. The Beep 2 Blue project uses acoustic data transmission via ultrasound to reliably transmit sensor data even from shielded environments. This technology improves security and efficiency in global supply chains.

Protection against climate-related threats: Nature-based solutions for cities

Heat islands and flooding are increasingly endangering urban areas. The EU project NBSInfra is investigating how nature-based measures can make cities more resilient to extreme weather events. EMI is analyzing which protective measures are particularly effective for critical infrastructures and developing models for targeted risk reduction.

Strengthening companies against cyber threats

Cyber attacks and system failures are increasingly endangering companies and critical infrastructures. The Horizon Europe project DYNAMO combines business continuity management with cyber threat intelligence to detect threats at an early stage. AI-supported simulation tools help companies to develop targeted defensive measures and increase their resilience to cyber threats.

Photo: ArTo / stock.adobe.com

Undetected threats in the Arctic: anomaly detection for greater security

The increasing economic use of the Arctic brings new challenges: extreme weather conditions, unseen navigational hazards and illegal activities threaten security. The AI-based platform AIARC analyzes ship movements, satellite data and weather forecasts to detect anomalies at an early stage. It is particularly important to reliably detect icebergs and minimize false alarms in order to reduce maritime risks.

Crisis resilience in the administration: ensuring effective response

Authorities must act quickly and effectively in crisis situations. The BMBF project RESKON is developing a digital tool that supports public institutions in measuring and improving their resilience. Practical solutions for crisis management are being developed based on real-life scenarios, such as prolonged heatwaves or hybrid threat situations.

Service portfolio

Analysis of impact and explosion events

Evaluation of security concepts against explosion, flood, storm

Resilience analyses of supply networks

Simulation of security at major events

Development of robust and resilient sensors, data analysis in particularly harsh environments

Testing and certification

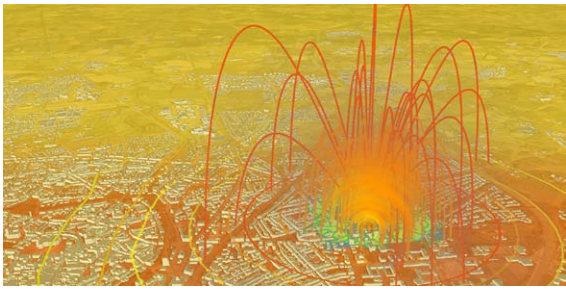
Development of resilience management tools for business resilience

Increasing the resilience of companies
The free online tool "Fraunhofer Resilience Evaluator FReE" helps to increase the resilience of companies and systems.
→ **www.resilience-evaluator.de**

Thousands of unexploded bombs from the Second World War still lie dormant in the ground: detonation of a World War II bomb in Munich, August 2012.

Unexploded ordnance: making controlled detonations safer

Fraunhofer EMI develops numerical models, that predict fragmentation flight and vibrations and minimize risks.



It is estimated that 5 to 15 percent of the 1.4 million tons of bombs dropped are still in the ground. In most cases, these unexploded bombs can be neutralized, but sometimes controlled detonations are necessary. To limit the blast wave and, above all, the flying fragments, the bomb is covered with sand again before detonation. However, this has a disadvantage: the energy of the explosion penetrates more deeply into the ground. The resulting voltage waves can damage nearby underground structures such as gas pipes, subway shafts or basement walls.

In the SIRiUS project, the Fraunhofer EMI, the Explosive Ordnance Disposal Service NRW and the company Virtual City Systems developed software that simulates controlled explosions in a 3D city model. The current BMBF project Schockanalyst builds on this. It extends the software so that explosive ordnance disposal services can compare different safety measures and better assess the effects of shock waves in the ground.

Numerical models are being developed at EMI to calculate the influence of sand cover on fragmentation and ground shock. The behavior of the soil as a three-phase mixture of particles and water- and air-filled pores poses a particular challenge. Precisely simulating these extreme dynamic loads is only one aspect of the project. A large-scale test – the planned detonation of six buried 500-pound bombs – will show how well the models reflect reality.

Project Shock analyst
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Increasing safety in dangerous waters: AI-supported monitoring supports ships in the Arctic.

Safe shipping in the Arctic: AI detects icebergs, anomalies and risks

Automatic hazard detection by analyzing large amounts of data.

The AI-ARC (Artificial Intelligence Based Virtual Control Room for the Arctic) project aimed to improve situational awareness in civil shipping and reduce safety risks – without increasing the workload of seafarers. Partners from 13 European countries were involved.

A key challenge was to efficiently process the AIS (Automatic Identification System) data from over 1500 ships as well as extensive weather information and satellite images on a daily basis. To achieve this, the partners developed innovative tools and services in which artificial intelligence (AI) plays a key role. In the AI-ARC project, AI automatically recognized suspicious activities and unusual occurrences. These findings were incorporated into a new type of platform for situation visualization. Particular attention was paid to the reliable identification of icebergs for safe navigation in the Arctic. Fraunhofer EMI developed an advanced method for estimating forecast uncertainty that goes beyond conventional approaches. Unlike previous methods, which often require a change in the AI model architecture, Fraunhofer EMI uses an additional AI model to quantify the reliability of iceberg detection. This model-agnostic approach enables quick and easy implementation with comparable results, setting it apart from existing solutions. To detect illegal fishing and smuggling, the researchers analyzed ship routes for anomalies. Reliability assessments were carried out at Fraunhofer EMI to inform users about the background to an alarm and reduce false alarms. Thanks to these advanced approaches, the AI-ARC project is making a significant contribution to the safety of shipping in the Arctic.

Project AI-ARC

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Funded by the European Union

Secure hydrogen grids for the future

Fraunhofer EMI is developing innovative numerical simulation methods for planning resilient hydrogen grids.

Hydrogen is increasingly seen as a promising fossil-free energy source and plays a key role in the energy transition. It helps to reduce greenhouse gas emissions and achieve climate neutrality. Green hydrogen, produced from surplus wind and solar energy, can be stored locally and transported to remote consumers via grids. However, storage and transportation involve risks: Natural disasters, sabotage or political sanctions can jeopardize supply. Careful planning of resilient hydrogen infrastructures is therefore essential in order to secure the energy supply in international networks.

Numerical network modeling which simulates physical conditions in hydrogen networks, offers valuable tools for this. It allows "what-if" analyses, reveals weak points and evaluates resistance to disruptions. Such models must accurately depict network behavior under extreme conditions in order to mitigate risks. The simulation of the network's dynamic reactions to extreme events is particularly important.

Fraunhofer EMI is developing a hydraulic simulation tool based on physical principles and engineering models. It analyzes the reactions of hybrid or pure hydrogen networks with storage systems to disruptions. This novel, numerically robust approach makes it possible for the first time to make consistent and rapid predictions of system behavior before, during and after disruptions as well as forecasts of survival and recovery times. The results can provide essential valuable contributions to the planning of resilient hydrogen networks.

Resilient infrastructure is crucial for a stable hydrogen supply. Simulation tools from Fraunhofer EMI analyze network reactions to disruptions and help to minimize risks from extreme events.

Hydrogen networks
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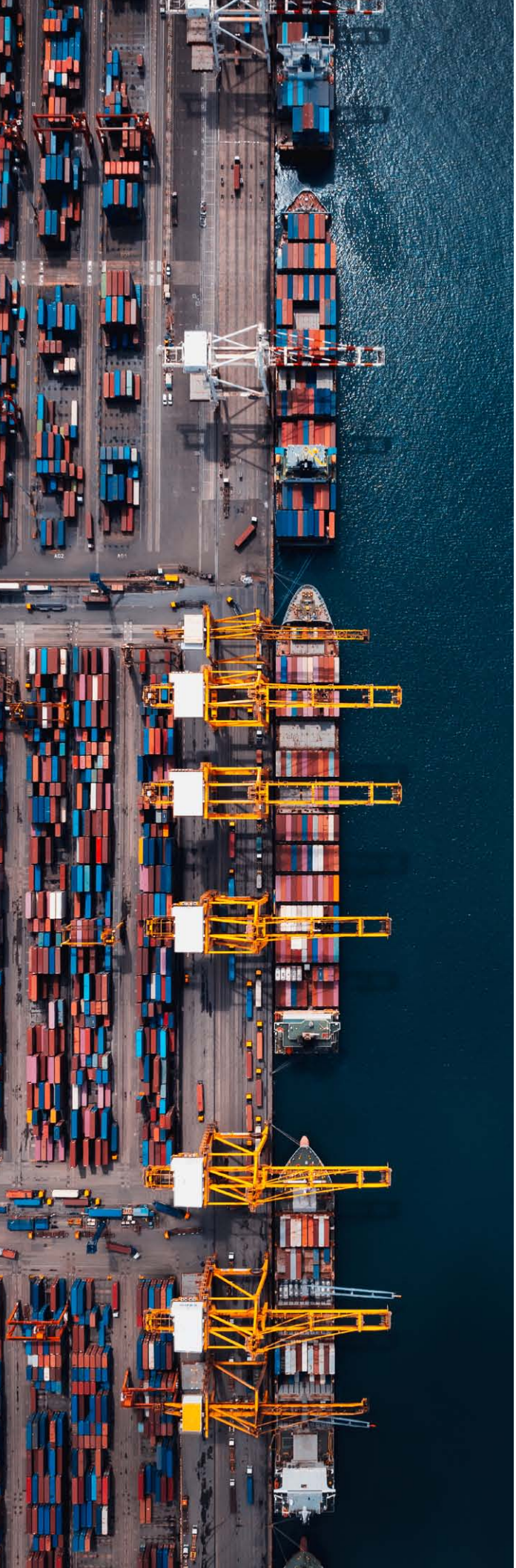
Photos: ONTRAS Gastransport GmbH, SHUTTER DIN / stock.adobe.com



Resilient and sustainable logistics networks

Real-time data and simulation approaches for logistics and transportation.

In recent years, global freight transportation has come under pressure due to a series of extraordinary events. The Covid-19 pandemic, the blockade of the Suez Canal in 2021 and the war in Ukraine caused a noticeable disruption to the international logistics network. Extreme weather events such as floods and wildfires also put additional strain on the system. Their frequency is likely to increase further due to climate change.

The SARIL project aims to develop decision support systems and provide recommendations for resilient and sustainable transportation and logistics networks. The research is in line with developments to fulfill the EU's European Green Deal and the United Nations' Sustainable Development Goals. As the transport sector is a major contributor to climate-damaging emissions, it will need to undergo a significant transformation towards more sustainable solutions. In order to reduce emissions and improve data exchange, it is important to combine different means of transportation in a sensible way. This is where synchro-modal approaches come in and also use physical internet concepts to ensure that efficiency and sustainability go hand in hand.

The SARIL project was funded by the EU and is coordinated by Fraunhofer EMI. It brings together research organizations, universities and companies from all over Europe as well as the European technology platform ALICE.
The proposed solutions will be demonstrated at three different levels, i.e. a regional scenario, a national/cross-border scenario and a European scenario. The scalability of the developed solutions is a key concern within the project.

Project SARIL
Dr. Corinna Köpke,
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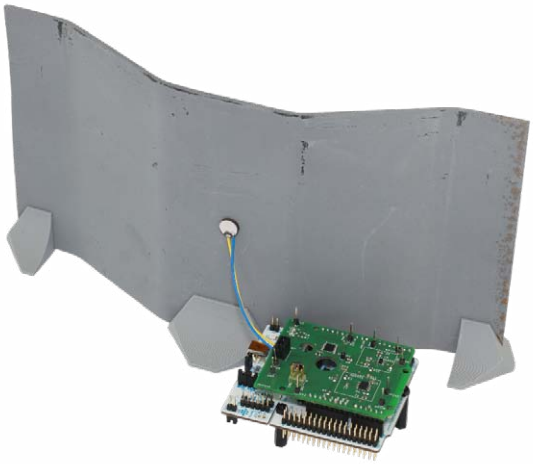
Funded by the European Union

Monitor supply chains efficiently

Beep2Blue: energy-saving monitoring system with ultrasound.

The Beep2Blue system monitors supply chains in ISO container logistics and tracks assets on construction sites. Using Fraunhofer EMI's energy-saving ultrasonic technology, it transmits sensor data from metal-shielded environments where radio connections are heavily attenuated. Inside, the Beep2Blue interface receives the data via Bluetooth and transmits it acoustically to the outside. There it is transmitted to web servers via 3G/4G wireless standards.



Penetrates metal with ultrasound: the Beep2Blue system transmits data acoustically to the outside. There it is picked up by sensors and processed further.

Nature-based solutions for urban resilience

In the European research project NBSInfra, Fraunhofer EMI is investigating how nature-based solutions can strengthen the resilience of urban areas to climate-related hazards.

The institute is examining the resilience of critical infrastructure in the event of flooding by mapping cascading effects. It also takes into account the results of a simplified model for measuring urban temperature developments and the heat island effect.

The aim is to illustrate the advantages of nature-based solutions for urban resilience and to promote their integration into urban planning.

Funded by the European Union

Cyber security for critical infrastructures

Cyber attacks are increasingly threatening critical infrastructures such as energy, healthcare and transportation. Fraunhofer EMI is coordinating the Horizon Europe project DYNAMO to address these threats. Experts from various fields are working together with end users to develop and optimize selected tools and bundle them into a single platform. The knowledge gained from DYNAMO is intended to accelerate the recovery process and enable systems to heal themselves. The DYNAMO platform collects organization-specific competence data, evaluates it and offers tailored training to strengthen resilience. DYNAMO combines AI-supported approaches from business continuity management and cyber threat intelligence to carry out resilience analyses and minimize cyber attacks in critical areas.

Cybersecurity measures protect the energy supply, healthcare and logistics sectors from attacks and thus prevent critical infrastructure failures.

Funded by the European Union

Increasing the resilience of public authorities in the face of crisis

The BMBF project RESKON is developing a practical tool that helps public authorities to measure their resilience, identify capability gaps, provide suitable solutions for improvement and facilitate their implementation. Together with the Federal Office of Civil Protection and Disaster Assistance, the Federal Agency for Technical Relief and the Dortmund Fire Brigade, this method is being applied in two scenarios: a prolonged period of heat and a hybrid threat situation. The aim is to identify measures to increase resilience.

GEFÖRDERT VOM

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Business unit Automotive

Battery crash at 60 km/h

Fraunhofer EMI's battery crash accelerator is a catapult system that carries out impact and crush tests on charged batteries to assess their crashworthiness. In conjunction with numerical simulations, it enables a comprehensive research and understanding of battery systems.

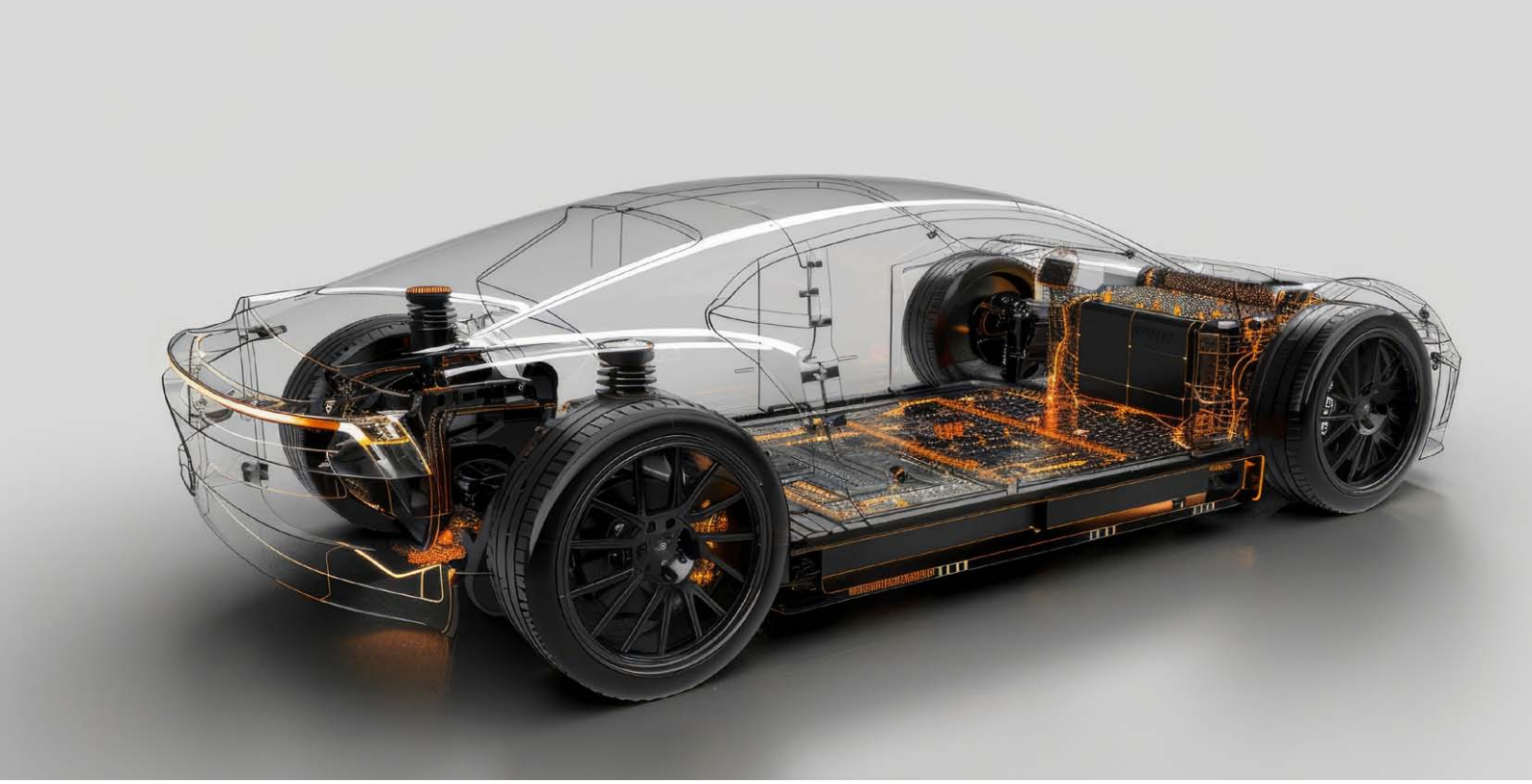
Pictured: Catapult system at the battery test center at the Efringen-Kirchen location.

Photos: Fraunhofer EMI (2)

Research for safe electric vehicles of the future

Battery electric vehicles continue to conquer the global market. But how do we need to design future generations of electric vehicles safely and efficiently to enable industrial scaling?

By **Dr. Michael Dlugosch**



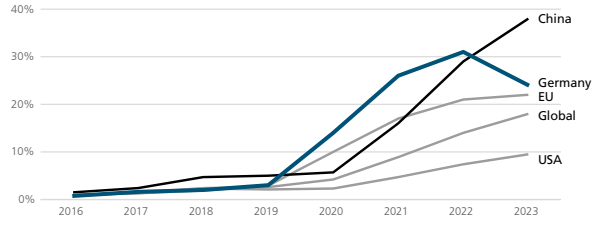
New vehicle architectures in transition: The integration of the battery as a load-bearing structural component requires innovative materials and design concepts for greater safety and efficiency.

Future trend battery-electric mobility

A look at the roads in German and international cities shows that the trend towards electric mobility continues unabated: The trend towards electromobility is unbroken. Despite a slight decline in new registrations of alternative drive systems in Germany for 2023 and 2024, which was due to political factors, the Federal Motor Transport Authority is reporting a significant increase starting in 2025. Germany is thus returning to the clear global trend.

Share of electrified vehicles in annual new registrations

Source: International Energy Agency



In terms of the total number of vehicles on the roads, electric vehicles tend to be newer and are therefore usually equipped with comparatively modern, active safety systems. However, they are of course also involved in road accidents and must ensure the protection of occupants and other road users. Increasing electrification is also reflected in the constant development of legal safety regulations and the star ratings of consumer protection crash tests.

A paradigm shift for new generations of electric vehicles

The first phase of the global triumph of battery electric vehicles in recent years was characterized by vehicle models whose structural design was adapted for the new drive systems. However, the basic vehicle architecture and the functional principles for crashworthiness were largely similar to those of conventional vehicles. The overriding principle for the safety design of these vehicle models is maximum protection of the energy-dense traction battery in a crash.
This cautious and at the same time pragmatic approach to the – to this extent – new technology led to major safety margins in the design of protective structures and thus to considerable reductions in weight and costs.

However, further research work and field experience in battery safety are now creating the basis for reducing this oversizing in the design of new vehicle generations and thus also enable efficient scaling to larger quantities. This fundamental reorientation in the safety design of new, purely electric vehicle models requires the introduction of a

Photos: Fraunhofer EMI (using Midjourney), kanesuan / stock.adobe.com

new design philosophy of integration: the entire high-voltage storage system must be considered as an integral part of the vehicle body and thus also of the load-bearing structures in a crash. More integrated, less modular architectures must also be developed inside the battery for this purpose. This is the only way to increase energy densities and thus relative ranges while at the same time saving space, weight and costs.

As part of a risk assessment, it is crucial to find an optimal balance between the permissible loads and ensuring a high level of crashworthiness. The basic prerequisite for this is a precise understanding of the properties and behavior of the individual components of the battery system under load as well as the mechanisms and cross-scale chains of action in a crash.

New architectures – new challenges

The characteristic feature of these new vehicle architectures is, of course, the traction battery, which is usually installed in the subfloor area. By eliminating essential drive components of conventional combustion vehicles such as gearboxes, drive shafts or exhaust systems, electric vehicles can be designed without a center tunnel. Together with some longitudinal and cross members and the door sills, this forms the main stiffening elements and crash load paths of the body. Energy absorption, force transmission and stiffening must (or may) be rethought, redesigned and ultimately designed for function and safety in new vehicle architectures. The battery and its housing are now also seen as a central component of this overall architecture. To ensure that this not only efficiently stores and supplies the electricity required for the drive, but also makes a mechanical contribution, new approaches must also be taken in the design of the internal battery architecture.

