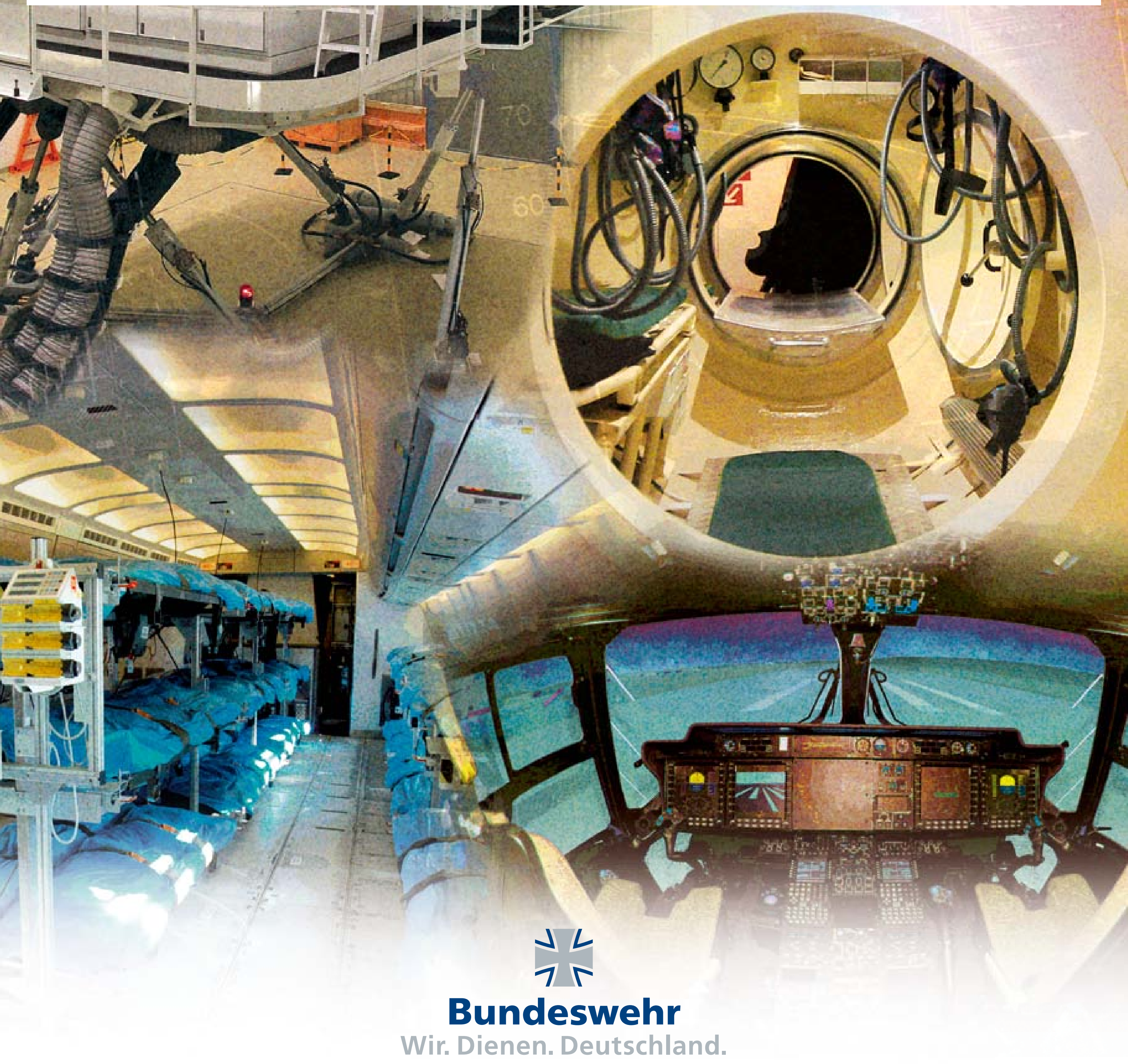
Federal Ministry
of Defence

Military Scientific Research Annual Report 2014

Defence Research for the German Armed Forces



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Military Scientific Research Annual Report 2014