The trend here is moving away from modular towards more integrated designs in which the individual cells are installed directly in the battery pack ("cell2pack") or even the body structure ("cell2body"). In order to improve these designs, engineers are also focusing on other material classes that have hardly been used here to date. Structural foam, for example, is not only suitable for reinforcing highly integrated battery architectures, but can also help to absorb energy in a crash and contain local fires or thermal phenomena. Fiber-reinforced plastics and their diverse properties in terms of shaping and, in some cases, excellent thermal and mechanical resistance can also play a decisive role in new architectures.

Photo: Ivan Traimak / stock.adobe.com

Vehicle manufacturers are faced with two main challenges: in parallel to the drive and storage technology of electric vehicles, the load cases, some of which are now also specific to electric cars, must be mastered for approval and good safety assessments. At the same time, engineers cannot draw on the experience gained from several previous generations of vehicles for the safe design of these new designs.
Considering that this transformation will also require significant adjustments to current production technologies and in other areas, the impression confirms the conclusions of current studies: in order to master these diverse challenges in the face of drastically increased dynamics and increased competition in the industry, substantial R&D expenditure on the part of the industry is urgently needed.

Safety through applied research

In fall 2024, the battery safety community visited Fraunhofer EMI as part of the carhs event "The SafeBattery Experience". OEMs, suppliers and research partners were able to gain an impression of the portfolio of experimental facilities and expertise in virtual design and analysis for battery and vehicle safety. In the course of its applied research work, EMI interlinks experiment and simulation across scales and along the phenomenological chain of effects in a crash: from mechanical loads, deformations

New production processes for new architectures: The battery as a load-bearing element is fundamentally changing vehicle architectures. New materials and designs are required to ensure safety and functionality. At the same time, changed load cases and production processes require high investments in research and development.

and material failure to electrochemical effects (e.g. thermal runaway) and gas and thermodynamic processes from the individual cell to the entire battery pack (propagation) through to the thermomechanical loads on the housing and surrounding structures. EMI can build on its decades of experience in material, structural and fluid dynamics as well as extensive experimental capacities (e.g. shock and impact tests of charged batteries up to 50 kWh). Special insights are also provided by in-situ X-ray diagnostics, which enable to dynamically visualize internal battery damage processes. Only with such an "integral" perspective on the high-voltage storage system and with the ability to understand, model and make targeted use of the underlying mechanisms an innovative, safe and efficient design of new generations of electric vehicles can be successfully achieved.

Service portfolio

Highly instrumented and customized experiments: from material to complete vehicle

Safeguarding vehicle batteries in experiment and simulation

AI-based optimization of simulation models and structural designs

Monitoring and simulation of traffic flows

Human models for the protection of pedestrians, cyclists and passengers

Better protection for pedestrians

One third of road fatalities are pedestrians. To improve their safety, Fraunhofer EMI is developing traffic simulations that integrate detailed pedestrian models for the first time.

Statistics from the European Commission report 7,665 fatal road accidents in urban areas in the EU in 2021. 31 % of the victims were pedestrians who collided with motorized vehicles. By 2023, the number of fatal accidents in urban areas had risen to 7,807, with the proportion of pedestrians increasing to 33 %. At the same time, the growing variety of modes of transport and increasing infrastructure congestion are making road safety more difficult. Autonomous vehicles are intended to better protect particularly vulnerable road users such as pedestrians and minimize human error in critical situations. In order to develop such systems, extensive test data from around 2.1 billion kilometers is required to ensure that each relevant traffic situation occurs at least once with a probability of 50 %. This problem is tackled using synthetic data from simulation environments. Until now, the focus of microscopic traffic simulations has been on motorized road users. However, a realistic representation of pedestrians is crucial, especially in cities. Fraunhofer EMI is closing this gap and has integrated improved modeling of pedestrians into the traffic simulation as a first step. In doing so, it is using its experience from the development of agent-based simulations for crowds at major events. These simulations already take into account the interaction between individuals and their reactions to obstacles, whether stationary or moving. They also model pedestrians with individual characteristics, such as goals, needs and the willingness to take risks.

Finally, optimization algorithms developed at EMI can be used for integrated behavioural models, which ensure an optimal choice of model parameter values based on a statistical comparison with real data. In addition to the classic rule-based simulation algorithms, EMI is also researching the use of AI methods. In particular, the question of whether decision-making processes, such as crossing roads, can be realistically predicted using reinforcement learning algorithms is being investigated.

Agent-based simulation methods
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AI recommendation systems: efficient design of sustainable vehicles

Fraunhofer EMI is researching the application of generative artificial intelligence in order to make data and the knowledge it contains usable for the design of vehicles in the long term.

Comprehensive specialist knowledge from a wide range of highly complex technical disciplines is essential for the development of a vehicle. Engineers must design entire vehicles and their individual components in such a way that they are functional, safe, economical and, increasingly, sustainable. In addition to good software tools, this requires many years of experience, but a study by the "German Association of the Automotive Industry" shows that a quarter of the workforce is expected to retire within the next 10 years. In a highly competitive environment with fast development cycles, it is crucial to retain in-house knowledge and make it efficiently accessible.

Gaining knowledge from data: Key to efficient development processes

Fraunhofer EMI is developing an innovative AI recommendation system that generates targeted advice for efficient product design. This system extracts the specialist knowledge of experienced engineers, which is contained in the raw data and metadata of past development cycles, among other things. The knowledge gained is converted into natural language to facilitate access to this information. The system acts as a development assistant to help engineers make faster and better decisions.

Create a basis for decision-making: Solutions for sustainable product design

In the use case of sustainable product design, engineers have to assess the long-term effects of their design decisions on the life cycle of a product at an early stage. Relevant information on sustainability effects is often lacking, especially when data is insufficiently linked. The AI systems developed at Fraunhofer EMI offer a solution by providing a contextual embedding for the data. Engineers receive customized recommendations that help them make sustainable design decisions. This knowledge transfer increases product quality and thus the innovative strength and competitiveness of the company.

Current research at Fraunhofer EMI

JSOL Consulting Partnership
AI consulting partnership with JSOL Corporation to promote AI in the development processes of Japanese vehicle manufacturers.

DigiTain
Development of software tools for the automated provision of sustainability-relevant data in the automotive product development process; publicly funded by the Federal Ministry of Economic Affairs and Climate Action

DECIDE
Elaboration of a demonstrator for rapid decision-making in the development process using the example of an automotive vehicle battery; internal research project.

HERAKLION
Demonstrator development of an AI recommendation system for resilience analyses based on data space functionalities; publicly funded project by the Federal Ministry of Education and Research.

Data & Knowledge Engineering
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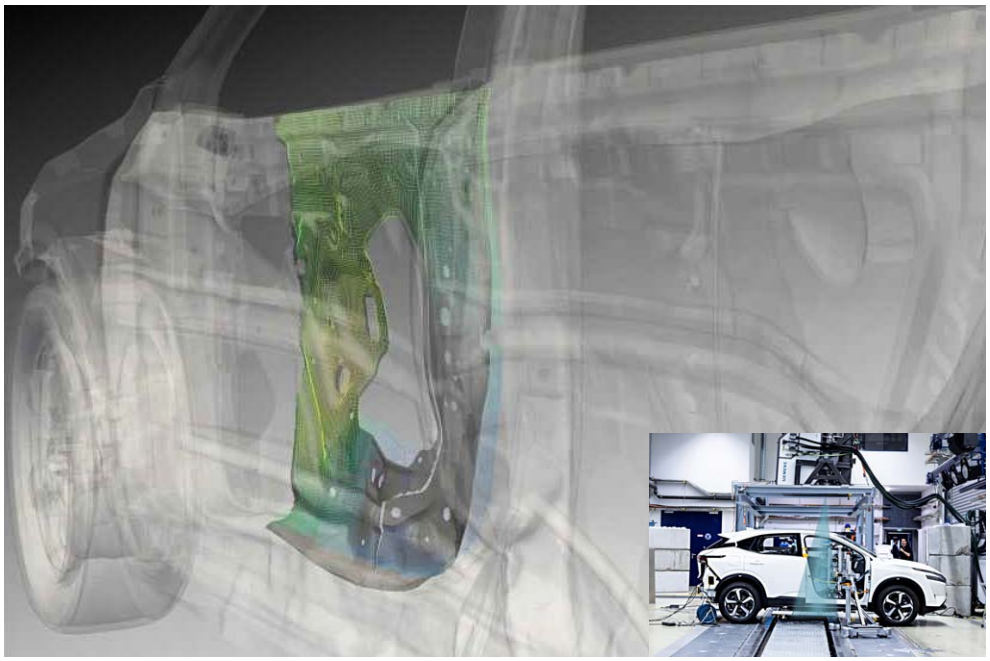

Together with Nissan Motor Co., Ltd., the combination of the X-Ray Car Crash with the Grey-Box-Processing evaluation method was used for the first time in a full vehicle side impact crash. The figure shows the deviation between experiment and finite element simulation.
Published with the kind permission of Nissan Motor Co., Ltd.

Efficient validation of crash simulations with Grey-Box-Processing

The utilization of experiment and simulation in vehicle development has constantly changed. Latest research results show: The integration of both worlds offers great potential.

The targeted, almost all-digital development of future vehicles as well as their digital certification is crucial considering the steadily increasing technical, economic, and ecological challenges in the development process. The realization of this vision requires the availability of simulation methods and models with high predictive capability in all phases of the development process. The predictive capability must be quantified during the validation process through comparative comparison of results from experiment and simulation. In addition to identifying particularly suitable validation load cases and the detection of the maximum amount of information through various measurement systems, the ideal utilization of the data gathered is of vital importance.

In addition to the development and research of novel measurement systems, Fraunhofer EMI has therefore developed an innovative validation method called "Grey-Box Processing". The fundamental idea is to integrate discrete, uncertain measurement data into numerical simulation models. The method enables not only the closing of temporal and spatial observation gaps but also the comprehensive analysis of deviations between the model predictions and the behavior in the validation experiment. By automating the processing of heterogeneous measurement data and transforming it into comprehensively interpretable datasets, the method allows not only for the acceleration of the validation process but also for a significantly improved utilization of measurement data.

The method is currently being used at Fraunhofer EMI at different levels of analysis in industry and research projects, enabling, for example, a "kinematic analysis" as well as a comprehensive "integral deviation analysis".

Grey-Box-Processing
Dr. Thomas Soot
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Funded by the European Union
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Restraint systems for maximum occupant protection

Fraunhofer EMI develops solutions that optimize restraint systems and improve occupant protection through experimental technologies and precise simulations.

In order to provide the best possible protection for vehicle occupants in the event of a crash, all the restraint systems available in the vehicle must work together optimally. Nowadays, this includes vehicle seats with active seat functions, multi-point safety belts with belt tensioners, airbags that are coordinated with each other in the interior and pre-crash functions that, in conjunction with sophisticated sensor technology, ensure that the occupants are moved into the best possible position in the event of a foreseeable accident.

Fraunhofer EMI supports suppliers and OEMs with an extensive portfolio of tests at material, component, subsystem and full vehicle level, accompanying simulations and AI methods as well as the use of state-of-the-art diagnostics in the development and testing of restraint systems. The interdisciplinary expertise in the field of airbag systems, which is continuously further developed at Fraunhofer EMI, can be cited as an example of a success factor. Current research questions from our customers concern the visualization of gas flows inside the airbag, improvements to specimen geometries for the structural-mechanical characterization of airbag fabrics and movements of the airbag inside the component that can only be visualized using X-ray technology, long before predetermined breaking points allow the airbag to deploy freely. Adaptive restraint systems that take into account the individual characteristics of the occupants, for example with regard to their alertness, posture or other measurable biomechanical variables, in order to implement even more precisely tailored measures for the best possible protection, open up another exciting field of activity. In this regard, the expertise in the area of human body and dummy models will be transferred to the newly founded research group "Body Protection and Occupant Safety", which will focus intensively on the industrial requirements expressed by customers.

Fraunhofer EMI is developing new characterization methods and measurement diagnostics. The institute uses these to test innovative technologies such as adaptive airbags, active seats and pre-crash functions in order to maximize occupant protection in the event of an accident through perfectly coordinated systems.

Human Protection and Occupant Safety
Dr. Matthias Boljen
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Airbag Symposium

The Airbag Symposium is an important international event at which international experts from industry and research present and discuss the latest developments, technologies and research results in the field of occupant safety.

EMI was represented with a presentation on the topic of high-energy X-rays for the in-situ observation of safety-relevant, dynamic processes in restraint systems.

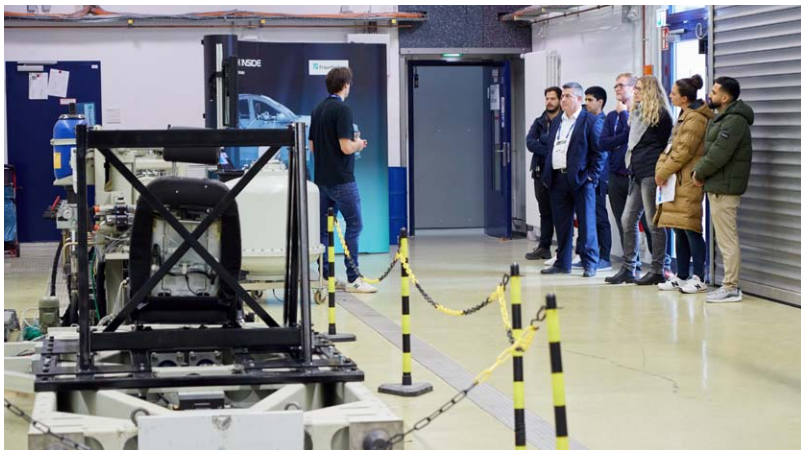
At the accompanying trade fair, the high-speed X-ray technologies for crash tests were presented in depth at a joint stand with the organizing Fraunhofer ICT and discussed in many interesting conversations.

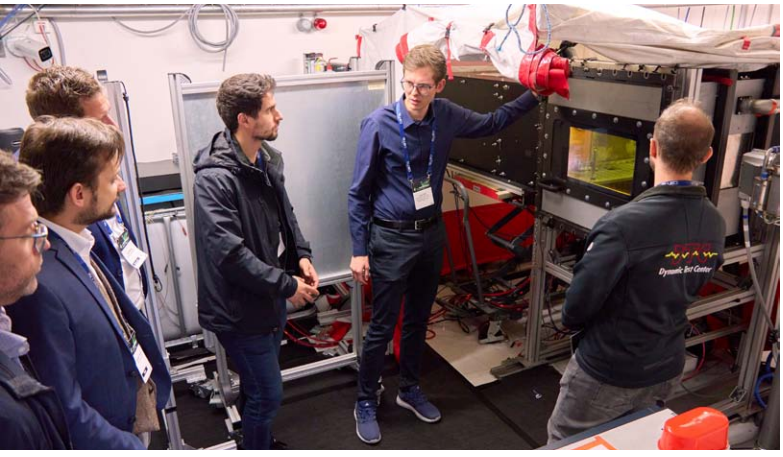
Innovative high-energy X-ray technologies for analyzing dynamic processes in restraint systems. Read more in the interview:

EMI at "SafetyWeek"

carhs SafetyWeek is the international meeting place for vehicle safety experts and comprises individual conferences on requirements, testing and the future of safe mobility, supplemented by the SafetyExpo, where leading companies present their innovations.

Fraunhofer EMI had an exhibition stand with the theme "Really Look Inside". High-speed X-ray technologies for crash tests were presented here. The focus was particularly on crash scenarios for the entire vehicle as well as restraint systems, airbags and battery abuse tests. The discussions opened up promising points of contact for future research cooperation with industry.





“The SafeBattery Experience” at Fraunhofer EMI

“Experience battery safety research” – this was the motto under which safety engineers and battery researchers from all over the world met at “The SafeBattery Experience” forum organized by carhs in Freiburg on October 15 and 16. Research and industry exchanged information on new developments, regulations and test procedures. One of the highlights was a tour of the Fraunhofer battery testing laboratories in Efringen-Kirchen. The consistently positive feedback from the participants and the organizers from carhs.training GmbH confirms the concept: on the way to successful innovation, theoretical research and practice must be considered together.

Photos: Fraunhofer ICT, Fraunhofer EMI (5)

Business unit Automotive
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BUSINESS UNIT Space

Business unit Space

Customized satellite solutions

Fraunhofer EMI offers a complete range of services for innovative satellite applications in Earth Observation: scientific cameras, powerful on-board data processing systems, new structural concepts, 3D printing, mechanisms, including construction and testing as well as launch and operation of research satellites.

Pictured: Test of a Data Processing Unit developed at Fraunhofer EMI. It processes image data, stores it temporarily and controls the payload – flexibly and automatically.

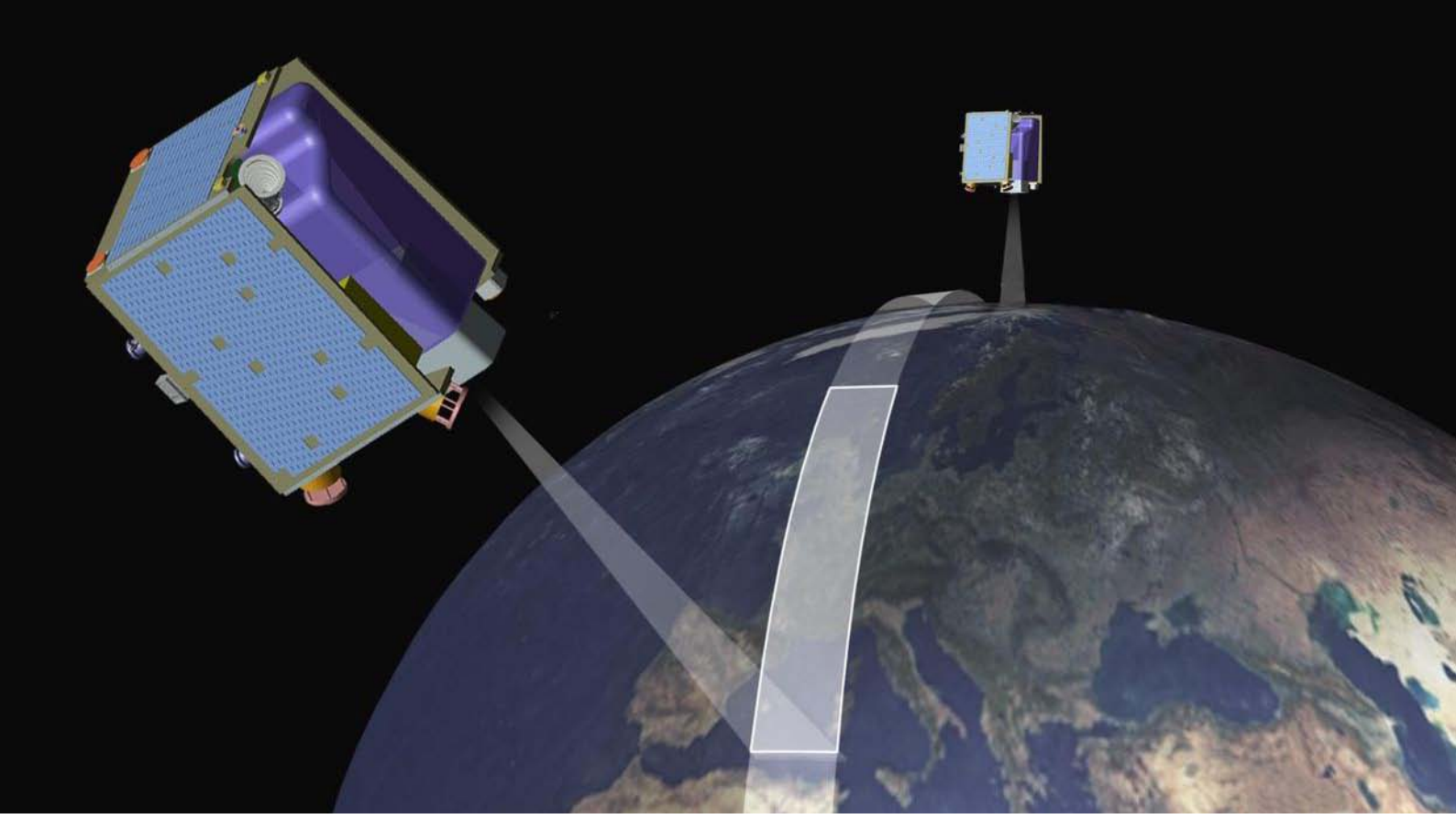
Photo: Fraunhofer EMI


HORIZONTAL
Position
Scale
Navigate

Satellite constellations as a key strategic technology

Satellite constellations are essential for independent capabilities in Earth Observation, communication and navigation.
Germany has some catching up to do – but Fraunhofer is driving the development of a powerful European infrastructure with innovative research and strong partners.

By **Prof. Dr. Frank Schäfer**



RapidEye – pioneering work from Germany: It was the first German commercial satellite constellation and consisted of five Earth observation satellites.