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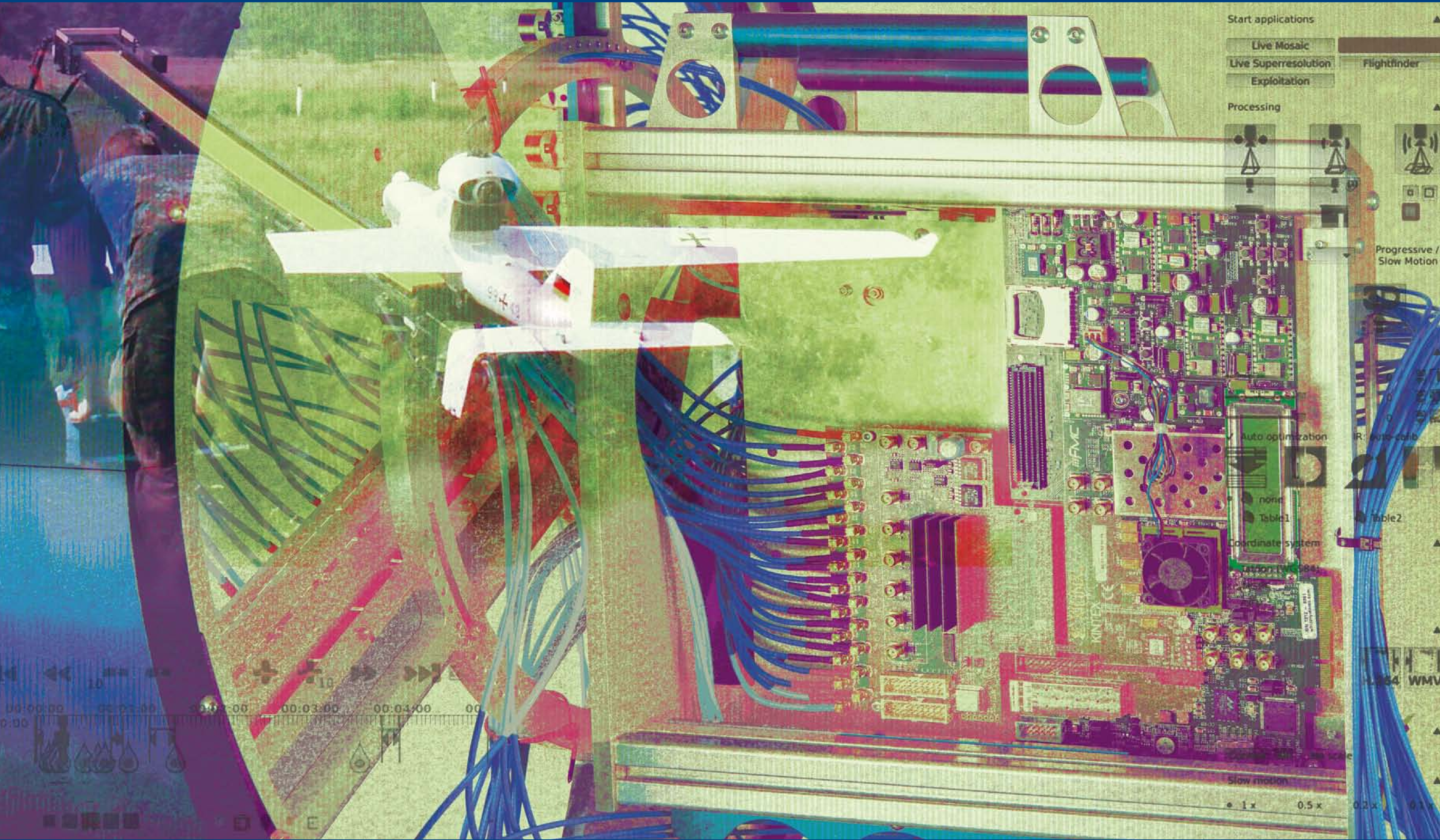
Defence Research for the German Armed Forces



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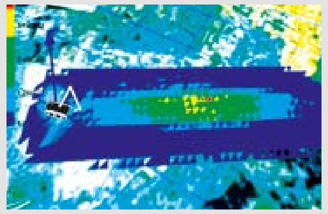

Ministerialdirigent Ralf Schnurr

Chief of Division AIN II and Research Representative,
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Defence Research for the German Armed Forces

The German armed forces (Bundeswehr) are an integral element of Germany's foreign and security policy. They serve to provide security and to protect its citizens, to maintain the territorial integrity and sovereignty of Germany and its allies, and to help meet international responsibilities.

Besides ensuring the capability for territorial and collective defence as well as humanitarian assistance, German armed forces are required particularly to contribute toward the prevention and management of international crises and conflicts.

The Bundeswehr consequently has to keep a broad and flexible spectrum of military capabilities available. For the various kinds of operational deployment it means having to plan and provide forces and assets that are flexible, robust, modular as well as capable of responding to escalating situations.

The broad spectrum of capabilities that the Bundeswehr is called upon to provide requires from defence research as a whole especially the preservation of an all-round ability to carry out analyses and assessments across all fields of research relevant to military science, as well as the early identification and pursuance of new defence developments and trends in research projects in preparation for ministerial decisions.

In this important role, defence research creates the requisite basis at an early stage for meeting the military capability needs of the Bundeswehr and, in particular, for closing existing capability gaps over the medium and long term.

Defence research also ensures Germany's capability for international cooperation in the defence domain by suitably consolidating bi- and multilateral research collaboration especially in the European context of the European Defence Agency (EDA) and in the transatlantic context of the North Atlantic Treaty Organisation (NATO).

The 2014 Annual Military Scientific Research Report illustrates, through selected examples, the diverse and successful activities being conducted in all areas of defence research:

- defence research and technology,
- military medical and military psychology research,
- social science research,
- military history research,

and

- geoscientific departmental research.

Ralf Schnurr

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Defence Research

The broad capability spectrum of the Bundeswehr calls for intensive monitoring and development of all fields of science and engineering relevant to defence applications.

Defence research and technology (R&T) activities provide the analysis and assessment capability required for decision-making on equipment, i.e. they serve to analyse technological developments for their future military usefulness or their threat potential, to identify new technologies for the advancement of Bundeswehr capabilities, to take account of findings from civilian research, and to drive relevant emerging technologies forward to the stage of production readiness at the proper time.

It can be said, then, that defence R&T is the first link in a value chain, at the end of which the Bundeswehr should have the best possible equipment available, on time and in compliance with mission requirements.

In Germany, R&T activities are conducted

- at Bundeswehr-own technical centres and research institutes,
- within the scope of shared government funding at the Fraunhofer Society for the Advancement of Applied Research (Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., or FhG), the German Aerospace Centre (Deutsches Zentrum für Luft- und Raumfahrt e. V. or DLR) and the French-German Research Institute of Saint-Louis (Deutsch-Französisches Forschungsinstitut Saint-Louis, or ISL), as well as
- in the context of project-funded research through the award of R&T contracts to third parties, i. e. to industry and business, universities and institutes of further education, and to non-university research institutes.

The articles hereinafter present examples of defence R&T activities conducted in 2014 on the basis of these three “pillars”.

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Safety assessment for unmanned systems in the military domain

Armed forces are using unmanned systems to significantly increase their performance capabilities. This is of great importance, given the prospect of the growing complexity of future operations. The indeterministic behaviour of these unmanned systems, however, indicates the challenges to be overcome with regard to safety, especially with increasing system autonomy.

The range of application for unmanned systems has grown in past years thanks to scientific and technological progress. Unmanned systems are currently being used or tested in the German Armed Forces for reconnaissance or demining purposes. In that context, multi-sensor systems have to identify mission goals or obstacles, whereupon built-in intelligent logic both determines and suggests optimal routes or actions. In several cases the system executes such actions autonomously. The complexity of unmanned systems thus increases, due to a high number of functions being implemented in a high number of components. In addition, these systems behave less deterministically, and interactions within the system and with the outside world can, therefore, be assessed only with great effort.

Hazard and risk analysis form the basis of classical safety assessments. Such analysis examines possible hazards and derives ensuing risks. Because of the high complexity of operations, including many different system and environment parameters, it is recommendable to conduct quantitative hazard and risk analyses with the aid of (software) tools which take all relevant parameters into account. To do this, there is a need to interlink deterministic phenomena (physical effects) with probabilistic input variables, such as possible failure of hardware, or deviations from navigation routes, so as to quantify and visualise the risks. Fraunhofer EMI possesses extensive expertise in the development of tools for hazard and risk analysis, including 3D visualisation.

The knowledge obtained regarding risks forms the basis for development and approval processes as well as for the safety and reliability requirements to be met by unmanned systems. Derived safety requirements that are not covered by organisational or constructive measures but are implemented technically in the system (safety function) have, in particular, to be developed and validated by means of appropriate techniques and methods.

It is found that established safety standards and the methods described therein are difficult to apply when developing and validating safety functions of unmanned systems due to the complex system structures, the variety of parameters in the application range, and the mentioned indeterminism. Fraunhofer EMI is looking to provide future solutions that improve the safety of unmanned systems and increase competence when applying scientific methods in this regard.

Fraunhofer EMI is developing simulation-based, automated fault analysis, as well as techniques that take account of dynamic aspects in safety analyses, such as in the context of time-dependent fault trees. New diagnostic, fail-safe and fail-operational concepts, as well as the systematic selection of sensor and logic technologies (e. g. COTS) provide the prospect of highly reliable safety functions. Also, new, partly automated test strategies are being developed to generate, on the one hand, authoritative safety and reliability data for highly intelligent safety functions based on system autonomy (e. g. algorithms for image processing or cognitive functions) and to achieve, on the other hand, a high level of test coverage during the assessment process in which a large number of test cases have to be considered.

In addition to the development of methods, Fraunhofer EMI is conducting research into approaches for the establishment of overall tool and method chains, where common and new methods in a fixed sequence are selected to ensure an efficient safety process for a specific problem.

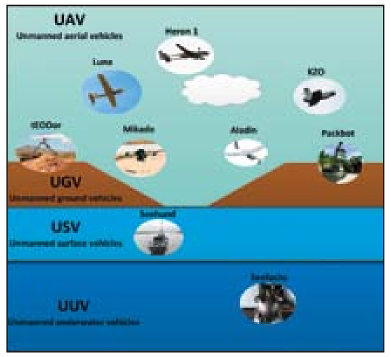

Fig. 1: Variety of unmanned systems in the German Armed Forces (in operation, procurement or testing).
(Source: bundeswehr.de, marine.de, deutschesheer.de, luftwaffe.de)

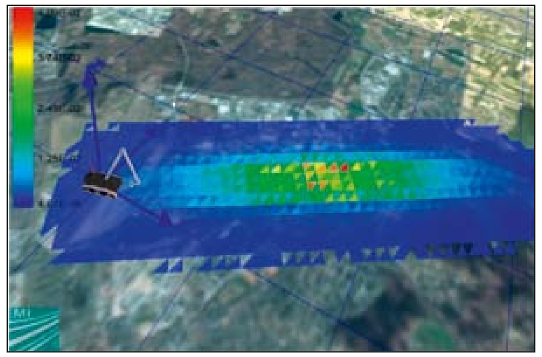

Fig. 2: Possible visualisation of quantitative hazard and risk analysis for a demining robot, depending on the probability of encountering persons at the site of operation