Large satellite constellations are the key to a sovereign German and European space infrastructure

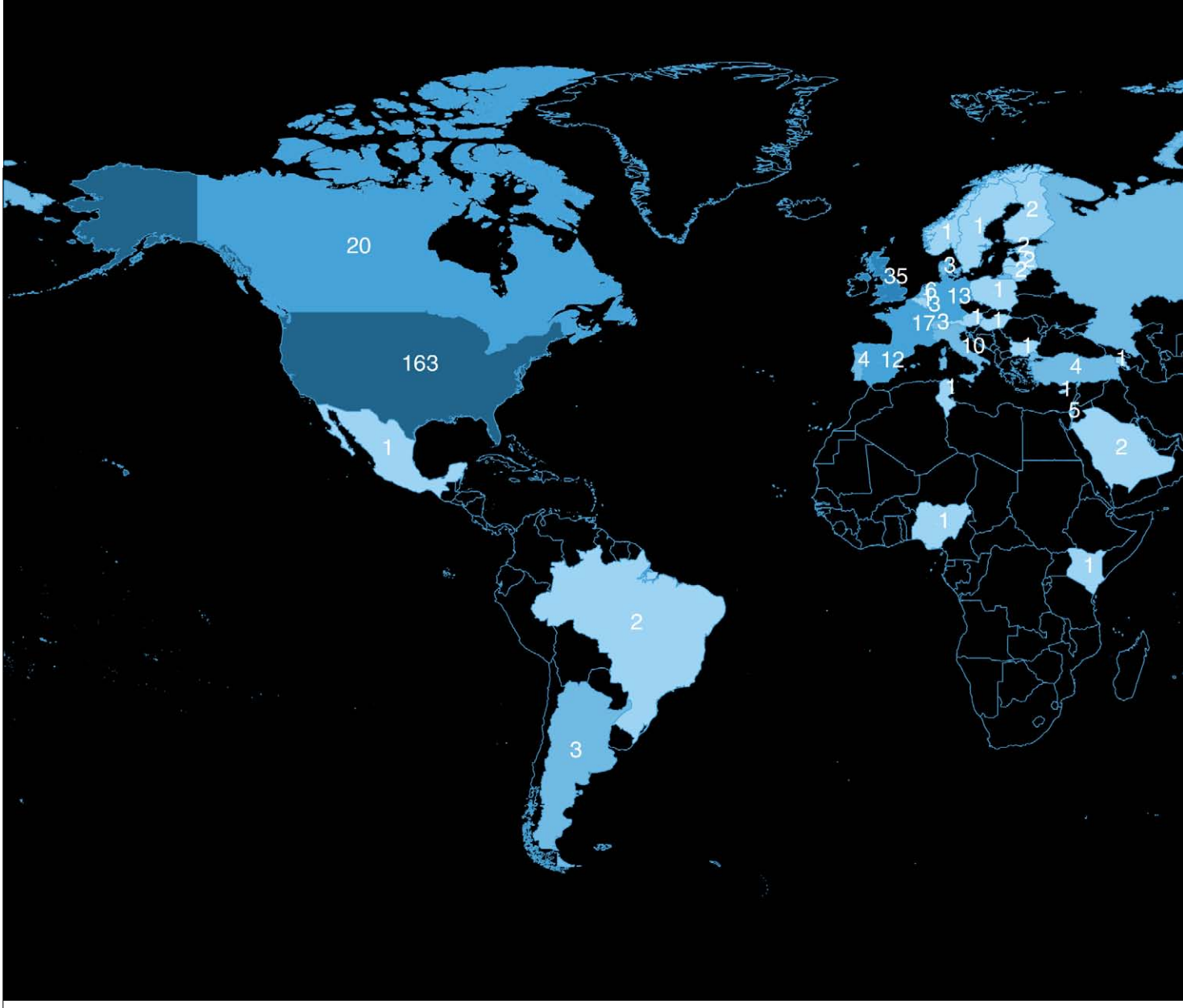
A satellite constellation is a group of artificial satellites that work together as a system and complement each other. Mega-constellations consist of hundreds to thousands of satellites and provide global coverage with minimal disruption, especially for Earth observation, communications and navigation.

RapidEye was the first German commercial satellite constellation consisting of five Earth observation satellites. On August 29, 2008, the five cube-shaped microsatellites, each weighing 156 kg and with an edge length of one meter, were launched from Baikonur, Kazakhstan, into a sun-synchronous orbit of 630 km by a Dnepr rocket. On board was an optical instrument for Earth observation containing five push broom scanning cameras, each with 12,000 pixels. This instrument was able to record multispectral images of the Earth's surface in five wavelength ranges between 440 nm (blue) and 850 nm (near infrared). The optical system was able to achieve a geometric resolution on the ground of 6.5 meters per pixel. The swath width amounted to 77 km and the maximum length of the recorded image strip was 1500 km. The five satellites allowed to record every point on Earth every day.

The Canadian company MDA was the main contractor for the RapidEye system, commissioned by the company RapidEye AG in Brandenburg. The company SSTL in Guildford, UK, designed and manufactured the satellite bus, and the German company Jena-Optronik GmbH in Jena developed and manufactured the optical instrument, including line scan cameras.

At the time of RapidEye's launch, there was no privately operated Earth observation constellation in the world. RapidEye AG was therefore a pioneer with the first commercial Earth observation satellite constellation. It delivered outstanding image quality and ground resolution for the time. At the same time, the company had to take high economic risks, as the market for geodata services was not yet well developed and the digitization of companies and authorities was often still in its infancy.

RapidEye AG's business model, which consisted of selling high-resolution optical Earth observation images, unfortunately did not last long. The joint decision taken in 1998 by the European Commission and the European Space Agency ESA to implement a major Earth observation program called Copernicus proved to be particularly problematic for the company. The aim of this program was to create an independent European Observation system that has been in operation since the launch of the first Sentinel satellite in 2014 and, among other things, provides



high-resolution image data similar to that of RapidEye – but makes it available to users worldwide free of charge. The company RapidEye AG, which initially had clear unique selling points with its services, was sold in 2011 to Planet Labs Germany in Berlin, a spin-off of the US company Planet Labs, which continued to operate the constellation until 2020.

New players and technological developments in Germany

For a long time, nothing happened in the economic field of Earth observation constellations in Germany. Fortunately, in recent years, there has been an increasing number of young space companies that are operating successfully in market niches. Two companies deserve special mention: OroraTech, based in Munich, which has already launched 11 small satellites of the FOREST constellation with thermal infrared cameras for the early detection of wildfires into low-Earth orbits since 2022, and constellr, based in Freiburg, which launched the first SkyBee-1 satellite of the HiVE constellation at the beginning of 2025. The HiVE constellation is equipped with thermal infrared technology that will be used to monitor global land surface temperatures, for example to adapt water consumption in agriculture to climate change and to detect heat islands in cities.

Other satellite projects in Germany in the field of Earth observation have so far been used exclusively for technology demonstrations.

In the field of satellite communication, relevant applications are primarily satellite-based IoT, M2M and internet applications. Some constellations of companies based in Germany have been announced, but have not yet entered

Photo: Erik Kulu / NewSpace Constellations / www.newspace.im

Global distribution of constellation companies with their headquarters in the countries indicated. The USA dominates with 39 %, while Germany only operates 0.3 % of constellations.
Source: newspace.im (as at 12/2024)

the market. This economically extremely interesting area of satellite communication applications is currently completely dominated by a few European players and above all by US and Chinese companies.

Global market development and Germany's backlog

The global distribution of companies that operate satellite constellations or have constellations under development is shown in the figure above according to the headquarters of the companies. A total of 411 headquarters of satellite constellation operators are recorded in the statistics. The figures include all commercial constellation operators, including those that are up to several years behind schedule or whose activities may have ended already. Due to the highly dynamic nature of the market for satellite services, the figures fluctuate and are generally difficult to record.

However, the large discrepancy between the number of companies in Germany on the one hand, and Europe, the USA and China on the other is clearly evident. The USA leads the way with 39 % of all constellation operators, followed by China with 10 %, the UK with 8 %, Canada with 5 % and France with 4 %. Germany is far behind with a share of 0.3 %.

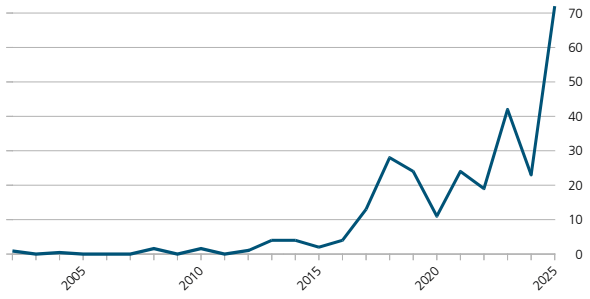
In 2023, almost 40 constellations launched their first satellites into space. In 2024, 23 constellation operators launched their first satellites and we expect even higher figures for 2025. The trend towards more satellite constellations in the future is unbroken, with the numbers increasing exponentially on average (see figure next page).

Research is the key to European space sovereignty

Over the last ten years, large satellite constellations have emerged as a crucial component of a sovereign space infrastructure. Constellations mostly consist of small satellites in Low Earth Orbits (LEOs) and act as innovation drivers that enable new applications and business models. The increasing demand for Earth observation data, fast internet and digital networks continues to lead to an increasing dependency on the associated services, which underlines their relevance for German and European sovereignty in the fields of Earth observation, communication and navigation with many application areas such as civil security, defense, climate change, telecommunications, agriculture, mobility, logistics, urban development.

Number of wordwide first launches of satellite constellations

Source: newspace.im (as at 12/2024)



Applied research at Fraunhofer plays an essential role in accelerating the commercial performance of the European space industry. With its innovative research services and products, Fraunhofer can make a decisive contribution to the rapid and cost-effective development of a German and European space infrastructure in the construction of satellite constellations. With more than 30 institutes focusing on space technologies and space applications, Fraunhofer is already represented in almost every German and European space mission with technologies ranging from innovative components to system solutions. The Fraunhofer AVIATION & SPACE Alliance bundles these activities and is the gateway to Fraunhofer technology for industry.

Fraunhofer institutes have the technology and know-how to build research infrastructures that enable industry to produce satellites in series in an agile and economical manner, including the test procedures required to qualify space systems.

On the following pages, we present our current research contributions at EMI, which are highly relevant for research on the construction of satellite constellations. With ERNST, we are successfully operating the Fraunhofer-Gesellschaft's first research satellite. In the VLEO demonstrator project, we are investigating the technological possibilities for realizing a satellite constellation in extremely low orbits. Serial manufacturability also plays a central role here. In the NeT pioneer project, we are working with industry to investigate the possibilities for the efficient and automated performance of functional and qualification tests on space systems.

Service portfolio

Hypervelocity impact of space debris and fragmentation of spacecraft during collisions

Scientific space instruments

Small satellite technology

On-board data processing of satellite data

Artificial intelligence for Earth observation

Heading into space: ERNST research satellite launched on August 16, 2024 with the Transporter 11 mission.

Successful launch of the ERNST mission

ERNST is the first satellite developed by Fraunhofer. The small satellite has been orbiting the Earth since August and provides valuable data for research.

In the summer of 2024, a particular success of Fraunhofer EMI attracted the attention of a wide audience of the Tagesschau and Tagesthemen: the launch of the ERNST research satellite. ERNST is a pioneer in several respects: the first small satellite built with Bundeswehr research grants, the first satellite developed by Fraunhofer and, what made it so prominent in the media coverage, the first European satellite with a camera payload for early missile detection on board a CubeSat measuring just $25 \times 25 \times 34$ cm^3.

After completion and passing the acceptance tests in spring 2024, ERNST was transported to its launch site at Vandenberg Space Force Base in California. The commercial launch on board a Falcon 9 launcher was made possible with funding from the German Armed Forces. Due to several postponements of the launch, an EMI employee traveled to ERNST again in California in July 2024 to refresh the batteries' charge status. On August 16, 2024, the time had finally come. With 99 other satellites on board the Transporter 11 mission, ERNST was launched into its target orbit at an altitude of 510 km.
After the second flyover, we successfully established contact with ERNST via our UHF ground station at EMI in Freiburg. Since then, the operations team has been working tirelessly to accompany the noon and midnight overflights and to command prepared task scripts. Until then, commissioning in orbit had to be completed and initial challenges had to be overcome. Since then, ERNST's full operational readiness and its ability to track a target by rotating the satellite during an overflight have been successfully tested. ERNST is now in scheduled experimental operation. In the coming years, this should demonstrate the performance of the small satellite and provide important data for early warning of missiles.

Project ERNST
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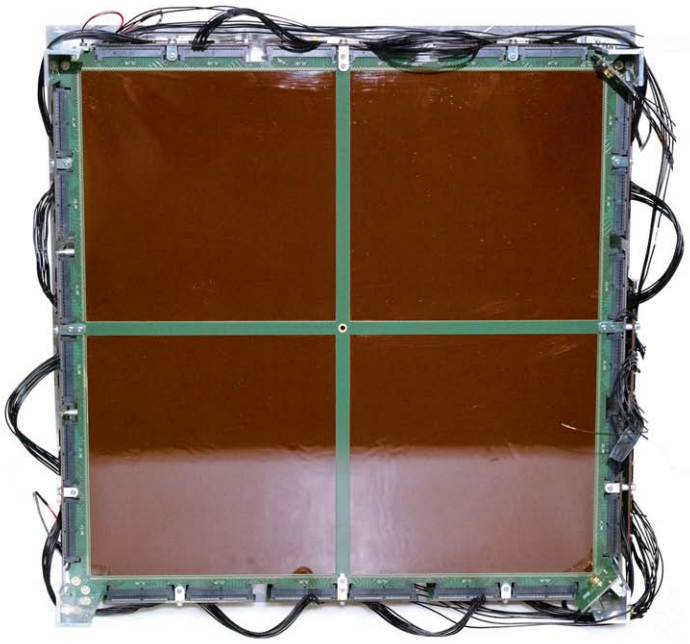
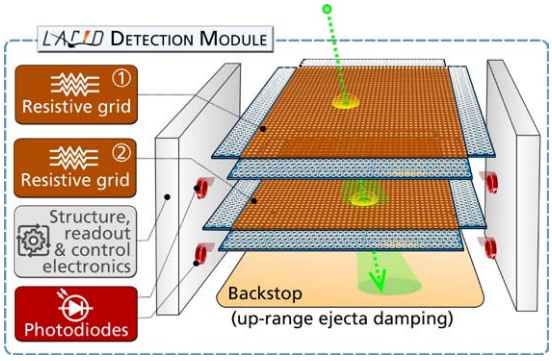
Photos: SpaceX, Fraunhofer EMI





New approach to space debris detection:
Test model and concept of the LArID impact detector.

Precise in-situ detection of space debris

Small space debris can severely damage satellites, but is difficult to observe. Fraunhofer EMI has developed a concept for ESA that records the speed, trajectory and size of tiny pieces of debris.

Space debris, human spaceflight remnants in orbit, threatens to impair the function of a satellite due to the high impact velocities of even small objects. Their small size and high energy density are not only dangerous but also the reason why they are difficult to observe. Ground-based measurements with radars and telescopes are limited to centimeter-sized objects. In-situ detectors can be used for smaller objects. Despite a long history of such detectors in orbit, their success rate is so low that space debris is one of the most unknown quantities in the orbital environment.

Fraunhofer EMI has investigated various detection concepts for the European Space Agency. The starting point for the development were ambitious requirements for the measurement accuracy, robustness and reliability of such a detector. The successfully developed concept of a "Large Area Low Resource Impact Detector", LArID, consists of two thin layers that are penetrated by a space debris particle. The upper and lower surfaces of the layers are provided with conductive paths that are only 188 µm wide and aligned perpendicular to each other. The severing of these conductive paths during the impact leads to a loss of conductivity. By measuring the time of this event and the position of the severed conductors, the speed, path and size of the particle can be traced. Additional photodiodes measure the time of appearance of the plasma flashes during the impact as a redundant measurement.

A special design feature is the modularity of the detector. The electronics are integrated into the side walls of a base unit, the combination of which allows a large detection surface to be achieved. Following successful laboratory tests, we have outlined various mission scenarios on board the ISS as well as further development on satellites. In this way, we hope to make a contribution to the detection of space debris.

LArID project
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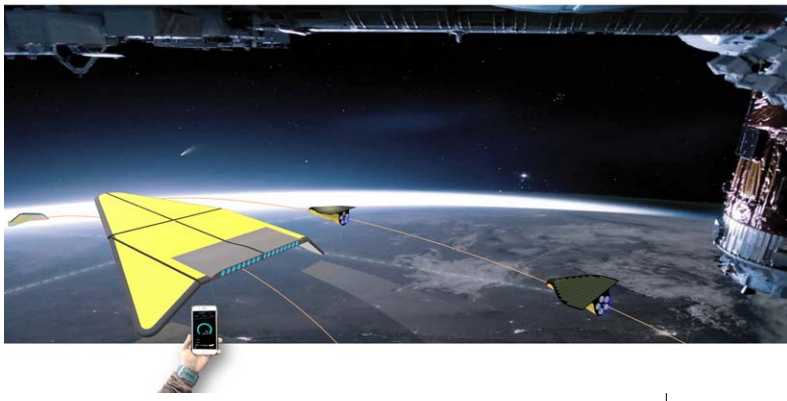
High-resolution Earth observation from Low Earth Orbits

Four Fraunhofer institutes are pooling their expertise to develop robust, sustainable and economical solutions for Earth observation and communication. A new EMI branch office is being established in Würzburg for this purpose.

Small satellites in extremely low orbits – known as Very Low Earth Orbits (VLEO) – open up completely new perspectives for high-resolution Earth observation and high-performance communication services. Due to their proximity to Earth, they provide high-resolution images and enable fast, direct connections to mobile devices – ideal for applications such as environmental monitoring, agriculture or future 6G communication networks. At the same time, they burn up naturally in the atmosphere at the end of their mission – a clear advantage in terms of sustainability.
However, VLEO is technically challenging: the residual atmosphere continuously slows down satellites, and aggressive components such as atomic oxygen attack materials. New solutions are needed to withstand these conditions – from flow-optimized designs and resistant coatings to miniaturized, robust electronics. Equally important is the cost-effective production of such satellites ready for series production so that larger constellations can be operated economically.

In the VLEO demonstrator project, funded by the Bavarian State Ministry of Economic Affairs, Energy and Regional Development, four Fraunhofer institutes are pooling their expertise: Fraunhofer EMI (small satellite technology), ISC (materials and coatings), IIS (communication systems) and IOF (Earth observation instruments). Together, they conduct research into key technologies in areas such as satellite design, attitude control systems, innovative materials and production aspects such as manufacturing processes and automated test procedures for industrial use. The focus is on production-ready, scalable solutions with short development cycles – tailored precisely to the requirements of the emerging NewSpace industry.
A central element is the establishment of the new EMI branch office in Würzburg – an up-and-coming NewSpace location in Bavaria. The aim is to strengthen the regional innovation ecosystem and facilitate access to space for small and medium-sized companies in particular. The project thus not only creates the technological basis for a new generation of satellites, but also promotes the economic use of space "made in Germany".



Small satellites in extremely low orbits: VLEO demonstrator opens the way to a new space era.
Thanks to their proximity to the Earth, VLEO satellites provide high-precision Earth observations and powerful communication services – perfect for environmental monitoring, agriculture or future 6G networks. At the end of their service life, they burn up in the atmosphere in a controlled manner, thus promoting sustainable space travel.

Challenge: aerodynamic interaction effects in VLEO orbits
In close orbits, particles in the residual atmosphere – especially atomic oxygen and molecular nitrogen – cause significant material degradation and increase drag. Simulations show these effects and help to develop material- and design-optimized satellites.

VLEO demonstrator
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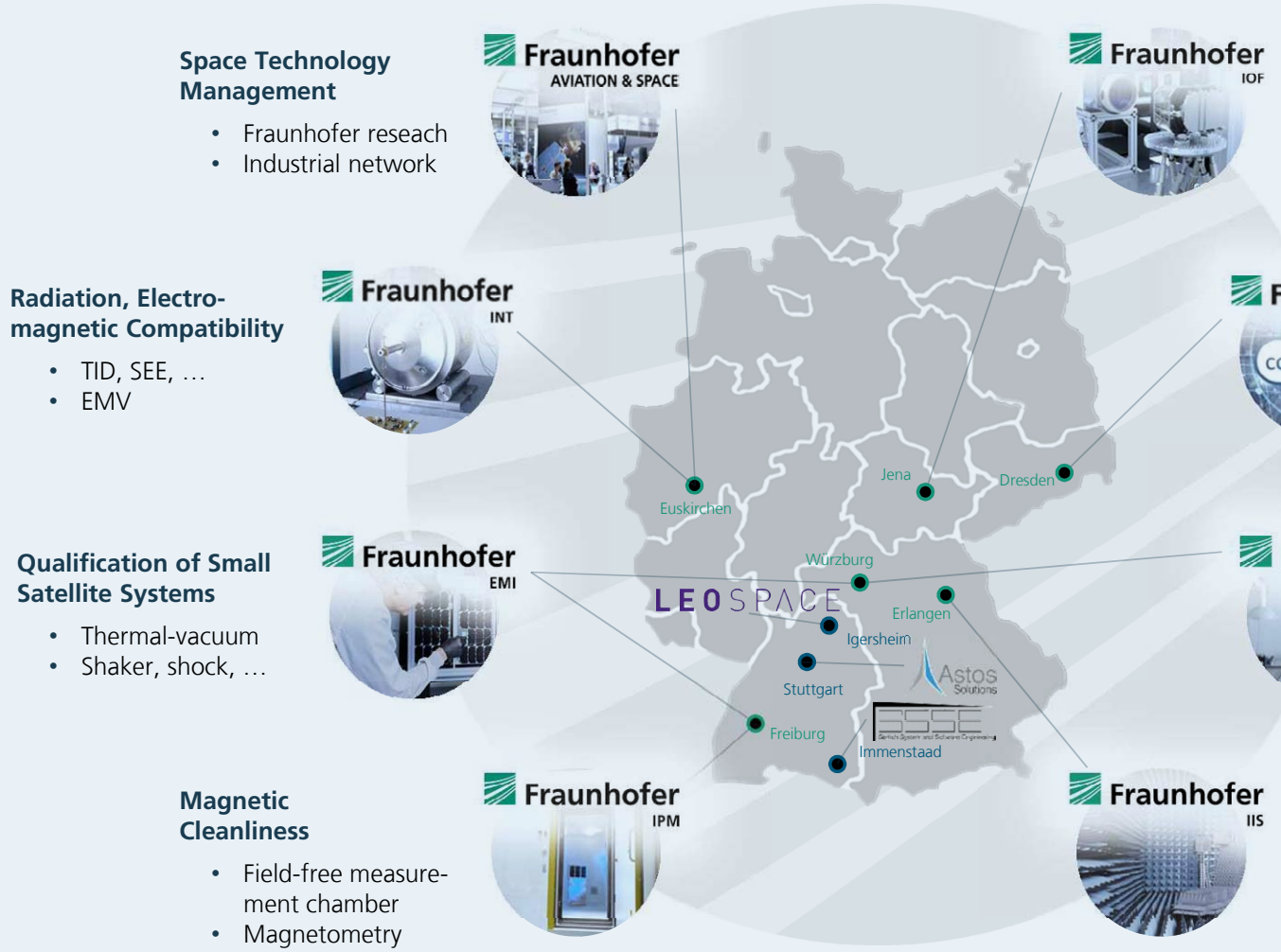
Photos: Fraunhofer EMI (3), Assembly: ESA and Fraunhofer EMI

Automated tests for NewSpace

NeT pioneer: on the way to the NewSpace test lane



Space is facing a paradigm shift: with the rise of NewSpace – i.e. the increased involvement of private sector players – the requirements for the production and testing of satellites are changing fundamentally. Instead of individual large systems, entire satellite constellations are coming to the fore, which must be manufactured and qualified efficiently, cost-effectively and in large quantities. At the same time, expectations of efficiency, flexibility and innovative strength are increasing. This is where the NeT pioneer project, coordinated by Fraunhofer EMI together with AVIATION & SPACE, comes in. Eight Fraunhofer institutes are pooling their interdisciplinary expertise to develop digitalized, automated and standardized test capacities for NewSpace technologies together with industrial partners from the space, digitalization and production sectors.