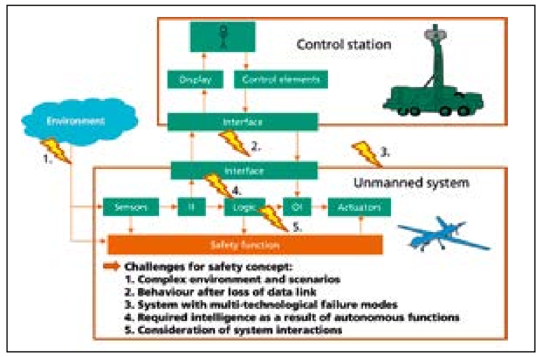

Fig. 3: Critical aspects in the structure of a partially autonomous unmanned system with implemented safety function

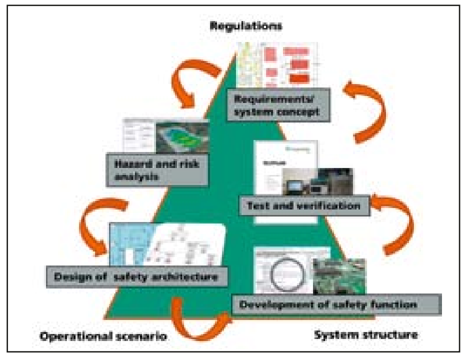

Fig. 4: Problem-specific selection of methods for the safety process of unmanned systems

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The impact of wind turbines on military radars

Lost radar contacts and wrong direction measurements above and behind wind farms, resulting in degraded radar performance, have been the subject of various reports. In this study, which is validated by measurements, the dynamic impact of wind turbines on radar is simulated in order to develop a tool that allows the quantification of the expected loss in radar performance caused by wind turbines.

For some time now, the command, control, communications and information services of the German Air Force have been observing anomalies with regard to radar detection and tracking in the vicinity of wind farms. Loss of contact and wrong target directions have been determined above and behind wind farms and constitute a restriction in the performance capability of these radar systems.

In a first step toward evaluating the compatibility of wind farms and military radars, therefore, an assessment tool has been developed which is based on topography and the locations and characteristics of military radars and makes it possible to analyse whether parts of newly planned wind turbines will extend into the field of view of military radars.

In a second step a procedure is now being developed which will compute the dynamic impact of wind turbines on the field of view of radars and provide the capability to quantitatively evaluate an expected loss of detection performance. Initial measurements have been conducted in the vicinity of a wind farm within the local area of a radar site at Brockzetel. The recorded data show not only a considerable change in the signal modulation of single radar pulses but also an amplitude modulation of the maxima of the pulses during the time of observation within as well as behind wind farms.

In a second measuring campaign, a Delphin aircraft owned by Fraunhofer FHR has been used to assess the impact of wind turbines and wind farms on radar signals at higher altitudes. A metering box ("pod") specifically developed and integrated for these measurements was attached to the aircraft for the retrieval of the required data.

A first analysis of the conducted measurements reveals that, due to the impact of wind turbines, not only increased propagation losses but also disturbances in the radar pulse modulation can be expected, which can cause losses in the signal-to-noise-ratio. Both effects need to be considered when simulating the impact of wind turbines on military radars used by the German Air Force.

Simulation programmes capable of analysing electromagnetic scattered fields are being developed at Fraunhofer FHR. These include, on the one hand, numerically exact procedures which, due to the calculations and memory load involved, are suited at best for the validation of single wind turbine impacts. Asymptotic procedures are, on the other hand, being developed which are also capable, given certain assumptions and simplifications, of modelling very large scenarios with good accuracy. The simulation procedure applied here is based on tracing discrete rays which are emitted from a source and serve to find all the relevant propagation paths. This procedure is being combined with Physical Optics and the Physical Theory of Diffraction. With this, it is possible to model any large scenarios with a comparably small memory load.

The studies hitherto conducted with simple generic as well as complex realistic scenarios show that the effects observed during the measurements can be reproduced qualitatively in the simulations. They address both signal-to-noise-ratio losses and their location dependence in the shadow of wind turbines as dynamic effects.

Two-dimensional analyses of the total field strength reveal a highly complex scattering and interference pattern in the shadow of wind turbines. The modulation of the received field strengths can be explained by the motion of the rotor blades.

Overall, both the measurements and the field strength simulations show that the impact caused by wind turbines can be highly complex. A further study will aim at providing a powerful tool, validated by measurements, for assessing the impact of wind turbines on radar systems.

Fig. 1: Measurement equipment on an elevated platform at a wind farm to assess wind turbine impacts

Fig. 2: Delphin research aircraft of Fraunhofer FHR equipped with measurement pod for radar signal reception

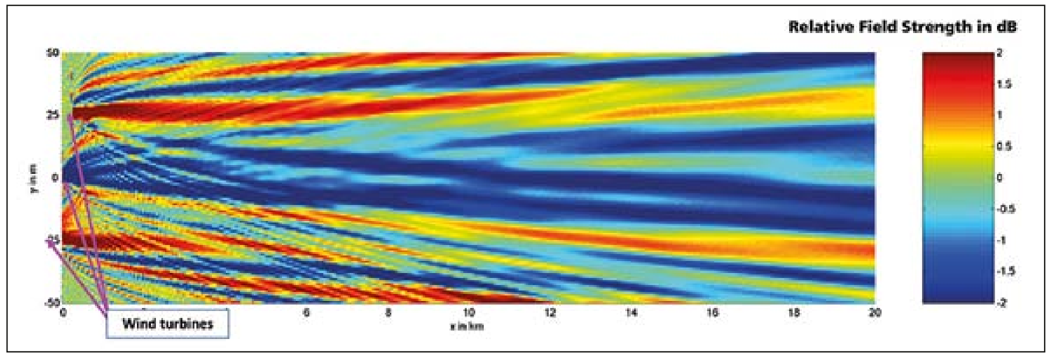

Fig. 3: Relative field strength distribution behind a small wind farm consisting of 3 generic wind turbines (logarithmic scale). Total field strength after elimination of free space loss

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Signal classification for radar reconnaissance

Passive sensors are best-suited for achieving situational awareness if active sensors, such as radar systems, cannot be used because of safety reasons. The digitisation of new radars implies innovative methods of signal intelligence for conducting threat analyses.

Bundeswehr deployments abroad make it essential to have a good knowledge of possible threats, whether they emanate from terrorists or from hostile combat units. Very often, it is not possible to use active sensors such as radars to achieve situational awareness in order to protect one's own armed forces. This means that a precise situational overview and requisite safety can often be attained only with passive sensors. With this in mind, the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR is refining already established methods of radar reconnaissance. Its scientists, furthermore, are researching new and advanced reconnaissance methods based on knowledge gleaned from existing and upcoming radar developments.

Radar signals are optimised with respect to the reconnaissance function required of them and, for that reason, can be used for the purpose of radar classification. The estimated signal parameters, such as angle of arrival, centre frequency, bandwidth, pulse duration, pulse repetition frequency, scan rate, signal arrival time, etc., are summarised in the pulse description word (PDW). Most radars in use to date can thus be clearly identified. By merging the data received from deployed receivers, it is possible to determine the radar location, the radar type and, in many cases, also the carrier platform. To be able to estimate pulse parameters of overlapping radar signals, it is necessary to attribute the received radar echoes clearly to the relevant transmitters. The methods of signal "de-interleaving" developed at Fraunhofer FHR do not use signal frequency as the primary parameter but, primarily, the signal modulation, besides the angle of arrival, to distinguish between several, simultaneously received signals.

Digital receivers with very high sampling rates up to 5 GHz offer the opportunity to improve signal intelligence as well as the classification and identification of radar transmitters. A fine resolution of the received radar signal in the time and frequency range often, depending on the radar, indicates features in terms of amplitude and phase which allow clear attribution of the signal to a certain radar of a given radar type ("Fingerprinting", cf. Figure 2).

Progress in digital technology is not only leading to new options with regard to signal intelligence and signal classification, but also opening up new prospects for radars. Digital signal processing and digital synthesizers allow radars to quickly change all radar signal parameters other than the radar location. The flexibility to modulate the signal transmitted by a radar so that an expected target can be better detected and the target classification improved, is leading to an increasing number of radar waveforms. In the future the multitude of radar waveforms and the expected signal agility will prevent classification of a radar type on the basis of its characteristic PDW.

To nevertheless be able to conduct a threat analysis and have full situational awareness despite the changing conditions, it is possible to use the information contained in the radar emitter waveform to determine the actual operational function of the radar ("Functional ESM"). The received signal waveform can also provide information about which target the radar is illuminating or expecting.

The main focus of the research at Fraunhofer FHR is on the improvement of ELINT algorithms, the classification of radar signals based on the use of emitter databases, the field of functional ESM, and the determination of received radar waveforms. Potential attribution of the signal modulation to the radar operating mode and attribution of the radar signal modulation to possible radar targets form a part of this research work.

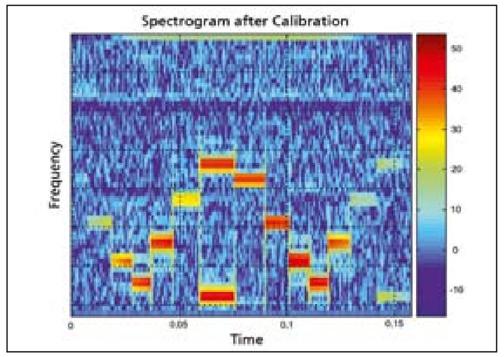

Fig. 1: Estimation of the pulse repetition rate of a radar in "Dwell and Switch" mode

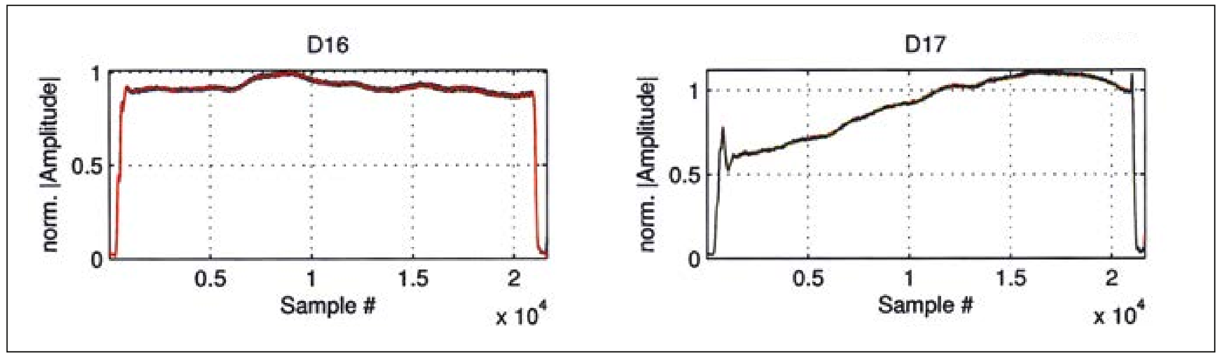

Fig. 2: An example of "fingerprinting" – characteristic phase properties of two radars of the same type

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MedEvac: Low-risk rescue of injured personnel by robots

Unmanned systems have become increasingly important for the protection of military personnel in dangerous situations. Apart from the technological challenges involved, a key aspect of deploying such complex systems is a simple and intuitive mode of interaction. During the European Land Robot Trial, Fraunhofer Institute für Communication, Information Processing and Ergonomics FKIE presented a new robotic system capable of rescuing wounded personnel in the field without exposing the rescue team to danger.