The focus is on researching innovative methods to automate and network test processes – from virtual preparation to real environmental tests in complex laboratories. The aim is to qualify space technologies faster, more efficiently and with less effort. This is crucial, as space environment tests have so far been complex, expensive and infrastructure-heavy. In the long term, the project aims to create a central, flexible production and test house for NewSpace technologies. As

Together for NewSpace: Eight Fraunhofer Institutes and industrial partners are developing automated and standardized test capacities for space in the NeT pioneer project.

Optical Precision Systems

- Optical wavefront Characterization

Digital Interoperability

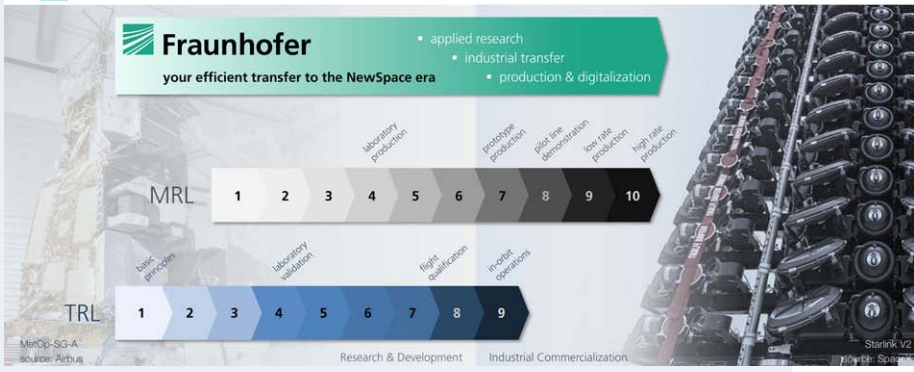
- Cooperants dataspace
- Digital standardisation

Automation and Test-as-a-Service

- Motion simulation
- Digitalization

Communication and Navigation

- Anechoic chamber
- Antenna characterization



Photos: Fraunhofer Aviation & Space, Fraunhofer EMI (2)

"Infrastructure-as-a-Service", it will offer logistics, clean rooms, integration areas, test benches and specialist knowledge in a flexible and scalable manner. This is supplemented by "Expertise-as-a-Service" with services such as design-for-testability or design-for-series production – in close cooperation with industry, on site and in efficient co-working sprints. NeT pioneer is a prime example of the Fraunhofer-Gesellschaft's practical research. With a focus on digitalization, production technologies and technology transfer, the project supports the transformation of space towards industrial series production and marketable solutions. The aim is to strengthen the economic usability of new technologies and pave the way for commercial applications. The German Space Agency at DLR is funding the pioneering project with funds from the Federal Ministry for Economic Affairs and Climate Protection (BMWK).

NeT pioneer
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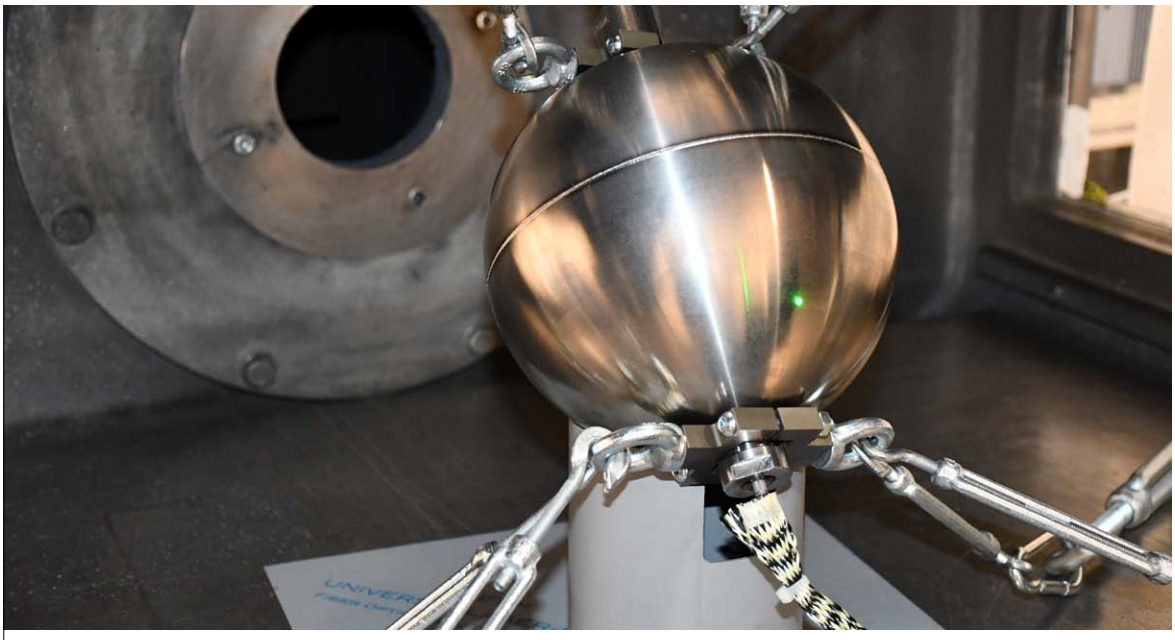
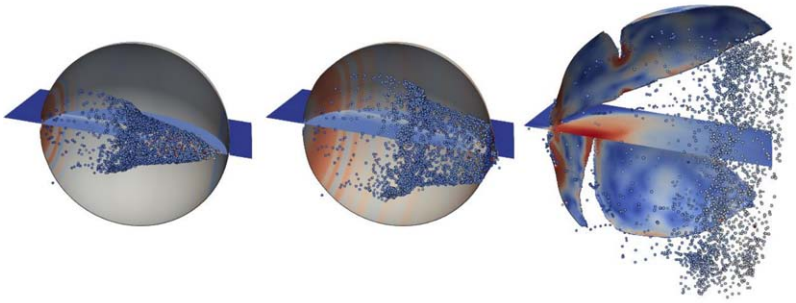


Impact tests on satellite tanks

Propellant tank explosions are a major source of space debris. Simulations help to better understand critical failure conditions.

Fragmentation events are the main source of space debris in orbit. One of the causes is the explosion of propellant tanks from decommissioned satellites and upper stages. There are regulations for passivating these tanks at the end of the mission by releasing the internal pressure. In the 2024 experiment, we investigated the critical residual pressure and impact conditions of titanium space tanks, in which the hypervelocity impact of a particle turns into a catastrophic explosion. Supplemented by extensive simulations, the critical failure conditions are to be derived.



Project: ESA Impact-Safe Tank Pressure Level

Dr. Martin Schimmerohn
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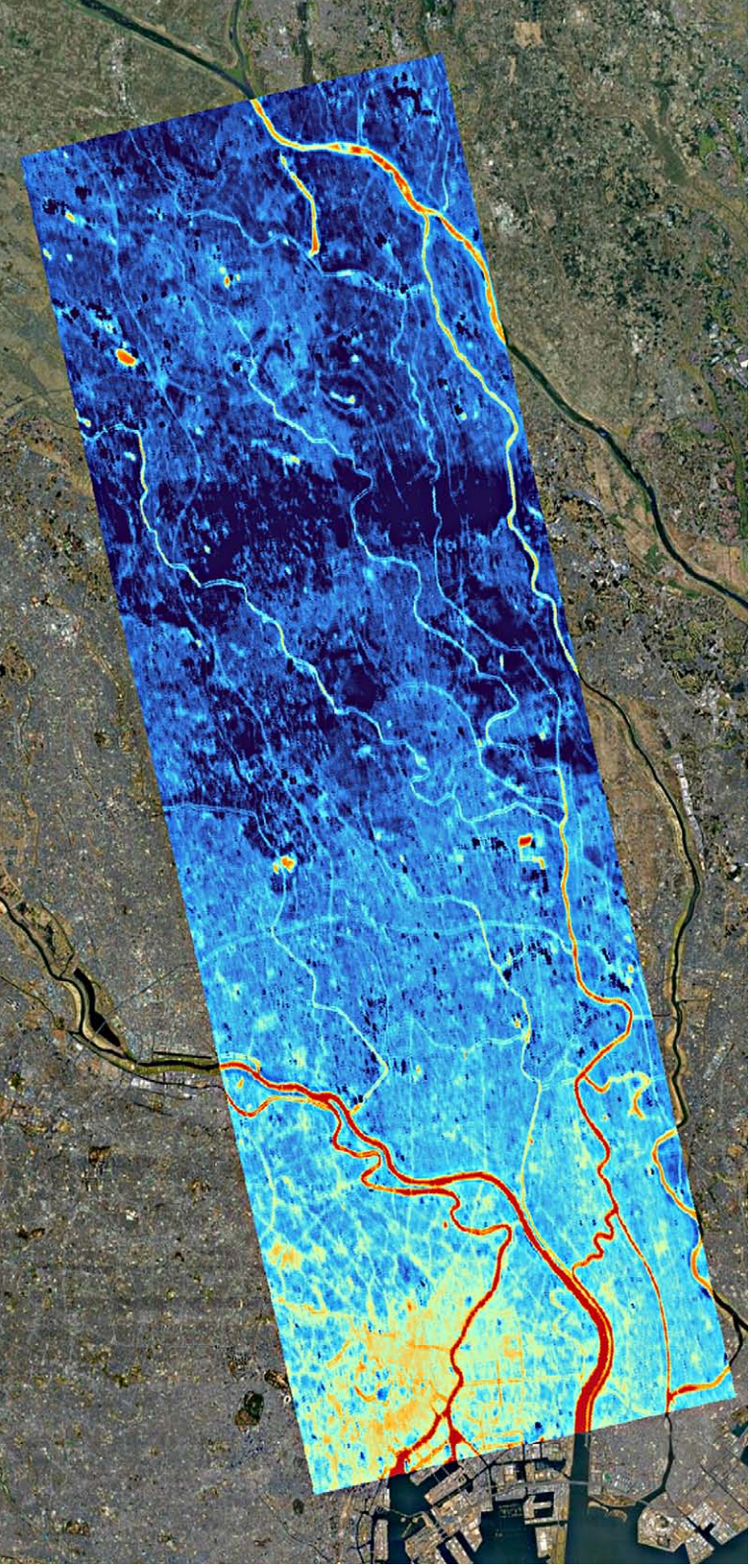
Prof. Dr. Frank Schäfer is the new spokesperson for the SPACE division of Fraunhofer AVIATION & SPACE

In August 2024, Prof. Dr. Frank Schäfer was elected the new SPACE spokesperson by representatives of the approximately 30 Fraunhofer institutes in the SPACE division of Fraunhofer AVIATION & SPACE. Frank Schäfer succeeds Prof. Dr. Dr. Michael Lauster, who has shaped the former Fraunhofer Alliance SPACE since 2014 and Fraunhofer AVIATION & SPACE as SPACE spokesperson since 2021. Additionally, Rainer Wansch from Fraunhofer IIS has been elected as the new deputy SPACE spokesperson.

Photos: Fraunhofer EMI (4), constellr GmbH



Tokyo at night: The first official infrared image from the SkyBee-1 satellite shows the temperature distribution in and around Tokyo in January 2025. Processing on board the satellite is carried out by a data processing unit built at Fraunhofer EMI.

Kick-off for the HiVE satellite constellation

EMI spin-off constellr: successful launch and first images from "SkyBee-1".

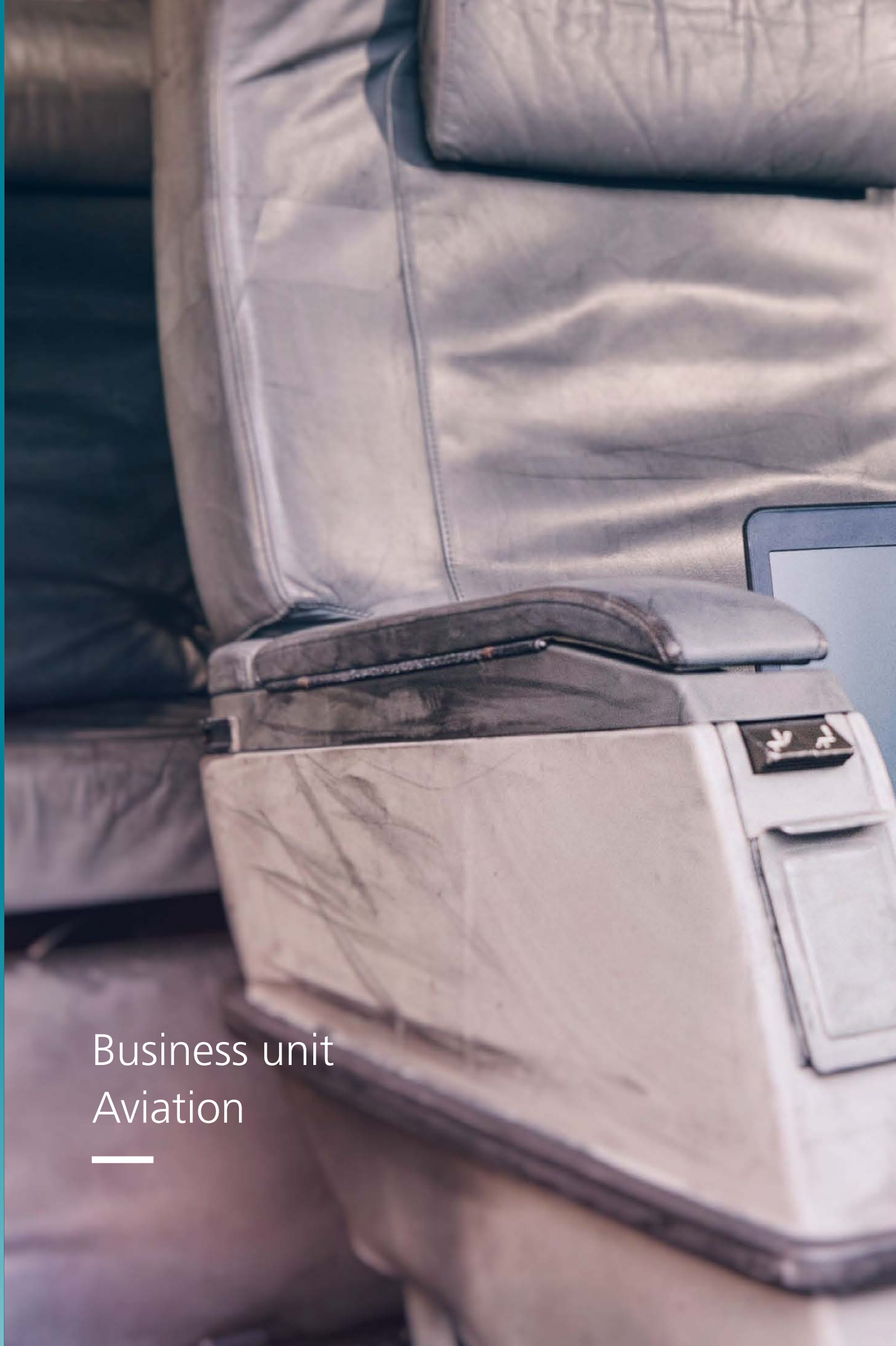
On January 14, 2025, the "SkyBee-1" satellite was launched into space as part of SpaceX's "Transporter-12" mission. The launch was successful and shortly afterwards the satellite took its first infrared image over Tokyo.

"SkyBee-1" is the first of up to 30 satellites in the "High-Precision Versatile Ecosphere" (HiVE) constellation, which EMI spin-off constellr is currently building. constellr wants to use HiVE to measure the surface temperature precisely and with high resolution. "SkyBee-2" will follow this year, and five satellites should complete the first expansion stage by 2028.

EMI is supplying the Data Processing Unit (DPU) as the central payload computer for these satellites.

Business unit Space
Prof. Dr. Frank Schäfer, frank.schaefer@emi.fraunhofer.de
→ emi.fraunhofer.de/raumfahrt

BUSINESS UNIT Aviation



Business unit Aviation

Lithium batteries on board: how great is the danger from cell phones and laptops?

Fraunhofer EMI is working with Airbus to research the risks of lithium batteries in aviation. Various laptops, tablets and smartphones were heated in the Fraunhofer EMI battery test center in order to obtain data on smoke propagation. These findings are incorporated into simulations that reproduce the behavior of smoke and fire in realistic aircraft environments.

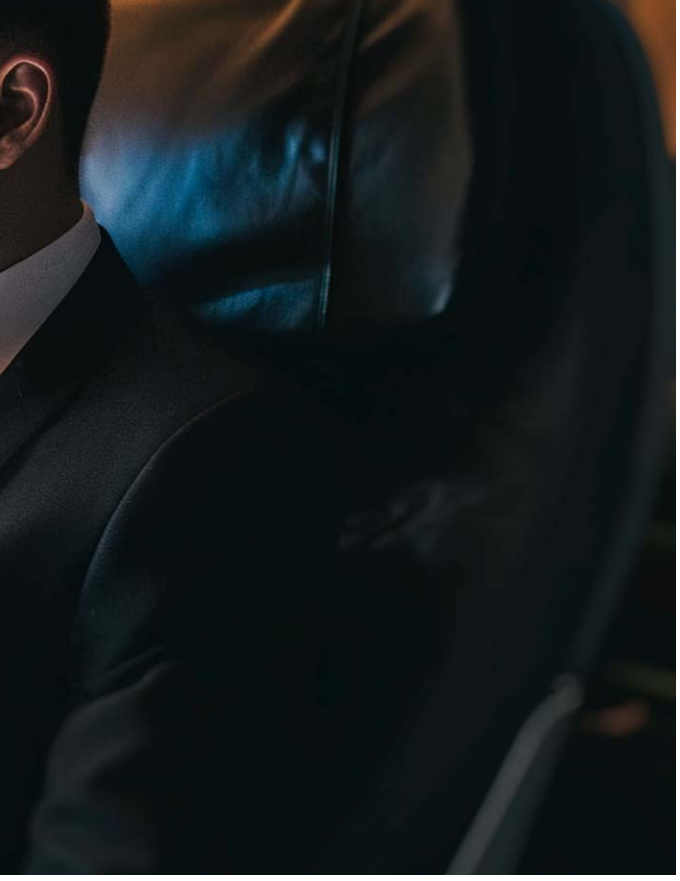
Photo: Fraunhofer EMI

Battery safety in aviation

Whether in personal devices or as a power source for future electric aircraft, the safety of batteries is a critical factor in aviation. The increasing number of incidents shows how great the risks are.

Fraunhofer EMI is working with Airbus and EASA on innovative solutions to prevent battery fires and make aviation safer.

By **Dr. Michael May**



Safe use on board: Together with the Fraunhofer Institute for Building Physics IBP and Airbus, Fraunhofer EMI is researching the dangers of battery fires in modern smartphones or tablets on planes.

Thermal runaway: Why battery fires in airplanes are particularly dangerous

In recent years, the number of incidents involving batteries catching fire in home storage units or electric cars has risen alarmingly. These incidents are often due to production errors, improper handling or overcharging and result not only in material damage but also in risks to personal safety. This phenomenon, also known as "thermal runaway", which occurs particularly in lithium-ion batteries, is critical and can lead to dangerous situations. It describes an uncontrolled rise in temperature in the battery cell that can trigger a chain reaction, causing the battery to overheat, burn or even explode. This issue is particularly relevant in aviation, as a battery fire in an aircraft can have catastrophic consequences. The confined space in the cabin, limited fire-fighting resources and long flight times to the nearest airport make fires in airplanes particularly dangerous. The effects of a fire in the air include danger to passengers and crew and the possibility of loss of control of the aircraft. It is therefore crucial to understand the risks of thermal runaway and the likelihood of occurrence in order to derive appropriate safety measures to ensure safety in aviation.