Unmanned ground vehicles (UGV) are well-suited for taking on missions involving high risks to military personnel. These may include surveillance missions, counter IED missions, as well as the rescue of injured personnel from danger zones.

Especially rescuing injured persons poses difficult challenges for a robotic system. The robot must be capable of rescuing a fully equipped soldier with an assumed total weight of over 100 kg without falling over or becoming stuck. Used in this regard is the GARM robotic platform developed by Fraunhofer FKIE in cooperation with Swiss enterprise RUAG. Because of its size and engine, this vehicle is offroad-capable and can also handle much heavier loads.

The GARM is equipped with a manipulator capable of carrying up to 5 kg, a payload common for systems of this size. The manipulator is used to attach a hook to the gear worn by the soldier, who is then pulled slowly on a steel cable out of the danger zone. Although this approach appears quite rough at first sight, it offers several advantages. Firstly, personnel can be rescued even if they are no longer able to actively assist and, secondly, during rescue they present only a small target while being pulled along slowly. Due to the low speed, the rescue process does not generally inflict any additional serious injuries.

The attachment of the hook to the soldier's gear is a critical moment. This remotely conducted task is difficult even for experienced operators using conventional control panels. An FKIE-developed assistance system provides the capability to control the robotic manipulator through the movements of the operator's arm. This direct man/manipulator interaction allows a degree of control whereby also complex manipulation tasks can be conducted in a fast and focused manner. The control system is portable and can be deployed quickly anywhere. The requisite sensors are integrated directly into the operator's clothing, thus necessitating only very little space. Thanks to an optimisation algorithm it does not require any calibration movements like other systems do.

The system as a whole is managed from a control station, which can be set up quickly and operated by a single person. The UGV makes a lot of information available about the system itself and its environment which is processed by smart assistance systems, thereby lightening the operator's work load and allowing precise control of the robotic system even in stressful situations.

A robotic system for rescuing injured persons from unsafe environments was presented for the first time at the M-ELROB 2014 in Warsaw. The M-ELROB is an annual competition organised since 2006 by Fraunhofer FKIE for outdoor robots employed in military scenarios. In 2014, rescuing injured personnel was introduced for the first time as a scenario, with a total of nine teams vying to rescue two training dummies hidden within an expansive outdoor area. Dummies with a weight of 10 kg, 35 kg or 74 kg could be selected, depending on the performance capabilities of the robotic platforms. The design of the GARM robot enabled the Fraunhofer FKIE team to rescue the 74kg dummy, with the intuitive arm control yielding a significant time advantage. The mission scenario was negotiated within 22 minutes, while the second-fastest team required 29 minutes.

The special award of "Best Novel Scientific Solution" additionally received for the innovative arm control system as best scientific contribution underlined that such intuitive support functions are regarded as a promising possibility for improving the usability of robotic systems.

Fig. 1: The robot pulls a dummy out of the danger zone

Fig. 2: In the MedEvac scenario, participants were tasked with locating and retrieving an injured person

Fig. 3: Attaching a hook to the soldier's gear proves to be a difficult task which cannot yet be performed automatically

Fig. 4: Once the dummy is hooked up, the robot can slowly pull it out of the danger zone

Fig. 5: The robot is operated from a remote control station. Assistance functions simplify task execution

Fig. 6: The operator's arm motions are intuitively conveyed to the robot's manipulator, making the difficult task much easier and quicker to complete

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Human systems integration for robotic assistant systems: controlling highly automated trucks on a tight or loose rein

Truck convoys are often associated with high levels of stress and risk for the personnel involved. Highly automated trucks that follow each other can mitigate this, but have so far been permitted only with safety drivers. The StrAsRob project is aimed at researching the robotic technology and the ergonomics and interaction of safety drivers and automation, and includes their testing in a simulator as well as in real vehicles.

The ability to transport men and materiel efficiently and safely in truck convoys is vital to the success of defence systems. Those who have experienced driving in convoys know how tiring it can be for drivers, not only through having to maintain a close distance to the vehicle in front but also through the journeys being very monotonous. Furthermore, the supply routes in operational areas are often under threat, necessitating the use of armoured vehicles, thereby imposing weight restrictions and making driving more difficult and risky because of a restricted field of view.