How dangerous are risk factor personal electronic devices?

Every passenger carries one or more personal electronic devices such as cell phones, tablets or notebooks. These devices often contain lithium-ion batteries, which can thermally runaway if damaged, overheated or faulty. An example of the risks of smartphone batteries occurred in 2016, when the FAA (Federal Aviation Administration) banned Samsung Galaxy Note 7 cell phones due to reports of overheating and fires. After numerous incidents of the devices bursting into flames or exploding, Samsung initiated a global recall. The FAA then issued a regulation prohibiting passengers from bringing the Galaxy Note 7 on board airplanes. This heightened concern about the safety of lithium-ion batteries in portable devices.
This incident highlights the need to raise safety standards for batteries in portable electronic devices. This includes raising passenger awareness of potential risks to ensure safety on board.

Together with the Fraunhofer Institute for Building Physics IBP and Airbus, Fraunhofer EMI is investigating the risks posed by battery fires in modern smartphones or tablets on board aircraft. This research project, called LOKI-PED, is funded by the European Union Safety Agency (EASA).

Photo: WS Studio 1985 / stock.adobe.com

Using state-of-the-art X-ray technology and simulations, Fraunhofer EMI is researching the behavior of high-performance batteries during thermal runaway – a decisive step towards safe and powerful energy storage for all-electric flight.

The future: (hybrid) electric propulsion

The climate-neutral aviation of the future will be significantly shaped by technological innovations, in particular hybrid-electric and all-electric propulsion systems. These propulsion systems are crucial for achieving the ambitious goals of Flightpath 2050, which aims to reduce CO_2 emissions from aviation by up to 75 %. In view of the growing challenges of climate change and the need to minimize the environmental impact of aviation, hybrid-electric engines offer a promising solution. They combine the efficiency of conventional engines with megawatt-class electric drives. Fully electric drives go one step further by enabling emission-free mobility. These developments are not only technologically fascinating, but also necessary to create a sustainable aviation industry that meets the requirements of the future.

Megawatt drives in aircraft: enabling change with batteries

Electric flight with megawatt-class drives poses a considerable challenge for battery technology, as the required energy density, weight efficiency and charging times far exceed the capacities currently available. For the realization of all-electric aircraft that offer greater ranges and payloads, batteries must achieve an energy density that is far higher than that of today's lithium-ion batteries.

In addition to issues of weight efficiency and charging times, the service life and safety of these high-performance batteries pose major challenges for research and development.

With its combination of outstanding technical test facilities for investigating the thermal runaway of large batteries, including the ability to look inside the battery during thermal runaway using imaging X-ray techniques, and its expertise in simulating the thermal runaway of battery cells, modules and packs, Fraunhofer EMI is ideally positioned to support the aviation industry on the road to electric flight.

The aviation industry benefits from the expertise of the scientists at Fraunhofer EMI, which has been built up over many years in the context of the mobility transition. A first reference project in which this knowledge is being transferred to aviation is the HYDRO project funded by the Federal Ministry of Economic Affairs and Climate Action as part of the German government's aviation research program Lufo VI-3. As part of this project, EMI scientists are working with engineers from Airbus Helicopters to investigate the safest way to integrate large batteries for an electric motor into a helicopter.

Photos: Fraunhofer EMI (using Midjourney), Fraunhofer EMI

Transferring knowledge from the automotive industry to aviation

Fraunhofer EMI plays a crucial role in supporting the aviation industry in evaluating and improving the safety of batteries. Given the challenges associated with the thermal runaway of lithium-ion batteries, it is essential to develop robust safety standards and protocols. Fraunhofer EMI's expertise in studying thermal runaway and the ability to use innovative imaging techniques to gain deeper insights into battery technology enables potential risks to be identified and minimized at an early stage. Through research projects such as LOKI-PED and the cooperation with Airbus Helicopters as part of the HYDRO project, the knowledge and experience gained in the automotive industry is being transferred to aviation. This not only improves the safety standards for batteries in aviation, but also contributes to the development of efficient solutions for future climate-neutral aviation. The advanced technologies and methods used at Fraunhofer EMI are key to supporting and sustainably transforming the aviation industry on the path to safe, megawatt-class electric propulsion systems.

Battery research at all levels: From cell behavior to system integration, Fraunhofer EMI researches the safety and performance of batteries. Thermal processes are analyzed using state-of-the-art test procedures, imaging technologies and simulations.

"A battery by definition is a collection of cells. So the cell is a little can of chemicals. And the challenge is taking a very high-energy cell, and a large number of them, and combining them safely into a large battery."

Elon Musk

Service portfolio

Analysis and optimization of aircraft structures under impact from hail, debris and bird strike

Acceleration tests for seats, cabin structures, etc.

Battery safety: for energy storage systems and cabin devices

Characterization of materials, testing of structures, components and joints

Modelling and optimization of lightweight structures

Airbus PioneerLab, the new research platform for twin-turbine helicopters

Safe integration of battery systems into a helicopter

Fraunhofer EMI is researching the safety of high-voltage battery systems under crash loads and thermal runaway.

Within the joint project HYDRO, Airbus Helicopters replaces one of two engines in its PioneerLab technology demonstration helicopter by an electric drive train. Fraunhofer EMI supports these activities with investigating the high-voltage battery system under crash loadings and thermal runaway conditions. The project is funded by the Federal Ministry for Economic Affairs and Climate Action based on a resolution of the German Bundestag within the LuFo VI-3 program. These research activities are the basis for future electric or hybrid-electric helicopter concepts, which will enable a reduction in fuel consumption and greenhouse gas emissions.

Based on its extensive knowledge in automotive battery safety, the battery team at Fraunhofer EMI, in close cooperation with the engineers at Airbus Helicopters, will elaborate reliable strategies for the safe integration of battery systems in future helicopter systems.
Therefore, the battery test team will conduct abuse tests on module and cell level covering both crash and thermal runaway conditions. These highly-instrumented tests will enrich the knowledge of the behaviour of the battery system under abnormal conditions. Furthermore, the battery simulation team will build up simulation models for both crash and thermal runaway. These simulation models, validated by the inhouse test data, will be used for design optimization of hazard mitigation means and risk analysis studies. Thus, Fraunhofer EMI supports the safe integration of the battery system into the flying platforms such as the Airbus PioneerLab.

Project HYDRO
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Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Test setup:
Mockup of an Airbus A320.

Laptop fire tests in aircraft cabin

Investigation of fire and smoke risks from lithium batteries in aircraft.

In the LOKI-PED (Lithium batteries in pOrtable electronic devices – risK of fIre and smoke) project, researchers at Fraunhofer EMI and Fraunhofer IBP are collaborating with Airbus to investigate and assess the smoke and fire risks associated with lithium batteries in portable electronic devices (PEDs) in cabins and cockpits. The project is supported by the European Union Aviation Safety Agency (EASA) and financed by the European Union's Horizon Europe program.

In 2024, cabin fire tests with laptops took place at the Fraunhofer EMI site in Efringen-Kirchen. The thermal runaway of laptops was investigated in a real cabin scenario under realistic ventilation conditions. The tests are conducted in a ventilated A320 single aisle mockup. Laptops with nine cells were placed in a metal box at five different locations in the mockup: on the floor, on seats and in the overhead compartment. During the tests, the amount and composition of the vent gases as well as the temperatures in the cabin were analyzed.

Project LOKI-PED
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Fire test: Eight subsequent snapshots of test V31 show venting events with strong jet flames (snapshots 1 5), explosions (snapshot 7), little fire (snapshots 3 4 6 8) and smoldering (snapshot 2). Although the cabin is ventilated with 60 l/s of fresh air, a reduction in visibility over time can be noted. Please note that this scenario resembles a worst-case scenario, without human intervention. In a real scenario, a flight attendant would have fought the fire at first notice.

Photos: AIRBUS, Fraunhofer EMI (10)

2024 in retrospect

AIRTAXI World Congress

In November 2024, London was the venue for the AIRTAXI World Congress, which took place for the fourth time. The congress offered the opportunity for numerous pre-organized B2B meetings, where stakeholders from various sectors such as air taxi manufacturers, airlines, fleet operators, investors, airports, vertiports and regulatory authorities came into contact with each other. Fraunhofer EMI was also represented at the congress, making exciting contacts in the B2B meetings and gaining valuable insights into current trends and developments in the field of advanced air mobility.

Simon Holz, LOKI-PED project manager, and Michael May, Head of business unit Aviation.

Exchange with international industry and academia

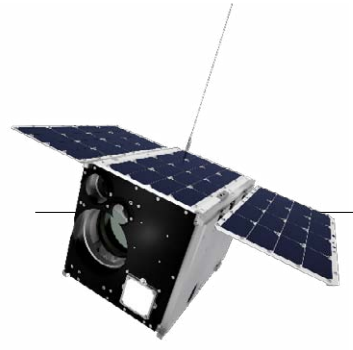
Fraunhofer EMI was represented at the AIAA SciTech Forum by Michael May and Simon Holz. Among others, Electra shared its vision on hybrid-electric flight. The results of the European research program Clean Aviation were outlined in special sessions focusing on future aircraft propulsion. Saab Aeronautics featured the Handbook for Development of Simulation Models. Fraunhofer EMI contributed with the presentation "Portable Electronic Devices in Cabin and Cockpit – Analysis of Hazards".

AIAA AVIATION Forum Las Vegas

In July 2024, the American Institute of Aeronautics and Astronautics (AIAA) hosted the AIAA AVIATION Forum in Las Vegas, Nevada. The AIAA AVIATION Forum is one of the largest scientific conferences in the field of aeronautical engineering.

Fraunhofer EMI presented two contributions to the development of a topology-optimized, additively manufactured metallic structural component for aviation, which was designed, optimized, printed and tested at EMI as part of the large-scale research project Clean Sky 2, in cooperation with SAAB Aerostructures.

Metal 3D printing for aviation: light, stable and efficient. The production technology offers numerous advantages: lower weight, high mechanical strength and optimized material usage.



International Aerospace Exhibition: Additive manufactured component and small satellite ERNST

At the last International Aerospace Exhibition ILA in Berlin (June 5-9, 2024), Fraunhofer EMI participated in a joint stand of the Fraunhofer AVIATION and SPACE Alliance and presented the small satellite ERNST as well as a 3D-printed metallic structural component for a cargo door, which was developed in cooperation with SAAB as part of Clean Sky 2 .

Business unit Aviation
Dr. Michael May, michael.may@emi.fraunhofer.de
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Sustainability Center Freiburg

Sustainability Center Freiburg

Floating PV: using standing water for photovoltaics

The FPV4Resilience project is researching how floating photovoltaic systems can be operated in an environmentally friendly and energy-efficient manner. Investigations on three lakes show: Optimized land use can improve sustainable use without significantly affecting ecosystems. The data obtained enables more precise simulations that will promote more economical FPV projects in the future.

Photo: ungvar / stock.adobe.com

Applying sustainability research

LEISTUNGSZENTRUM NACHHALTIGKEIT FREIBURG

Five Freiburg Fraunhofer institutes – EMI, IAF, IPM, ISE and IWM – and the University of Freiburg work together in the Sustainability Center Freiburg (LZN). The aim is to promote excellent research and develop sustainable technologies. Their results should benefit the economy and society and thus promote sustainable development.

New funding phase from 2025 to 2027
A new funding phase makes it possible to continue advancing sustainable technologies through research funding and transfer activities.

Clear priorities for a sharpened profile
For the proposal for a new funding phase of the LZN, Fraunhofer EMI dealt intensively with the term "technological sustainability". The LZN is now pursuing three research priorities, each of which is divided into three subject areas. A moderated exchange between LZN researchers on the respective topics takes place in specialist communities.

Program diversity between research and transfer
The new program is based on proven and new funding measures. It supports three research collaborations on technologies with varying degrees of maturity. It also promotes transfer through spin-offs, licensing, standardization and further training. Two new annual "transfer projects" serve as a link between research and application. These projects are aimed at technologies that are about to enter the market and are intended to provide the final impetus for their use in industry and society.

Main research areas

Sustainable energy systems

The "sustainable energy systems" field conducts research into technologies and transformation processes for the energy transition. A particular focus here is on "sustainable and resilient power supply", "sustainable and safe batteries" and "hydrogen technologies".

Sustainable materials, components and products

To promote circularity strategies, value-preserving processes and technologies, the LZN is researching "sustainable materials, components and products". Important topics here are "Digitalization and artificial intelligence for circular value creation", "R-technologies such as reuse, repair, recycling for components and products" and "Increasing the energy and resource efficiency of production processes".

Resilient infrastructure and living spaces

In order to make cities and regions crisis-proof and safe in the long term, the LZN supports research projects on "resilient infrastructure and living spaces". This is defined along the lines of "Traffic safety research", "holistic analyses, modelling and evaluation of critical infrastructure and living spaces" and "resilience management in organizations (companies, cities, municipalities)".

Research for the market: The FoTraBox project develops strategies and methods to align research with the market at an early stage.

Bringing excellent research to the market

FoTraBox project – strategies for improving the market opportunities of engineering research.

A common problem in science: research often ignores the needs of industry and business. At the same time, researchers have to adapt to changing conditions with regard to the possibilities of public project tenders and the profitability of their research in the form of industry contracts, license income or spin-offs. These factors have a significant impact on the quality of their work.

A bridge between research and the market
The Sustainability Center Freiburg's FoTraBox research project aims to close this gap. The aim is to orient research towards the market at an early stage. To this end, the project is developing a methodological toolbox that offers tried-and-tested methods. This "research transfer box" is intended to help researchers independently identify market requirements and tailor their work to them.

Funding and implementation
The project is funded by the Federal Ministry of Education and Research (BMBF). It runs from November 1, 2024 to November 30, 2025 and is being implemented by the Sustainability Center Freiburg together with the consulting agency "machn" of Grünhof 3000 GmbH.

FoTraBox project
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Photos: Fraunhofer EMI using Midjourney

Research projects at the LZN

Floating photovoltaics

Increased climate resilience of standing waters through yield-optimized floating photovoltaics.

In the FPV4Resilience project, Fraunhofer ISE and the Chair of Hydrology at the University of Freiburg researched how floating photovoltaic systems can be operated in harmony with nature and still be as energy-efficient as possible.

To this end, photovoltaic systems in different configurations were examined on three different lakes and the effects on the ecosystems of the lakes were analyzed using various parameters. The studies show that the water quality remains unchanged at all three locations despite the different system designs and sizes. In the German lake, turbidity even decreased as mussels colonize the substructure of the solar plant and filter the water. These results help project planners to design systems in such a way that they hardly affect or even improve water quality.

Floating PV (FPV) is a comparatively new technology in Europe with considerable global potential. Here, the PV modules are placed floating on substructures on the water.
European lakes will experience temperature changes as a result of climate change. This can lead to severe impairment and in some cases even complete loss of aquatic ecosystems, which significantly influences the function of lakes as climate regulators.
In order to investigate the effects of FPV systems on lakes, wind reduction, shading effects and water quality (water temperature, oxygen saturation, nitrate levels, turbidity) were observed.
It was found that all parameters are highly dependent on the installed FPV system design. However, the changes caused by the systems do not suggest any serious consequences for the ecosystems.

Based on the measurement data collected, a GLM-AED2 model setup was created for all the lakes studied, which can simulate the effects of the FPV systems in detail. This model provides a valuable basis for the planning and optimization of FPV systems. In the future, hydrodynamic modeling should help to replace intensive monitoring procedures and thus make FPV projects more economical.

Investigated FPV system on Lac de Toules in the Swiss Valais: The system, which is the size of a soccer pitch and has a nominal output of 0.45 MWp, is installed on a water reservoir.

FPV4Resilience project
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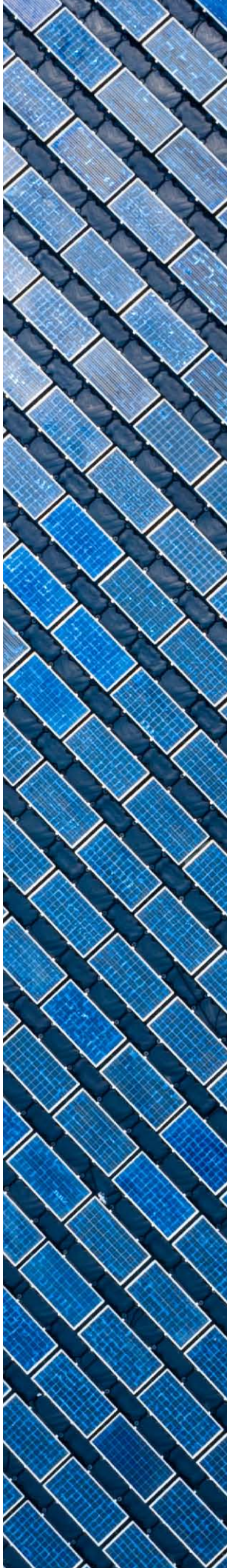

Barrier-free cities: Monitoring and efficiency analysis

Project SAVIS – Creating the basis for accident-free cities of tomorrow with precise sensors and simulation-based hazard analyses.

Who are our cities built for? People with special mobility requirements in particular will often ask themselves why their needs are rarely taken into account in urban planning measures. This omission often results in serious obstacles to mobility, such as non-accessible planning elements, poor visibility of vulnerable road users or inadequate maintenance of infrastructure elements, which impairs inclusive mobility for all road users. To counteract this, precise analysis methods are needed to systematically record and evaluate barrier-free infrastructure.

Fraunhofer EMI is providing a remedy: the innovative SAVIS (System Analysis for Traffic Safety and Inclusive Urban Mobility) pilot project, supported by the Sustainability Center Freiburg, is working to identify potential hazards and barriers in the urban landscape. Precise sensor technologies, stereo matching methods and simulation-based safety assessments are used for this purpose. The results will be used to plan alternative infrastructure adaptations.

As part of the project, methods for creating depth maps and 3D models will be developed and tested and a comprehensive data basis for optimizing urban mobility will be created. On this basis, recommendations for action for inclusive mobility solutions can be drawn up in order to further sharpen expertise in the field of road safety and barrier-free mobility as a whole. The SAVIS research pilot project is part of the "Resilient Infrastructure and Living Spaces" research focus of the Sustainability Center Freiburg by addressing the topics of "Road Safety Research" and "Holistic Analysis, Modeling and Evaluation of Critical Infrastructure and Living Spaces". It is planned to involve associated partners from industry and administration at an early stage in order to ensure user-centered technology development.

Barrier-free cities for all: The SAVIS research project is developing innovative analysis methods to identify obstacles to mobility and promote inclusive urban planning.

SAVIS project
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Photos: Fraunhofer ISE, AU USAnakul+ / stock.adobe.com, Fraunhofer EMI using Dall-E

Excellent research for the market: The FoTraBox project is developing strategies and methods to make engineering research market-oriented at an early stage

INATECH
Institute for Sustainable Technical Systems
www.inatech.de

INATECH: developing sustainable solutions for the future today

Establishing sustainability as a guiding principle in the development of technical systems.

Engineering science for greater sustainability
The "Institute for Sustainable Technical Systems" (INATECH) researches and develops sustainable engineering solutions. The focus is on sustainable materials, energy systems and resilience. INATECH is the engineering core of the LZN.

Focus on the needs of current and future generations
Together with research partners from the public sector and industry, INATECH researches methods, models, materials, technologies and demonstrators. It develops sustainable technical systems that meet needs with the smallest possible ecological footprint.

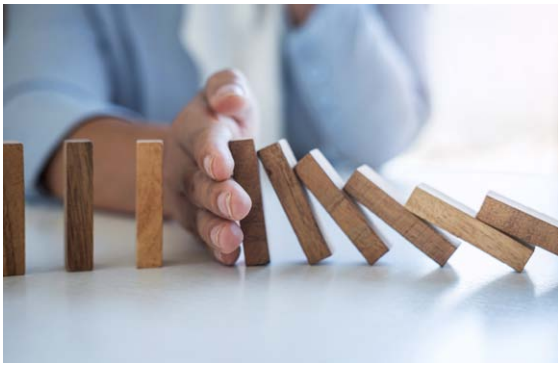
From basic research to industrial application
The cooperation between Fraunhofer and the university pools scientific and technological expertise: The entire spectrum from basic research to industrial application is covered. INATECH is an institute at the Faculty of Engineering at the University of Freiburg.

Norms and standards for future-oriented technologies

Project "Business continuity and resilience of SMEs including KRITIS"

In accordance with the "Norms and Standards" transfer pathway, the LZN supports researchers in developing standards in newly emerging fields of technology as part of committee work and expert commissions. At EMI, a team led by Prof. Alexander Stolz and Dr. Kai Fischer was funded on the topic of business continuity and resilience.

The funding enabled the business unit "Security & Resilience" to answer fundamental questions about participation in beneficial committees and working groups. They were able to join relevant committees, alliances and associations in order to help shape future technological trends in terms of quality and sustainability.



Workshop: Solar power plants learn to float

On April 11, 2024, the LZN organized an industry workshop on the funded pilot project FPV4Resilience under the direction of Dr. Karolina Baltins, Fraunhofer ISE. Representatives from research, industry and administration exchanged views on floating PV systems and examined the topic from various perspectives. The subsequent panel discussion "Is ecological floating PV possible?" focused on ecological issues. Finally, the participants discussed the ecological effects, technical hurdles and economic challenges for the further expansion of such systems in groups. Among other things, they discussed how the installation should differ depending on the type of water body and how adaptive monitoring of the systems can be implemented.

High-quality carbon fiber tape recycling

From 2022 to 2024, the LZN demonstrator project WEiteR researched strategies for the sustainable handling of carbon fiber-reinforced pressure vessels (CFRP tanks) after their initial use. Ageing and recycling tests on the materials of a hydrogen pressure tank showed that influences such as temperature, moisture or UV radiation only slightly affect the mechanical properties. These results open up promising prospects for the further use of such tanks as part of value-preserving recycling. The findings on the longevity of the hydrogen tanks form the basis for developing scenarios for the reuse, further use and recovery of carbon fibers.