Technological advances have already made it possible for vehicles, in certain situations, to drive fully automatically, i. e. without a driver. One example among a number of robotic driving systems is the Google car, which is designed to operate with no driver whatsoever but, for that very reason, will be permitted only in limited circumstances for the foreseeable future. Far more realistic are developments toward assisted, partially as well as highly automated vehicles which can be driven either automatically or with varying degrees of automation, but with human drivers being able to override and take over the driving themselves. Encouraged by the success of automation in aviation, there have been developments in the civilian automotive industry toward highly automated driving on congested roads and on highways which, thanks to an amendment to the Vienna Convention on Road Traffic, has also been permissible since 2013, with some aspects now already in serial production and on the market. This technology offers a high potential also for military vehicles but, because of the focus to date on public road use, can be applied to military environments only after additional research.

The StrAsRob project being undertaken for the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw) addresses this issue of highly automated military transport vehicles. Building upon the many years of research into automated driving carried out by the University of the Bundeswehr in Munich, enterprises Diehl and Rheinmetall are constructing a demonstration vehicle based on an MAN truck capable of following other vehicles fitted with rear-mounted target markers.

Fraunhofer FKIE, together with the Bundeswehr Logistics School, the licensing authority, industry and the BAAINBw, is working on the interaction between drivers and automatic driving systems and is conducting tests in simulators as well as with test vehicles. The starting point in this regard is the cooperative handling of vehicles in which the human driver and automation system work together in a degree of automation that can be chosen by the driver. This is comparable to a well-trained horse which the rider can steer using short or long reins and thus control directly or indirectly.

This interaction has been developed together with future users in what is referred to as an “exploroscope”, a laboratory specialising in the exploration of new technologies which allows different models and variations to be tested relatively quickly with the aid of driving simulators. The best variants are then realised in software form, which itself is then tested in a simulator, improved iteratively, and applied to the test vehicle.

The concept offers good prospects for significantly improving convoy driving, for making it not only safer but also for freeing up drivers to engage in other tasks such as surveillance of the surrounding environment. The concept can also be applied to other vehicle types and driving situations, in particular to remotely controlled vehicles where the safety driver is no longer located in the (only lightly armoured) vehicle itself but has the ability, if need be, to intervene from a distance via radio transmission.

Fig. 1: Highly automated convoy driving using target markers (Source: BAAINBw)

Fig. 2: Participatory design of real-life scenarios for StrAsRob and their interaction in the FKIE exploroscope

Fig. 3: Generic prototype of the StrAsRob display with four levels of automation

Fig. 4: Highly automated convoy driving in a simulator test

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Full-motion video exploitation for reconnaissance and surveillance

Video exploitation is a major backbone of modern reconnaissance, surveillance and security systems. However, most existing video processing solutions provide only basic video visualisation features and recording possibilities. Fraunhofer IOSB has, with this in mind, developed the ABUL (German acronym for 'automated image exploitation for unmanned aerial vehicles') video exploitation system, which integrates current research work in order to assist the operator in the exploitation process.

One focus of the scientific work conducted by Fraunhofer IOSB lies in researching video exploitation methods for reconnaissance and surveillance tasks. It is not possible to view video exploitation algorithms in isolation, as they have to be embedded in a complex structure that incorporates aspects such as geospatial data processing, human computer interfaces, sensor properties (IR, VIS, SAR, …), interoperability, etc. Failure to consider these aspects at an early stage of research work can mean that the implementation of research findings for military use can lead to high costs both financially and in terms of development time, or even become impossible. Fraunhofer IOSB therefore works very closely together with end-users in the exploration of new methods in order to shorten the transitional phase from research to application. Funded by industrial contracts, research is conducted not only into theoretical methods but also into specific system developments. The advantage of this is that, firstly, up-to-date findings can be made available at short notice to the military's photo interpreters and, secondly, feedback from the military can be taken directly into account in the research work.

Fig. 1: UAV LUNA in launch position.
The ABUL video exploitation system provides interoperability by meeting the STANAG 4609 video interface standard

Fig. 2: ABUL video exploitation system integrated in the LUNA GCS (ground control station)

Fig. 3: Graphical user interface of the ABUL system that assists the photo interpreter with a variety of algorithms

The core system in this connection is the ABUL video exploitation software and its algorithms, which have been under development at Fraunhofer IOSB for more than 10 years. ABUL provides photo interpreters with real-time-capable methods for online airborne surveillance and tactical reconnaissance as well as functionalities valuable for offline exploitation. The algorithms cover, among other things, activity detection, object tracking, georegistration, and image stabilisation and enhancement through real-time multi-frame superresolution.

Novel image processing methods for detecting changes are also being explored and examined, in which connection a newly developed video database plays an important role. The latter allows the user to search selectively and efficiently for specific reference material from several hundreds of thousands of images from prior reconnaissance flights. For this purpose it is possible to search on the basis of geographical similarity, as well as specific markers or image properties such as ground spatial resolution.

In addition to the efficient algorithms for image and video exploitation, interoperability, which is crucial for mission success, is established through processing and generation of STANAG 4609 video streams and other STANAG-compliant products both for images (STANAG 4545) and for tracks / plots (STANAG 4607). This also includes interfaces to the Coalition Shared Databases (CSD, STANAG 4559) developed at IOSB to provide NATO-wide distribution of the exploitation products, as well as the IOSB tool i2exrep (STANAG 3377) for interoperable reporting.

Originally developed for processing the videos of remotely piloted aircraft systems (RPAS), the ABUL algorithms are not restricted to just this application. Several projects have demonstrated that the methods are also suitable to process data from maritime and land-based reconnaissance systems or surveillance cameras. MABUL, a mobile version of ABUL, is the latest development aimed at broadening the field of application and provides selected functionalities for notebooks or tablets. This has already been realised successfully for MTI and image mosaicing through optimised image processing algorithms.