Sustainability Center Freiburg
Christiane Felder, christiane.felder@emi.fraunhofer.de
Dr. Juri Lienert, juri.lienert@emi.fraunhofer.de
→ www.leistungszentrum-nachhaltigkeit.de

Institute overview

Administration, personnel, publications at a glance

Photos: Fraunhofer EMI (2)

← **Training at Fraunhofer EMI**
Precision mechanics, electronics, media design, and dual studies: EMI offers numerous training opportunities. Currently, 27 people are being trained.

The institute in figures

395
Employees

- 42 % Scientific staff in specialist departments
- 13 % Non-scientific staff in specialist departments
- 29 % Management and infrastructure
- 10 % Research assistants, interns
- 7 % Apprentices, DHBW students

Total personnel all locations.

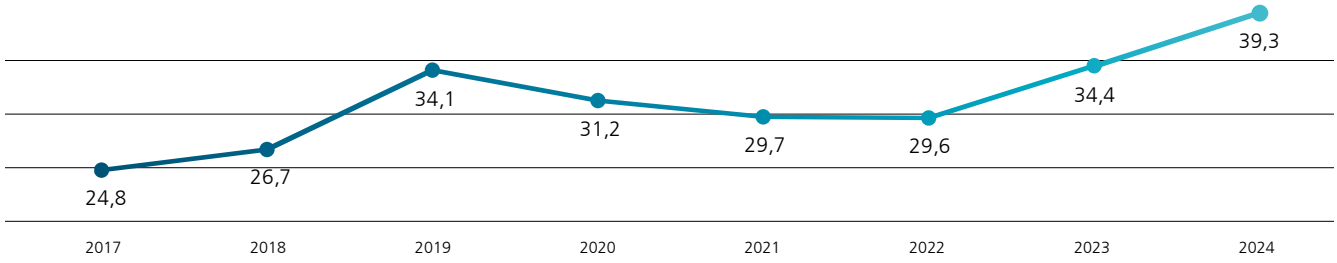
Personnel by location:

229	127	25	11	3
Freiburg	Efringen-Kirchen	Kandern	Berlin	Würzburg

Finances

39.3 million total budget	21.5 million external funding	125 externally funded projects

Total budget in € million



Science

99 Publications with peer review	100 Lectures	44 Courses
5 Patents	10 Doctorates	25 Bachelor's and Master's theses

Scientific cooperation

University of Freiburg · University of Oxford · NTU Singapore · Cranfield University

MIT · Cluster Micro TEC Südwest · Center for Security · Cluster Electric Mobility Southwest

Personnel

At the end of 2024, a total of 395 people were employed at Fraunhofer EMI: 329 permanent staff, 27 apprentices and DHBW students and 39 research assistants, interns and trainees.

Of the permanent staff, 215 worked directly in research and 114 in management and infrastructure. The proportion of female permanent staff was 25.5 percent.

Of the permanent staff, 55.9% were employed at the Freiburg location, 33.5% at the Efringen-Kirchen location, 7.6% at the Kandern location, 2.4 % at the Berlin location and 0.6 % at the Würzburg location.

Of the total of 27 trainees, 15 were employed in the areas of precision mechanics, electronics and media design. 12 employees were employed at Fraunhofer EMI for the purpose of their vocational training or as part of their studies at the Baden-Württemberg Cooperative State University (DHBW).

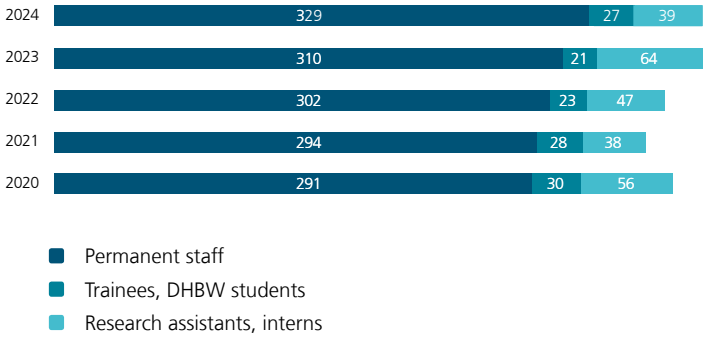
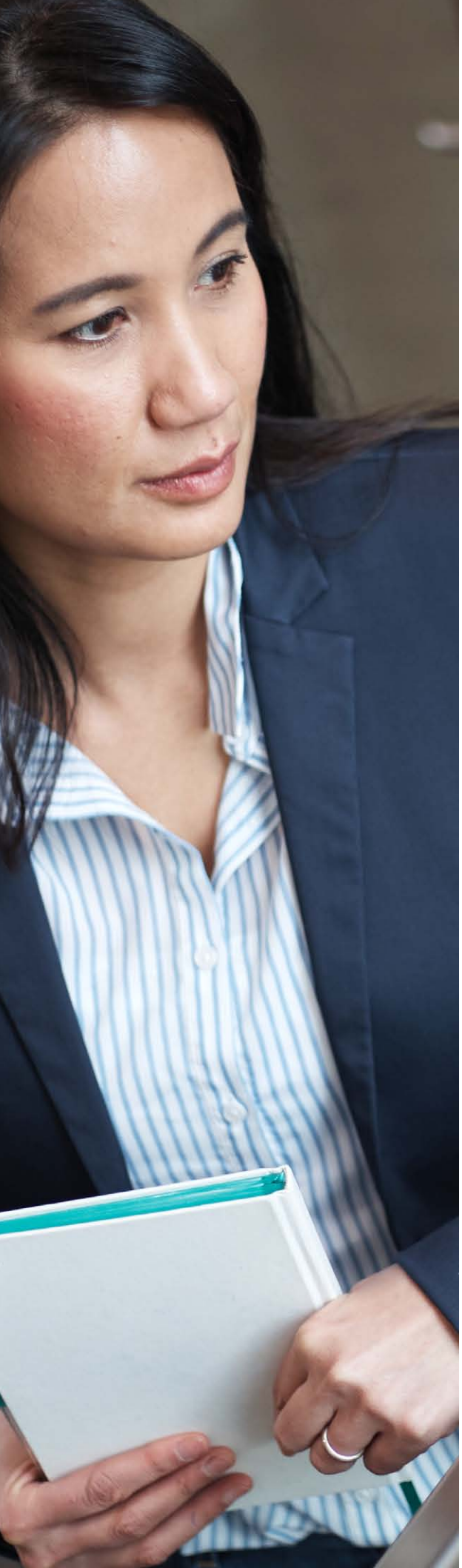


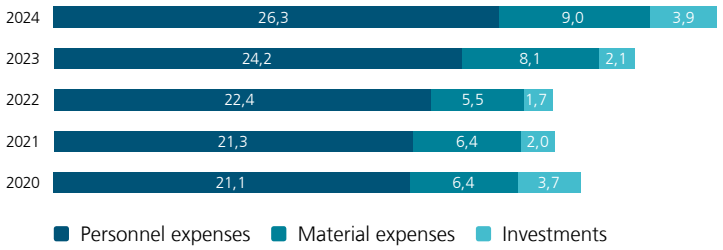
Photo: Fraunhofer EMI



Finances

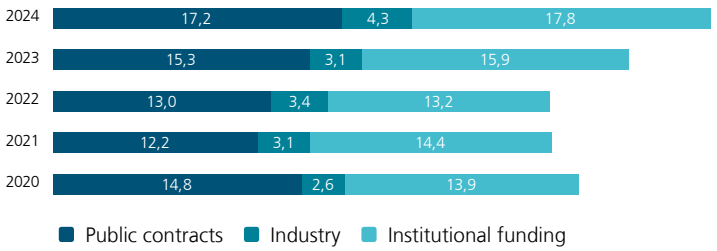
Total budget expenditure

in millions of euros

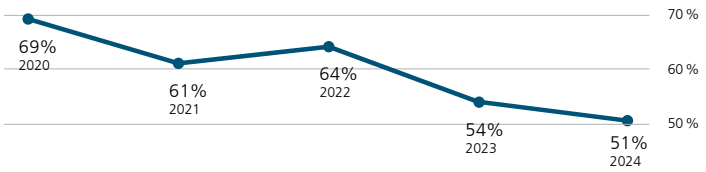


Total budget revenue

in millions of euros



The total budget of Fraunhofer EMI increased by 14.3 % compared to the previous year (from 34.4 to 39.3 million euros). The operating budget increased by 9.6 % (from 32.2 to 35.3 million euros). There was growth in all general income areas. The share of BMVg funding amounts to 51 % (previous year: 54 %).



BMVg share in relation to the total budget, in percent.

Advisory board 2024

The Advisory board supports the institute's management in an advisory capacity. It promotes the institute's contacts with organizations and with industry.

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

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

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

Rainer Hoffmann
CEO carhs.training GmbH, Alzenau

Ministerial councilor Maik Kammermann
Head of National Research and Technology, Research and Innovation Hub, Planning Division, Federal Ministry of Defence (BMVg), Bonn

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

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
Head of Combat Division, Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw), Koblenz

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

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

Dr. Isabel Thielen
Management Thielen Business Coaching GmbH, Munich

The Fraunhofer-Gesellschaft

With over 30 000 employees in 76 institutes, the Fraunhofer-Gesellschaft is the world's leading organization for applied research.

Prioritizing key future-relevant technologies and commercializing its findings in business and industry, the Fraunhofer-Gesellschaft 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.

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 are 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.

The impact of applied research goes far beyond the direct benefits to the client. Fraunhofer institutes strengthen companies' performance and efficiency and promote the acceptance of new technologies within society while also training the future generation of scientists and engineers that the economy so urgently requires.

"Approximavit sidera" ("He brought the stars closer to us") was the epitaph of Joseph von Fraunhofer (1787-1826). He was equally successful as a researcher, inventor and entrepreneur. The quality of his optical lenses was unrivaled for decades. Fraunhofer combined the most precise scientific work with practical application and thus created new innovative products. Today, he is considered a pioneer of modern space exploration.

In the painting: Fraunhofer demonstrates his spectrometer (standing, with black coat).

Photos: Fraunhofer EMI, Fraunhofer-Gesellschaft

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Publications, lectures, scientific exchange

Zeitraum:
1.4.24 – 31.3.25

Publications (with peer review)

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Roller, C.; Ruiz-Ripoll, M. L.; Dirlewanger, H.; Schmitt, D.; Schneider, J.; Ramin, M. von (2024): **Structural behavior of multi-component perimeter walls – numerical study of SHIELD21 tests.** In: Proceedings of the 19th International Symposium on Interaction of the Effects of Munitions with Structures (ISIEMS). Bonn, 09.-13.12.2024.

Rosin, J.; Stocchi, A. (2024): **Assessing the blast performance of masonry walls: development and validation of a hydrocode model.** In: Proceedings of the 19th International Symposium on Interaction of the Effects of Munitions with Structures (ISIEMS). Bonn, 09.-13.12.2024.

Ruiz-Ripoll, M. L.; Rey de Pedraza Ruiz, V.; Roller, C.; Enfedaque, A.; Gálvez, F. (2024): **Caracterización de hormigones criogénicos bajo cargas dinámicas.** Seguridad en tanques de gas licuado. In: Encuentro Español del Grupo de Fractura. Palma de Mallorca, Spain, 06.-08.03.2024.

Ruiz-Ripoll, M. L.; Rey de Pedraza Ruiz, V.; Roller, C.; Enfedaque, A.; Gálvez, F. (2024): **Caracterización de hormigones criogénicos bajo cargas dinámicas.** Seguridad en tanques de gas licuado. In: Revista de Mecánica de la Fractura 7.

Sauer, C.; Burtsche, J.; Roller, C.; Heine, A.; Bongartz, A. (2024): **Penetrating impacts on fiber reinforced concrete – hydrocode simulations, ballistic tests, and model application.** In: Proceedings of the 19th International Symposium on Interaction of the Effects of Munitions with Structures (ISIEMS). Bonn, 09.-13.12.2024.

Sauer, C.; Riedel, W.; Bagusat, F.; Ruiz-Ripoll, M. L.; Roller, C.; Sauer, M.; Heine, A. (2024): **Combined experimental and numerical study of shock properties of an ultra-high-performance concrete.** In: Proceedings of the 19th International Symposium on Interaction of the Effects of Munitions with Structures (ISIEMS). Bonn, 09.-13.12.2024.

Schaufelberger, B.; Steiert, A.; Kisters, T.; Schopferer, S. (2024): **Development and validation of a finite element model of a prismatic cell under crash loading.** In: Proceedings of the Stuttgart Conference on Automotive Production. Stuttgart, 20.-22.11.2024.

Signetti, S.; Klomfass, A.; Riedel, W.; Putzar, R.; Heine, A. (2024): **Safe operation of light-gas guns with hydrogen: the case study of the "large gun" at Fraunhofer EMI.** In: Periodic Bulletin (International Ballistics Society) (13), S. 29–33.

Stocchi, A.; Rosin, J.; Roller, C.; Jehle, S. (2024): **Performance assessment of façade greening system under blast loads.** In: Proceedings of the 19th International Symposium on Interaction of the Effects of Munitions with Structures (ISIEMS). Bonn, 09.-13.12.2024.

Stocchi, A.; Ruiz-Ripoll, M. L.; Riedel, W.; Stolz, A.; Roller, C.; Rosin, J. (2024): **Experimental and numerical analysis of soil structure interaction during high-speed load.** In: Proceedings of the 18th World Conference on Earthquake Engineering. Milan, Italy, 30.06.-05.07.2024.

Strobl, M.; Aurich, H. (2024): **On the determination of ignition thresholds of HMX based cast cured PBX at non-shock loads.** In: Proceedings of the 53rd International Annual Conference of the Fraunhofer ICT. Karlsruhe, 25.-28.06.2024.

Presentations

Ballal, N.; Soot, T.; Dlugosch, M. (2024): **Enhancing ML-based VRU injury prediction with high-fidelity crash simulation data and domain knowledge.** NAFEMS Dach-Konferenz. Bamberg, 10.06.2024.

Bauer, S. (2024): **Modellbildung für transparente Schutzwerkstoffe – Quantitative Modellbildung zur Materialvorschädigung durch dem Projektil vorauslaufende mechanische Wellen.** DWT-Tagung "Angewandte Forschung für Verteidigung und Sicherheit in Deutschland VI". Bonn, 19.03.2024.

Bauer, S.; Wilhelm, N.; Prajapati, B.; Singler, M. (2024): **Application of neural networks for the quantification of cracks in transparent armor materials.** 4th International Conference on Impact Loading of Structures and Materials (ICILSM). Freiburg, 17.05.2024.

Boljen, M. (2024): **E-Scooter-Unfälle – Dummys und Menschmodelle im Einsatz.** XXII. Forensische Gespräche 2024 "Unfallrekonstruktion". Institut für Rechtsmedizin des Universitätsklinikum Schleswig-Holstein. Lübeck, 30.11.2024.

Busch, S. (2024): **Digitalization of SmallSat production and testing procedures.** : Space Workshop NewSpace: Project ideas for Japanese and German Space Actors. Tokio, Japan, 29.10.2024.

Busch, S. (2024): **Digitalisation of testing procedures for New Space.** SpaceTech Expo 2024. Bremen, 19.11.2024.

Cortes Magalhaes, L. O.; Schaufelberger, B.; Holz, S. (2024): **Numerical modelling of thermal runaway in Li-ion battery modules.** CAE Grand Challenge. Hanau, 16.04.2024.

Fischer, G. K. J.; Rupitsch, S. (2024): **Evaluierung von spärlich besetzten, akustischen Arraygeometrien für Innenraumlokalisierung.** XXXIX. Messtechnisches Symposium. Hall, Austria, 19.09.2024.

Fischer, K. (2024): **BMBF-Projekt HERAKLION – Heuristische Resilienzanalysen für Kommunen mittels Datenraumfunktionalitäten.** KAHR (Klima Anpassung Hochwasser Resilienz) Synthese- und Vernetzungskonferenz. Wesseling, 26.11.2024.

Fischer, K.; Andrae, M.; Brunnabend, L. (2024): **Urbane Sicherheit.** Schutz vor Überfahrtaten und Explosionslasten. 10. Workshop Bau-Protect. Berlin, 12.11.2024.

Fischer, K.; Mehnert, K.; Beck, E.; Stolz, A.; Mauermann, M. (2024): **Konzept zur Resilienzbewertung von Verarbeitungs- und Verpackungsprozessen der Lebensmittelindustrie.** Wissenschaftliche Fachtagung für Verarbeitungsmaschinen und Verpackungstechnik, VVD, 2024. Dresden, 21.03.2024.

Fischer, K.; Mitschke, A.; Klaproth, O.; Schirrmann, A.; Stolz, A. (2024): **Resilience assessment of industrial processes within the aircraft industry.** 14th EASN International Conference. Thessaloniki, 08.10.2024.

Fischer, K.; Roller, C.; Keil, S.; Ramin, M. von; Stolz, A. (2024): **Dynamic response on lightweight walls due to blast loading.** 19th International Symposium on Interaction of the Effects of Munitions with Structures (ISIEMS). Bonn, 09.12.2024.

Fredrich, T. (2024): **Soldat und Waffe als System: Train as you fight – Anwendung von Digitalisierung und autonomer Robotik für die Kampfausbildung mit scharfem Schuss.** DWT-Tagung "Angewandte Forschung für Verteidigung und Sicherheit in Deutschland VI". Bonn, 19.03.2024.

Fredrich, T.; Heß, S. (2024): **Future combat training system – improved live fire training by digitalization.** 2024 Interservice/Industry Training, Simulation and Education Conference (2024 I/ITSEC). Orlando, FL, USA, 04.12.2024.

Gan, E.; Remennikov, A.; Roller, C.; Ruiz-Ripoll, M. L.; Klomfass, A.; Ritzel, D. (2024): **Comparison of simulated blast environment between the Australian and German blast simulators.** 19th International Symposium on Interaction of the Effects of Munitions with Structures (ISIEMS). Bonn, 09.12.2024.

Guimaraens, E. (2024): **Optimizing blast response: material improvement for sandwich structures with lattice core manufactured via L-PBF.** AuxDefense 2024. Braga, Portugal, 20.06.2024.

Guimaraens, E. (2024): **Optimizing blast response: material improvement for sandwich structures with lattice core manufactured via L-PBF.** MSE Congress 2024. Darmstadt, 26.09.2024.

Guimaraens, E. (2024): **Additive manufacturing and lightweight design in automotive engineering: applied research case studies.** AHK Deutsch-Tschechische Industrie- und Handelskammer. Prag, Tschechien, 05.11.2024.

Gutt, F.; Huschka, M.; Stolz, A. (2024): **Cascading effects analysis enabled by semantic interoperability in the resilience data space.** IDSA Workshop. Budapest, Hungary, 01.10.2024.

Hecker, P. (2024): **Lightning Talk: Super-Resolution of Earth Observation Data.** 2. Fraunhofer KI-Woche, 27.09.2024.

Hecker, P.; Bäuerle, H.; Schäfer, F. (2024): **Analysis of the applicability of super-resolved Sentinel-2 images for segmentation of photovoltaic power plants.** ESA SUREDOS24 Conference. Frascati, Italy, 29.05.2024.

Heine, A. (2024): **Wirkmechanismen zur Abwehr hypersonischer Bedrohungen: Neue Herausforderungen infolge nichtballistischer Flugbahnen.** DWT-Tagung "Angewandte Forschung für Verteidigung und Sicherheit in Deutschland VI". Bonn, 20.03.2024.

Heine, A. (2024): **New approaches to the constitutive modeling of protective materials.** LWAG 2024 – Lightweight Armour for Defence and Security. Rocamadour, France, 13.06.2024.

Hess, S.; Jaspers, F.; Fredrich, T. (2024): **Future combat training system – improved life fire training by digitalization.** I/ITSEC 2024. Orlando, FL, USA, 02.12.2024.

Holz, S.; Norrefeldt, V. (2024): **The LOKI-PED project.** International Aircraft Materials & Systems Forum Meeting. Bremen, 14.04.2024.

Holz, S.; Pfaff, J. (2024): **The LOKI-PED project.** IATA World Operations and Safety Conference. Marakesh, 01.10.2024.

Holz, S.; Schopferer, S. (2024): **Developing safe battery systems by highly instrumented off-nominal tests.** Europe Energy Storage Safety Summit 2024. Petten, Netherlands, 08.10.2024.

Hoschke, K. (2024): **Optimization and experimental investigation of the blast response of additive manufactured sandwich structures with lattice core.** International Conference on Impact Loading of Structures and Materials (ICILSM). EMI Freiburg, 13.05.2024.

Jenerowicz, M. (2024): **Numerische Menschmodelle und anthropomorphe Prüfvorrichtung – Biomechanische Analyse bei hochdynamischen Belastungsszenarien für persönliche Schutztechnologien und Körperschut.** DWT-Tagung "Angewandte Forschung für Verteidigung und Sicherheit in Deutschland VI". Bonn, 20.03.2024.

Jenerowicz, M. (2024): **Evaluation of behind armour blunt trauma: dynamic analysis with finite element human body models.** 29th Congress of the European Society of Biomechanics. Edinburgh, 03.07.2024.

Jenerowicz, M. (2024): **Assessment of female human body models for ballistic impact analysis with post mortem human subject (PMHS) data evaluation: A comparative study with various impact loading conditions.** International Research Council on the Biomechanics of Injury, IRCOBI Conference. Stockholm, 12.09.2024.

Jenerowicz, M. (2024): **Comparative numerical analysis of the posterior and anterior behind armour blunt trauma using GHBMC M50-P model.** International Research Council on the Biomechanics of Injury, IRCOBI Conference. Stockholm, 12.09.2024.

Köpke, C. (2024): **Pitchvortrag und Messestand zum EU Projekt SARIL.** ALICE Logistics Innovation Summit. Brüssel, 06.11.2024.

Köpke, C.; Steiert, M. (2024): **Großveranstaltungen: Den Überblick behalten durch intelligente Datenanalyse und Simulationen.** Polizeitag München. München, 05.12.2024.

Kurfiß, M.; Léost, Y. (2024): **X ray Car Crash insights into cars and dummies.** 4. Dummy Crashtest Konferenz. Münster, 26.06.2024.

Lickert, B.; Srivastava, K.; Schroven, K.; Fehling-Kaschek, M.; Stolz, A. (2024): **Modeling impact of power outages on interdependent critical infrastructure.** 34rd European Safety and Reliability Conference (ESREL 2024). Krakau, Polen, 23.06.2024.

Lickert, B.; Srivastava, K.; Schroven, K.; Fehling-Kaschek, M.; Stolz, A. (2024): **Modeling damage cascades in critical infrastructure for power outages.** CIRED 2024. Chicago, USA, 07.11.2024.

Lück, M.; Schäffer, S.; Osterholz, J.; Allofs, D.; Gruhn, P.; Gülhan, A. (2024): **Potential von Laserwaffen zur Flugkörperbekämpfung – Laserwirkung im Windkanal von Unterschall bis Hyperschall.** DWT-Tagung "Angewandte Forschung für Verteidigung und Sicherheit in Deutschland VI". Bonn, 19.03.2024.

Matura, P. (2024): **Beitrag des Fraunhofer EMI zur Kernfusionsforschung – Den Folgen von Plasmastörungen in Kernfusionsreaktoren entgegenwirken.** Institutsseminar Fraunhofer INT, 06.11.2024.

Matura, P.; Signetti, S.; Moser, S.; Gebhardt, D.; Watson, E.; Schindler-Tyka, A. et al. (2024): **Pellet shattering process for the ITER disruption mitigation system Part II: Synthetic diagnostics based fragment tracking, calibration, and validation of simulation models.** 17th Hypervelocity Impact Symposium. Tsukuba, Japan, 12.09.2024.

Matura, P.; Signetti, S.; Moser, S.; Sandoval, L.; Durr, N.; Watson, E. et al. (2024): **Pellet fragmentation process in the context of the SPI technology for the ITER DMS – Analysis of the fragment characteristics supported by numerical simulations and image diagnostics of shatter tests.** 3rd Technical Meeting on Plasma Disruptions and their Mitigation. Saint Paul Lès Durance, France, 04.09.2024.

May, M. (2024): **Towards more sustainable aviation: Topology optimization and additive manufacturing of a cargo door latch fitting.** 2024 AIAA Science and Technology Forum and Exposition (AIAA SciTech Forum). Orlando, FL, USA, 08.01.2024.

May, M. (2024): **Towards more sustainable aviation: Life cycle analysis of a topology optimized 3D printed cargo door latch fitting.** 2024 AIAA Science and Technology Forum and Exposition (AIAA SciTech Forum). Orlando, FL, USA, 09.01.2024.

May, M. (19.-21-2024): **Drohnenimpakt – Erweiterte Anforderungen an die sichere Auslegung von Flugzeugen und Hubschraubern.** DWT-Tagung "Angewandte Forschung für Verteidigung und Sicherheit in Deutschland VI". Bonn, 19.-21-03.2024.

May, M. (2024): **A look inside – The journey towards X-ray instrumented car crash.** International Conference on the Dynamic Behaviour of Composites (DyCOMP) and European Conference on Crashworthiness of Composite Structures (ECCCS). Enna, Italy, 03.09.2024.

May, M.; Kurfiß, M.; Fritsch, J. (2024): **X-ray instrumended side impact crash test – a technology demonstration.** 22nd Asia Pacific Automotive Engineering Conference 2024. Jeju Island, South Korea, 18.11.2024.

May, M.; Kurfiß, M.; Fritsch, J. (2024): **X-ray instrumended side impact crash test – a technology demonstration.** JSOL CAE Forum, 27.11.2024.

Meyer, R.; Schmidt-Colberg, A.; Kruse, A.; Köpke, C. (2024): **How to get people to leave -- exploring the influence of warning message informativity on the evacuation of large-scale events.** Social Simulation Conference 2024 (SSC 2024). Krakau, Polen, 18.09.2024.

Neuhäuser, S.; Gerold, M. (2024): **Developing networked twins of highly complex systems in the built environment.** NRC-CNRC Workshop "Digital Twins". Berlin, 29.04.2024.

Niklas, W. (2024): **Softwaregestützte Analyse zur Sicherheit bei der Laserwaffenerprobung.** DWT-Tagung "Angewandte Forschung für Verteidigung und Sicherheit in Deutschland VI". Bonn, 19.03.2024.

Patil, S. (2024): **A metallic friction lattice structure under crash.** 4th International Conference on Impact Loading of Structures and Materials (ICILSM). EMI Freiburg, 15.05.2024.

Putzar, R.; Zweigle, T.; Matura, P.; Bagusat, F.; Jung, M.; Weninger, L. et al. (2024): **Rupture prediction for spacecraft pressurized titanium tanks.** 73rd ARA Meeting. Bryan, TX, USA, 11.08.2024.

Putzar, R.; Zweigle, T.; Matura, P.; Bagusat, F.; Jung, M.; Weninger, L. et al. (2024): **Rupture prediction for spacecraft pressurized titanium tanks.** 4th European Hypervelocity Impact Risk Assessment Forum. Fraunhofer EMI, 01.10.2024.

Reich, S.; Heunoske, D.; Lück, M.; Osterholz, J. (2024): **Laser hardening of steel with a 120 kW laser at high throughput.** 13th CIRP Conference on Photonic Technologies [LANE 2024]. Fürth, 15.09.2024.

Reich, S.; Schäffer, S.; Heunoske, D.; Goesmann, M.; Lück, M.; Osterholz, J. (2024): **Zur nächsten Generation von Lasereffektoren – Wirkung im Ziel für hochenergetische Laserstrahlung bis 120 kW.** DWT-Tagung "Angewandte Forschung für Verteidigung und Sicherheit in Deutschland VI". Bonn, 19.03.2024.

Reich, S.; Schäffer, S.; Heunoske, D.; Goesmann, M.; Lück, M.; Osterholz, J. (2024): **Effects of a 120 kW cw laser with focus on metal perforation and steel hardening.** Stuttgarter Lasertage (SLT). Stuttgart, 04.06.2024.

Rey de Pedraza Ruiz, V.; Ruiz-Ripoll, M. L.; Roller, C.; Enfedaque, A.; Gálvez, F. (2024): **Characterization of cryogenic concrete under dynamic loadings.** DYMAT 2024. Zürich, 08.09.2024.

Rietkerk, R.; Heine, A. (2024): **Anwendung der Methoden künstlicher Intelligenz für Wirkung und Schutz – Die Ableitung von Modellparametern für dynamische Werkstoffmodelle.** DWT-Tagung "Angewandte Forschung für Verteidigung und Sicherheit in Deutschland VI". Bonn, 19.03.2024.

Rodinger, S.; Kölble, F.; Harwick, W. (2024): **Entfestigungsvorgänge unter Einwirkung von Temperatur bei Hochleistungsstählen.** VDEh-Tagung Werkstoffprüfung, 06.12.2024.

Roller, C.; Ruiz-Ripoll, M. L.; Dirlewanger, H.; Schmitt, D.; Schneider, J.; Ramin, M. von (2024): **Structural behavior of multicomponent perimeter walls – numerical study of SHIELD21 tests.** 19th International Symposium on Interaction of the Effects of Munitions with Structures (ISIEMS). Bonn, 09.12.2024.

Rosin, J.; Stocchi, A. (2024): **Numerical analyses of steel tanks subjected to high detonation pressure: A case study on ammonia tanks with 300 mbar overpressure.** Cryogenic Storage Tank Conference. München, 18.04.2024.

Ruiz-Ripoll, M. L.; Rey de Pedraza Ruiz, V.; Roller, C.; Enfedaque, A.; Gálvez, F. (2024): **Caracterización de hormigones criogénicos bajo cargas dinámicas.** Seguridad en tanques de gas licuado. Encuentro Español del Grupo de Fractura 2024. Palma de Mallorca, Spain, 06.03.2024.

Ruiz-Ripoll, M. L.; Stocchi, A.; Riedel, W.; Bagusat, F.; Sauer, M.; Roller, C.; Stolz, A. (2024): **Characterization and modelling of granular materials under impact and shock loading.** 4th International Conference on Impact Loading of Structures and Materials (ICILSM). Freiburg, 14.05.2024.

Rüthnick, P.; Bagusat, F.; Sauer, M. (2024): **On the observation of surface temperatures in taylor impact tests.** DYMAT 2024. Zürich, 11.09.2024.

Sättler, A.; Aurich, H. (2024): **Wirkmechanismen und Zielannäherung – Anforderungen an zukünftige Gefechtsköpfe zur Wirkung gegen gepanzerte Landplattformen.** DWT-Tagung "Angewandte Forschung für Verteidigung und Sicherheit in Deutschland VI". Bonn, 20.03.2024.

Sauer, C.; Burtsche, J.; Roller, C.; Heine, A. (2024): **Penetrating impacts on fiber reinforced concrete – hydrocode simulations, ballistic tests, and model application.** 19th International Symposium on Interaction of the Effects of Munitions with Structures (ISIEMS). Bonn, 10.12.2024.

Sauer, C.; Riedel, W.; Bagusat, F.; Ruiz-Ripoll, M. L.; Roller, C.; Sauer, M.; Heine, A. (2024): **Combined experimental and numerical study of shock properties of an ultra-high-performance concrete.** 19th International Symposium on Interaction of the Effects of Munitions with Structures (ISIEMS). Bonn, 09.12.2024.

Schaufelberger, B.; Hall, T.; Cortes Magalhaes, L. O. (2024): **Simulation models to support the design of polymer-based battery housings against thermal runaway.** The Safe Battery Experience. Freiburg, 15.10.2024.

Schaufelberger, B.; Kisters, T.; Kuder, J.; Schopferer, S.; Hermann, P.; Hall, T. (2024): **Integration of pouch cells in polymer battery enclosures – analysis of thermal runaway experiments on cell level.** Automotive Battery. München, 11.06.2024.

Schaufelberger, B.; Steiert, A.; Kisters, T.; Schopferer, S. (2024): **Development and validation of a finite element model of a**

prismatic cell under crash loading. Stuttgart Conference On Automotive Production (SCAP2024). Stuttgart, 20.11.2024.

Schneider, J. (2024): **Schutzbauten unter Berücksichtigung von Nachhaltigkeitsanforderungen.** DWT-Tagung "Energiewende im militärspezifischen Kontext". Bonn, 08.10.2024.

Schneider, J.; Cordova, J.; Tawfik, A.; Ramin, M. von (2024): **Sustainable protective structures.** International Physical Security Forum (IPFS). Brüssel, 19.04.2024.

Schulz, T.; Huschka, M.; Dlugosch, M. (2024): **Leveraging knowledge graphs to fill data gaps for life cycle assessment during product development.** Stuttgart Conference On Automotive Production (SCAP2024). Stuttgart, 21.11.2024.

Signetti, S.; Matura, P.; Sandoval, L.; Durr, N.; Büttner, M.; Watson, E. et al. (2024): **Pellet shattering process for the ITER disruption mitigation system Part I: Development of a discrete element code for the dynamic fragmentation of cryogenic materials.** 17th Hypervelocity Impact Symposium. Tsukuba, Japan, 12.09.2024.

Signetti, S.; Moser, S.; Sandoval, L.; Durr, N.; Watson, E.; Gebhardt, D. et al. (2024): **Modeling and simulation of the pellet shattering process for the ITER Disruption Mitigation System.** 4th International Conference on Impact Loading of Structures and Materials (ICILSM). Freiburg, 16.05.2024.

Soot, T.; Dlugosch, M.; Fritsch, J. (2024): **"Grey-Box-Processing" Ein neuartiger Validierungsansatz für Struktursimulationen in der Fahrzeugsicherheit.** 21. VDI-Tagung "SIMVEC – Auslegung und Absicherung von Fahrzeugsystemen". Baden-Baden, 19.11.2024.

Stocchi, A.; Rosin, J. (2024): **Tank structures as part of the critical infrastructures – Can steel tanks safely withstand high explosion pressures?** Conference on Flat Bottom Storage Tanks. München, 29.10.2024.

Stocchi, A.; Ruiz-Ripoll, M. L.; Riedel, W.; Stolz, A.; Roller, C.; Rosin, J. (2024): **Experimental and numerical analysis of soil structure interaction during high-speed load.** 18th World Conference on Earthquake Engineering (WCEE2024). Milan, Italy, 02.07.2024.

Stolz, A. (2024): **Fähigkeiten resilient gestalten: ein Ansatz zum Resilienz Management am Beispiel der Flugsicherung.** DWT-Tagung "Angewandte Forschung für Verteidigung und Sicherheit in Deutschland VI". Bonn, 19.03.2024.

Stolz, A. (2024): **Sichere und resiliente Gesellschaften: die Forschung am Standort Freiburg.** Jahresmitgliederversammlung des Bundesverbandes der Sicherheitswirtschaft BDSW. Freiburg, 16.05.2024.

Stolz, A. (2024): **Resilienz messbar und praktikabel gestalten, geht das?** Wissenswerkstatt SifoLIFE zum Thema "Resilienz in kommunalen Kontexten" vom Team BeLIFE. Braunschweig, 27.06.2024.

Stolz, A. (2024): **Schutz öffentlicher Räume gegen terroristische Angriffe.** Marburger Sicherheitstage. Marburg, 26.09.2024.

Strobl, M.; Aurich, H. (2024): **On the determination of ignition thresholds of HMX based cast cured PBX at non-shock loads.** 53rd International Annual Conference of the Fraunhofer ICT. Karlsruhe, 28.06.2024.

Strobl, M.; Aurich, H. (2024): **Low velocity impact experiments – On the determination of non-shock ignition thresholds of cast cured PBX formulations.** 17th International Detonation Symposium. Kansas City, USA, 05.08.2024.

Trube, N. (2024): **Development and plausibility assessment of an active human body model in numerical cyclist to vehicle collision simulations based on real-life accident data.** IRCOBI Conference. Stockholm, 13.09.2024.

Trube, N. (2024): **Development and plausibility assessment of an active human body model in numerical cyclist to vehicle collision simulations based on real-life accident data.** carhs Human Modeling and Simulation Symposium. Marburg, 13.11.2024.

Seminar presentations at EMI

Guimaraens, E. (2024): **Microscopy in material science and engineering.** What can we see here at EMI? EMI-Hausseminar. EMI Freiburg, 11.01.2024.

Hecker, P. (2024): **Deep-Learning for super-resolution of Sentinel-2 imagery.** EMI-KI-Kolloquium, 08.10.2024.

Jenerowicz, M. (2024): **Simulationsmethoden zur prognosefähigen Analyse von Knochensurrogaten.** Doktorandenseminar. EMI Freiburg, 21.01.2024.

Martini, T. (2024): **Fraunhofer-Zentrum für die Sicherheit Sozio-Technischer Systeme (Fraunhofer SIRIOS): Vortrag zum Themenschwerpunkt: "Sicherheit kritischer Infrastrukturen".** EMI-Hausseminar, 14.03.2024.

Matura, P.; Signetti, S.; Moser, S.; Sandoval, L.; Durr, N.; Watson, E. et al. (2024): **Next ITERation – Fragments for Fusion.** EMI-Hausseminar. EMI Freiburg, 19.09.2024.

Pfaff, A. (2024): **Graded steel microstructures by laser powder bed fusion for increased material efficiency.** Doktorandenseminar. EMI Freiburg, 20.09.2024.

Soot, T. (2024): **Grey-Box-Processing – Ein integrales Validierungsverfahren für Struktursimulationen in der Fahrzeugsicherheit".** Disputationsvortrag. EMI Freiburg, 05.02.2024.

Tang, J. H.; Franz, R. (2024): **Datengetriebene kommunale Resilienzbewertung in Bezug auf Extremwetter und Pandemie.** EMI-Hausseminar. EMI Efringen-Kirchen, 18.07.2024.

Courses of the Carl Cranz Society

Heine, A. (2024): **Panzerstähle – Schutzanwendungen, endballistische Bewertung, dynamische Charakterisierung.** CCG-Seminar VS 1.42 "Ballistik und Effektivität von Geschossen". Gilching, 17.10.2024.

Heine, A. (2024): **Wissenschaftliche Untersuchungsmethoden für die Geschosswirkung.** CCG-Seminar VS 1.42 "Ballistik und Effektivität von Geschossen". Gilching, 17.10.2024.

Sättler, A. (2024). CCG-Seminar VS 1.02: **"Innenballistik von Rohrwaffen", 24.09.2024.**

Straßburger, E. (2024): **Endballistik kleinkalibriger Geschosse – Keramik für den ballistischen Schutz.** CCG-Seminar VS 1.43 "Endballistik – Grundlagen und Anwendungen". Saint Louis, France, 25.06.2024.

Teaching

Lectures

Asa, P.; Neuhäuser, S. (Wintersemester 2024/2025): **Design-Build-Studio "Digital Design and Fabrication of Timber 2.0".** Seminar. TU Berlin.

Asa, P.; Neuhäuser, S.; Noda, S. (Sommersemester 2024): **Design-Build-Studio "Digital Design and Fabrication of Timber".** TU Berlin.

Asa, P.; Neuhäuser, S.; Noda, S. (Wintersemester 2024/2025): **Digital Form-finding and Optimization.** Semina. TU Berlin.

Balle, F. (Sommersemester 2024): **Anwendbarkeit eines optischen Mikrofons zur Charakterisierung von Ermüdungsschäden in Verbundwerkstoffen.** Projekt. Albert-Ludwigs-Universität Freiburg.

Balle, F. (Sommersemester 2024): **Herausforderungen an die Fügetechnik bei der Fertigung von Lithium-Ionen-Batterien.** Projekt. Albert-Ludwigs-Universität Freiburg.

Balle, F. (Wintersemester 2024/2025): **Lightweight Design and Materials.** Vorlesung.

Balle, F. (Wintersemester 2024/2025): **Materials Selection for Sustainable Engineering.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Balle, F. (Sommersemester 2024): **Nachhaltige Materialien.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Balle, F. (Sommersemester 2024): **Technische Funktionswerkstoffe.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Balle, F. (Wintersemester 2024/2025): **Werkstofftechnik und -prozesse.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Balle, F. (Wintersemester 2024/2025): **Widerstandsmessungen Ultraschall-geschweißter Proben zur Entwicklung einer zerstörungsfreien Inline-Prozesskontrolle.** Projekt. Albert-Ludwigs-Universität Freiburg.

Ganzenmüller, G. (Sommersemester 2024): **Advanced Materials Laboratory.** Vorlesung und Praktikum. Albert-Ludwigs-Universität Freiburg.

Ganzenmüller, G.; Hiermaier, S. (Sommersemester 2024): **Angewandte Finite Elemente für die Strukturmechanik.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Ganzenmüller, G.; Hiermaier, S. (Sommersemester 2024): **Werkstoffdynamik / Dynamics of Materials: Numerik dynamischer Deformationsprozesse.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Ganzenmüller, G.; Kilchert, S.; Hiermaier, S. (Wintersemester 2024/2025): **Materiallebenszyklen / Material Life Cycles.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Ganzenmüller, G.; Stilz, M.; Hiermaier, S. (Wintersemester 2024/2025): **Konstitutive Gleichungen und Diskretisierungsverfahren zur Versagensmodellierung / Physics of Failure.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Häring, I. (Sommersemester 2024): **Functional Safety, Security and Sustainability: Active Resilience.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Häring, I. (Wintersemester 2024/2025): **Quantification of Resilience.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Häring, I. (Wintersemester 2024/2025): **Quantitative Risikoanalyse.** Vorlesung. Hochschule Furtwangen.

Harwick, W. (Wintersemester 2024/2025): **Werkstoffe.** Vorlesung. DHBW Lörrach.

Hiermaier, S. (Sommersemester 2024): **Grundlagen resilienter Systeme.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S.; Ganzenmüller, G. (Wintersemester 2024/2025): **Grundlagen der mechanischen Werkstoffcharakterisierung.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S.; Ganzenmüller, G.; Schroven, K.; Rinnert, T. (Wintersemester 2024/2025): **Fundamentals of Resilience.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S.; Matura, P. (Wintersemester 2024/2025): **Kontinuumsmechanik.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Hoschke, K. (Wintersemester 2024/2025): **Vorlesungsbeitrag "Nachhaltigkeitsorientiertes mechanisches Design mit Topologie-Optimierung".** In Vorlesung von Pascal Matura am INATECH.

Kilchert, S.; Hiermaier, S. (Wintersemester 2024/2025): **Lebenszyklusanalyse.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg,

Kilchert, S.; Hiermaier, S. (Sommersemester 2024): **Material Flow Analysis.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Kilchert, S.; Hiermaier, S.; Balle, F. (Sommersemester 2024): **Studienseminar Sustainable Systems Engineering.** Seminar. Albert-Ludwigs-Universität Freiburg.

Lickert, B.; Stolz, A. (Sommersemester 2024): **Resilience of Supply Networks.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Lickert, B.; Stolz, A. (Sommersemester 2024): **Resilience of Supply Networks.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Matura, P. (Sommersemester 2024): **Numerische Methoden in der Mathematik.** Vorlesung. DHBW Lörrach.

Matura, P.; Hoschke, K.; Hiermaier, S. (Wintersemester 2024/2025): **Kontinuumsmechanik.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

May, M.; Imbert, M. (Wintersemester 2024/2025): **Composite Materials.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Osterholz, J. (Sommersemester 2024): **High-Energy Density Physics.** Vorlesung. Heinrich-Heine-Universität Düsseldorf.

Ramin, M. von (Sommersemester 2024): **Lehrbeauftragter im Masterstudiengang "Katastrophenvorsorge und -Management", Unterrichtseinheit 4 "Bauliche Prävention im Bevölkerungsschutz" im Modul 5: "Ausgewählte Konzepte und Maßnahmen der Katastrophenvorsorge".** Rheinische Friedrich-Wilhelms-Universität Bonn.

Riedel, W. (Wintersemester 2024/2025): **Schutz baulicher Infrastrukturen.** Hochschule Furtwangen.

Sauer, M. (Wintertrimester 2024): **Laborpraktikum.** Universität der Bundeswehr München.

Sauer, M. (Wintertrimester 2024): **Numerische Simulationsverfahren.** Vorlesung. Universität der Bundeswehr München.

Sauer, M. (Wintertrimester 2024): **Werkstoffcharakterisierung.** Vorlesung. Universität der Bundeswehr München.

Schäfer, F. (Sommersemester 2024): **Shock Waves in Rocks I.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Stolz, A. (Wintersemester 2024/2025): **Communal Pandemic Resilience Indicators: Effective Durations.** Projekt. Albert-Ludwigs-Universität Freiburg.

Stolz, A. (Sommersemester 2024): **Konzeption großer Infrastrukturen / Design and Monitoring of Large Infrastructures.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Stolz, A. (Sommersemester 2024): **Minderung des städtischen Wärmeinseleffekts durch Gewässer.** Projekt. Albert-Ludwigs-Universität Freiburg.

Stolz, A. (Wintersemester 2024/2025): **Strukturelle Robustheit: Resiliente Entwurfsprinzipien / Structural Robustness: Resilient Designs.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Visiting scientists

M.Sc. Guisepp Bua, August – Dezember 2024.

Prof. Dr. Mohammad Gharaibeh, August – September 2024.

Sho Ikeda, M.Sc., Ballistics Research Division Ground Systems Research Center GSRC Acquisition, Technology & Logistics Agency ATLA Ministry of Defense Japan 01.04.2024 – 31.03.2025.

Doctorates

Grunwald, C. (2024): **Fragmentation of Concrete under Dynamic Loading – a Numerical Multiscale Approach.** Dissertation. Albert-Ludwigs-Universität Freiburg.

Pfaff, A. (2024): **Graded Steel Microstructures by Laser Powder Bed Fusion for Increased Material Efficiency.** Dissertation. Albert-Ludwigs-Universität Freiburg.

Premanand, A. (2024): **Ultrasonic Fatigue of Polymer Composites: Self-heating and Damage Characterization under Cyclic Three-point Bending.** Dissertation. Albert-Ludwigs-Universität Freiburg.

Rabus, M. (2024): **Modell zur Prognose von Dummybelastungen für eine effiziente Auslegung der passiven Sicherheit von Fahrzeugen.** Dissertation. Albert-Ludwigs-Universität Freiburg.

Roth, A. (2024): **Achieving Efficiency and Accuracy through Kinematic Integrity: A Novel Approach to Metamaterial Modelling.** Dissertation. Albert-Ludwigs-Universität Freiburg.

Schmid, V. (2024): **Zylindrische Klebstoffverbindungen unter Biegemomentenbelastung.** Dissertation. Albert-Ludwigs-Universität Freiburg.

Soot, T. (2024): **Grey-Box-Processing – Ein integrales Validierungsverfahren für Struktursimulationen in der Fahrzeugsicherheit.** Dissertation. Albert-Ludwigs-Universität Freiburg.

Stilz, M. (2024): **Second-Gradient Elasticity and Isogeometric Analysis for Three-Dimensional Pantographic Metamaterials.** Dissertation. Albert-Ludwigs-Universität Freiburg.

Strobl, M. (2024): **Analysis of Constitutive Relations in the Phase Field Approach to Brittle Fracture and its Application to Hertzian Indentation Fracture.** Dissertation. Karlsruher Institut für Technologie (KIT), Karlsruhe.

Suarez del Fueyo, R. (2024): **Systematic Analysis of Real-world Motor Vehicle Crash Data to Identify Areas for Action and Enhanced Occupant Protection.** Dissertation. Albert-Ludwigs-Universität Freiburg.

Bachelor's and Master's theses

Backes, L. (2024): **Erprobung von In-situ Wärmebehandlungsstrategien zur Reduktion von Defekten in L-PBF Wolfram.** Bachelorarbeit.

Boccolari, E. (2024): **Parametric mission and system analysis for future VLEO missions for small satellites with special focus on perturbations in upper atmosphere.** Julius-Maximilians-Universität Würzburg.

Böhler, M. (2024): **Augmentation, calibration and validation of a fast and efficient urban heating model.** Master Thesis. EMI-Bericht A 27/24. Albert-Ludwigs-Universität Freiburg.

Burtsche, J. (2024): **Simulationsbasierte Analysen zur Ableitung von Ingenieurmodellen für die Starrkörperpenetration in ultrahochfesten Beton.** Masterarbeit. EMI-Bericht A 02/24. Hochschule Offenburg.

Eich, N. (2024): **Entwicklung eines Versuchsaufbaus zur Charakterisierung des Entgasungsvorgangs von Li-Ionen-Zellen.** Bachelorarbeit. EMI-Bericht A 04/24. FH Aachen.

Fischer, L. (2024): **Gegenüberstellung und Implementierung von Packalgorithmen für eine sichere und effiziente Lagerung von Munition.** Bachelorarbeit. EMI-Bericht A 17/24. DHBW Lörrach.

Iberer, M. (2024): **Grundlagenermittlung für ein ganzheitliches kommunales Risikomanagement zur Steigerung der Resilienz – am Beispiel Bayern.** Masterarbeit. EMI-Bericht A 23/24. Rheinische Friedrich-Wilhelms-Universität Bonn.

Imreoglu, Y. (2024): **Mechanical-thermal recycling of thermoset composites.** Master Thesis. EMI-Bericht A 25/24. Albert-Ludwigs-Universität Freiburg.

Kirschenbauer, S. (2024): **Analysis of a pax counter towards uses in crowd probing.** Master Thesis. EMI-Bericht A 28/24. Albert-Ludwigs-Universität Freiburg.

Lipp, K. (2024): **Integration von keramischem Werkstoff in additiv gefertigte Panzerstähle für Schutzanwendungen.** Bachelorarbeit.

Luther, M. (2024): **Auslegung einer Split-Hopkinson-Pressure- Bar (SHPB) Anlage zur Untersuchung von Treibladungspulver.** Bachelorarbeit. EMI-Bericht A 21/24. DHBW Lörrach.

Mangold, P. (2024): **Auslegung und Umsetzung einer Getter-Einheit zur Realisierung hochreiner Prozessgasatmosphären im L-PBF.** Bachelorarbeit.

Padariya, R. (2024): **Failure rate estimation of lane detection from CARLA Simulation for Markov model safety assessment of autonomous driving functions.** Master Thesis. EMI-Bericht A 01/24. Westsächsische Hochschule Zwickau.

Patel, R. (2024): **Simulation of underwater explosions and their effect on seabed.** Master Thesis. EMI-Bericht A 30/24. Universität Rostock.

Rajeev, V. (2024): **Development of an authentication library in ASP.NET.** Master Thesis. EMI-Bericht A 12/24. Berlin School of Business and Innovation.

Rathnayake, S. (2024): **Compressible lattice Boltzmann solver for supersonic flow.** Master Thesis. EMI-Bericht A 03/24. Friedrich-Alexander-Universität Erlangen-Nürnberg.

Sangsinsorn, S. (2024): **Vulnerability and Robustness Analyses for the Planning of Resilient Hydrogen Networks.** Master Thesis. EMI-Bericht A 26/24. Albert-Ludwigs-Universität Freiburg.

Schnabel, A. (2024): **Analysis and comparison of carbon-neutralcompressed air storage technologies and hydrogen storage technologies for the storage of**

energy in carbon-neutral energy grids. Bachelorarbeit. Albert-Ludwigs-Universität Freiburg.

Shat, A. (2024): **Numerical characterization of masonry structures.** Master Thesis. EMI-Bericht A 14/24. Ruhr-Universität Bochum.

Shehab, S. (2024): **Assessing the validity of the social vulnerability indicator for the German pandemic situation.** Master Thesis. Albert-Ludwigs-Universität Freiburg.

Strahringer, S. (2024): **Investigation of peeling-based recovery of thermoplastic wound composites.** Master Thesis. EMI-Bericht A 24/24. Albert-Ludwigs-Universität Freiburg.

Sutton, L. (2024): **Automated topology optimization for laser-based powder bed fusion of metals: incorporation of design guidelines and multi-load case scenarios.** Bachelorarbeit.

Xu, L. (2024): **Assessing the validity of the social vulnerability indicator for the german pandemic situation.** Master Thesis. EMI-Bericht A 05/24. Albert-Ludwigs-Universität Freiburg.

Yüksek, A. (2024): **Predictive resource modelling of processing routes towards sustainability-oriented LPBF.** Master Thesis. EMI-Bericht A 29/24. Albert-Ludwigs-Universität Freiburg.

Zurnieden, J. (2024): **Optimierung der Energieabsorption – Zelluläre Strukturen aus dem 3D-Drucker.** Masterarbeit. EMI-Bericht A 19/24. Hochschule Furtwangen.

Events organized by Fraunhofer EMI

10. Workshop Bau-Protect – Gefährdung, dynamische Analyse und Schutzkonzepte für bauliche Strukturen. Berlin, 12.-13.09.2024.

3. Konsortialtreffen des BMBF-Projekts FreiburgRESIST am 9.-10. Oktober 2024. EMI Freiburg.

4th International Conference on Impact Loading of Structures and Materials (ICILSM), 29.06.-03.07.2024, Freiburg.

Co-Organisation des Workshops "Qual2Rule Workshop: Using qualitative data to inform behavioural rules in agent-based models" auf der Social Simulation Conference 2024.

Digitain Projekttreffen, Freiburg.

Doktoranden-Summer-School (10.-12.07.2024).

Doktoranden-Winter-School (25.-26.11.2024).

EMI-Symposium 2024 "Forschung im Dialog: Wirkung und Schutz". Freiburg, 04.12.2024.

Mechanical behavior of HE – Experimental characterization and evaluation. Discussion on future cooperation opportunities with AFRL and follow on project. Kandern, 09.09.2024.

RESIST-Endworkshop am Fraunhofer Forum in Berlin (Organisiert von Gruppen Agentenbasierte Simulationsmethoden und Socio-Technical System Analysis).

SIFO-Workshop zum BMBF-Innovationsforum "Kommunale Krisenfestigkeit und Resilienz mit SIFO-Projekten", Berlin 2024.

Workshop Safe Battery Experience Carhs / Live Experience am Standort EK.

Workshop mit dem assoziierten Partner Lörrach, Projekt HERAKLION (2024). Landratsamt Lörrach, 19.04.2024.

Workshop mit dem assoziierten Partner Nürnberg, Projekt HERAKLION (2024). Gesundheitsamt Nürnberg, 18.06.2024.

Workshop mit assoziierten Partnern Freiburg und Lörrach, Projekt HERAKLION (2024). EMI Freiburg, 17.07.2024.

Patents, prizes, excellence in research

Patents

Heine, A. (2024): **Explosive Schutzpanzerung mit steuerbarer Flugplattengeschwindigkeit.** Veröffentlichungsnr.: DE10 2024 001096.

Herschel, R.; Moser, S.; Heusinger-Hess, V. (2024): **An apparatus and a method for generating an image of an observed object and a system for imaging an object.** Anmeldenr: 20196238.8. Veröffentlichungsnr.: EP 3 968 013.

Hess, S.; Nothdurft, S.; Nau, S.; Kuschke, E. (2024): **Gefechtstrainingssystem.** Veröffentlichungsnr.: EP 4 217 990 B1.

Patil, S.; Ganzenmüller, G. (2024): **A deformable structure.** Veröffentlichungsnr.: EP4148295 A1.

Pfaff, A.; Balle, F. (2024): **Method for post-treating additively manufactured structures by means of ultrasound.** Veröffentlichungsnr.: EP4389323 A1.

Prizes and awards

Balle, F.: **Auszeichnung digitale Lehrprojekte durch das BW-Wissenschaftsministerium und dem Stifterverband für das Projekt "SSE-Navi".**

Dlugosch, M.: **Best pitch, BMW Summer School.**

Dlugosch, M.: **Best poster, BMW Summer School.**

Hiermaier, S.: **Stanford / Elsevier Top 2 % Scientist List – Jahr 2024.**

Hiermaier, S.: **Stanford / Elsevier Top 2 % Scientist List – Karriere.**

May, M.: **Stanford / Elsevier Top 2 % Scientist List – Jahr 2024.**

May, M.: **Stanford / Elsevier Top 2 % Scientist List – Karriere.**

Rosin, J.: **Best Presentation Award für die Präsentation "Building Vulnerability Assessment on an Urban Scale: A Case Study on Heavy Rainfall Events".** 11th International Conference on Civil and Urban Engineering ICCUE 2024, Rome August 20-22.

Schäfer, F.: **Stanford / Elsevier Top 2 % Scientist List – Karriere.**

Evaluated excellence research

Projekte, die vom DFG, BMBF oder European Research Council gefördert werden:

BMBF-Förderung für **Fraunhofer SIRIOS** 2021-2025.

BMBF-Verbundvorhaben: **Handwaffen mit selbstgedruckten Teilen – eine Risikoabschätzung (HamsTeR).** Förderkennzeichen 13N16030.

DFG-Forschungsprojekt: **Charakterisierung und Modellierung der Ermüdungseigenschaften von thermoplastischem CFK und HCF – bis in den VHCF-Bereich durch Hochfrequenz-Methoden.**

DFG-Forschungsprojekt: **Entwicklung langlebiger Sonotrodenkonzepte zum Ultraschallschweißen von Ti-Legierungen durch die Auslegung effizienter Strukturierungen der Sonotrodenkoppelfläche.**

DFG-Forschungsprojekt: **Kreislauffähigkeit thermoplastischer gewickelter Faserverbund-Strukturen durch innovatives Materialdesign, abschälbasierte Demontage und Neu-Wickeln.**

LOKI-PED – Lithium Batteries Fire/Smoke Risks in Cabin.

Projekt **RESIST** (grant No. 03SF0637.) Projektstart: 2021.

Participation in specialist committees

Balle, F.: Aktivitäten in Verbänden: DGM-Fachausschuss "Hybride Werkstoffe und Strukturen" (Gründungsmitglied), DVM-Arbeitskreis "in-situ-Prüfung im Elektronenmikroskop"(Gründungsmitglied).

Balle, F.: Gutachter für die Deutsche Forschungsgesellschaft (DFG), die Netherlands Organisation for Scientific Research (NWO).

Balle, F.: Gutachter für wissenschaftliche Journals: Materials & Design, Internat. Journal of Fatigue, Journal of Visualized Experiments, Advanced Materials Engineering, Composite Science and Technology, Composites A, Composite Interfaces, Fatigue and Fracture of Engineering Materials and Structures, Polymers, Sandwich Structures and Materials, Journal of Materials Processing and Technology, Materials Letters, Materials Science and Engineering A, NDT & E International, Ultrasonics, Carbon.

Balle, F.: Herausgebertätigkeiten: Guest editor (Special issues): Advanced Enginnering Materials (Wiley), Ultrasonics (Elsevier), JOM (Springer).

Balle, F.: Initiator und Leiter der Symposien "Ultrasonic Welding of Advanced Materials", "Ultrasonic Fatigue of Advanced Materials" anlässlich der Konferenzen: TMS Annual Meeting 2011, San Diego (CA), 2012 San Antonio (TX, USA) und 2013 Orlando (FL, USA).

Balle, F.: Initiator und Leiter des Fortbildungsseminares der DGM "Hybride Werkstoffverbunde durch innovative Fügeverfahren" (früher "Rührreib- und Ultraschallschweißen") – gemeinsam mit Prof. Wagner (TU Chemnitz).

Balle, F.: Mitglied im Editorial Board und Mitherausgeber der Zeitschrift "Ultrasonics" (Elsevier).

Balle, F.: Mitglied im Freiburger Materialforschungszentrum (FMF).

Balle, F.: Mitglied im Gemeinschaftsausschuss (GA) "Verbundwerkstoffe" der DGM, DGG, DGO, DVS, VDI und DKG.

Balle, F.: Mitglied im Programmbeirat der Tagung "Verbundwerkstoffe und Werkstoffverbunde".

Balle, F.: Mitglied im Scientific Committee der Konferenzen: "Very High Cycle Fatigue (VHCF)", "European Conference on Composite Materials (ECCM)", "International Conference on Fatigue of Composites (ICFC)".

Balle, F.: Mitgliedschaften in folgenden Verbänden: Deutsche Gesellschaft für Materialkunde (DGM), Deutscher Verband für Materialforschung und -prüfung e.V. (DVM), Deutscher Hochschulverband (DHV), The Minerals, Metals & Materials Society (TMS), USA.

Boljen, M. (2024): Teilnahme 50. Mitgliederversammlung Fraunhofer-Netzwerk "Simulation". Fraunhofer IWTM. Kaiserslautern, 05.11.2024.

Ganzenmüller, G.: Mitglied des DYMAT Governing Boards.

Heine, A.: Editorial Advisory Board, International Journal of Impact Engineering.

Heine, A.: Member of the Organizing Committee, 4th International Conference on Impact Loading of Structures and Materials, ICILSM 2024, 13-17 May 2024, Freiburg, Germany.

Heine, A.: Scientific Committee, Light-Weight Armour for Defence & Security, LWAG 2024.

Hess, S.: Co-Chair der NATO-Arbeitsgruppe NMSG-ET054 "Unified network architecture for live fire exercise systems".

Hiermaier, S.: Clean Aviation // Member of Steering Board.

Hiermaier, S.: Koordinator Leistungszentrum Nachhaltigkeit.

Hiermaier, S.: Member of the German Association for Computational Mechanics (GACM).

Hiermaier, S.: Member of the Organizing Committee, 4th International Conference on Impact Loading of Structures and Materials, ICILSM 2024, 13-17 May 2024, Freiburg, Germany.

Hiermaier, S.: Mitglied der Carl-Cranz-Gesellschaft e.V.

Hiermaier, S.: Mitglied der Deutschen Gesellschaft für Materialkunde (DGM) e.V.

Hiermaier, S.: Mitglied des Freundeskreis BA Lörrach.

Hiermaier, S.: Mitglied des Förderkreis Deutsches Heer e.V.

Hiermaier, S.: Mitglied des MicroTEC Südwest e.V.

Hiermaier, S.: Mitglied DYMAT.

Holz, S.: EASA/FAA Hydrogen Fire & Explosion Task Group.

Jenerowicz, M.: European Working Group (EWG) on Non-Lethal Weapons.

Jenerowicz, M.: NATO Team of Experts on Non-Lethal Kinetic Energy (NLKE).

Köpke, C.: Mitgliedschaft bei der Young Academy of Sustainability Research (YAS), Freiburg.

Köpke, C.: Program Committee of the 5th International Workshop on Cyber-Physical Security for Critical Infrastructures Protection (CPS4CIP 2024).

May, M.: American Institute of Astronautics and Aeronautics (AIAA) International Activities Group.

May, M.: American Institute of Astronautics and Aeronautics (AIAA) Technical Committee Survivability.

May, M.: Editorial Board "Journal of Dynamic Behavior of Materials" (JDBM).

May, M.: Editorial Board "Unizik Journal of Technology, Production and Mechanical Systems" (UJTPMS).

May, M.: Fraunhofer Program Management Clean Aviation.

May, M.: Governing Board Clean Aviation Joint Undertaking (stellv. RTO-Repräsentant).

May, M.: Michael May: Scientific Committee "International Conference on the Dynamic Behaviour of Composites – DyCOMP and European Conference on Crashworthiness of Composite Structures – ECCCS", Enna, Italien, 3-5 September 2024.

May, M.: Programmausschuss "24. Symposium Verbundwerkstoffe und Werkstoffverbunde Verbund 2024", 22-24 Mai 2024, Freiburg i. Brsg.

May, M.: Stellv. Sprecher Fraunhofer VVS im Kontext FCAS.

Meyer, R.: Programmkomitee der Social Simulation Conference (SSC 2024), Programmkomitee International Workshop for Multi-Agent Based Simulation (MABS 2024).

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

Putzar, R.: Secretary der Aeroballistics 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 des Technical Committee der 19th ISIEMS – International Symposium on Interaction of the Effects of Munitions with Structures, Bonn, 9.-13.12.2024.

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)".

Ramin, M. von: Mitglied in der Deutschen Gesellschaft für Erdbebeningenieurwesen und Baudynamik, DGEB.

Riedel, W.: Member of the Organizing Committee, 4th International Conference on Impact Loading of Structures and Materials, ICILSM 2024, 13-17 May 2024, Freiburg, Germany.

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

Rosin, J.: Mitglied im europäischen Normenausschuss CEN/TC 265/WG 10.

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On the way to modern impact physics

At the end of the 1960s, construction of the first light gas gun began at Fraunhofer EMI. This system reached impact velocities of over 3000 m/s. Reliable computer simulations in the field of impact physics were not available until the 1990s. Physical experiments with high-speed cannons were therefore essential in order to obtain empirical data. The research of this period laid the foundation for today's simulation techniques and modern impact physics.

Photo: Fraunhofer EMI

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