The Air Force Imaging Reconnaissance Training Centre in Fürstenfeldbruck has equipped one of its classrooms with ABUL systems for the training of Bundeswehr aerial reconnaissance officers, thus providing the capability to teach video image exploitation with the latest methods and to close the gap in the chain between algorithm research work and application in real systems.

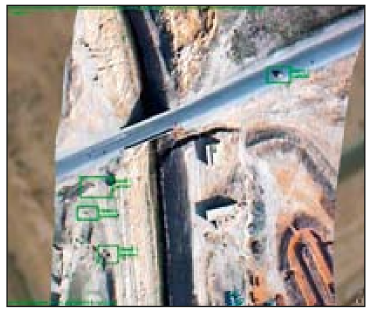

Fig. 4: Result of change detection: relevant changes between two video mosaics

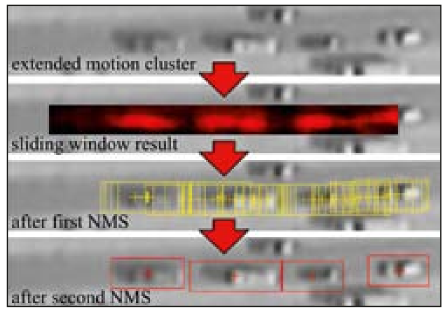

Fig. 5: Vehicle detection algorithm: step-by-step extraction of vehicles from video data

Fig. 6: Mobile derivative of the video exploitation system on a tablet (fully rugged). Vehicle detection is activated and marks moving vehicles (red markings)

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Ad hoc generation of 3D reference data

Military missions are teamwork and therefore depend on the exchange of spatially referenced information. A soldier learns to utilize tools such as maps, drafts, etc. skillfully for such purposes. Command and control (C2) as well as target hand-off systems are able, however, to carry out this demanding work faster and more precisely. The attainable improvement in performance is contingent on the same basic tool: up-to-date georeference data.

As early as his or her basic training, a soldier will learn to transfer information of spatial and temporal reference and later will perform this task recurringly. The target to which attention is to be drawn is described in connection with distinctive features of its surroundings, and the description is transferred together with the target's position, which is determined by comparing the maps and the terrain. The recipient locates the target after further comparing the maps and the terrain for him- or herself and identifies it from its description. This everyday yet demanding procedure can cost time that possibly is unavailable or leads to results that are so inaccurate that target engagement becomes impossible. This represents a high risk which can be minimized through the use of modern technology. An image-based target hand-off system allows the recipient, for example, to carry out precise localization, automatic feature descriptor processing and real-time target re-identification. Although image processing algorithms replace thought processes, the basic principle has remained the same: referencing spatial and temporal information in relation to common reference data. Just as a map has to be optimized for interpretation by a human being, the reference data have to be tailored to the requirements of the automatic target hand-off system. Among these requirements, the most important is up-to-dateness, next to efficient processability of the data. To be able to function as an all-aspect system, in other words also including land-based elements, 3D reference data are necessary.

It is for this reason that Fraunhofer IOSB is researching possibilities to generate appropriate reference data, besides developing an image-based, all-aspect target hand-off system. At the forefront of the research is the utilization of geo data provided by the Bundeswehr Geoinformation Service. These data can be made available to the Bundeswehr in the necessary quality and in compliance with the legal requirements. However, criteria such as resolution, information density and up-to-dateness are difficult to meet to the extent required, especially in the context of obtaining data during mission initiation processes.

Fraunhofer IOSB has developed a process chain for the ad hoc generation of 3D reference data so as to be able to rapidly supply modern C2 as well as target hand-off systems with the reference data that are needed. While broadly available official 2.5 or 3D data constitute the basic framework, 3D and 2D land-based or airborne measuring techniques, in combination with data fusion processes, allow fast densification, updating and specialization of the reference data. A multi-sensor platform with a processing station for airborne use has the capability to record and process laser scanner data, imaging data in different spectral ranges, and even hyperspectral images. It is thus possible to demonstrate how future remote sensing systems as well as operational reconnaissance assets can be incorporated into the generation of reference data. The information derived in the process ranges from texturized 2.5D surface models to surface material maps. A vehicle-based multi-sensor platform can be used for fast laser scanning and multispectral imaging. This technology allows small-scale densification of 3D geo data with high precision and resolution.

Data fusion processes bring together the geo information obtained from sensor data and merge it with the basic data already available. The datasets thus generated are so comprehensive that they can be used as source data for various applications, ranging from the generation of reference data for target hand-off to the derivation of simulation terrain databases.

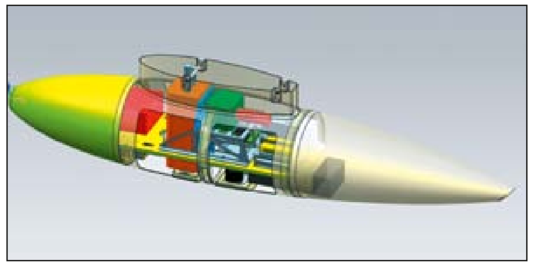
Fig. 1: Airborne multi-sensor platform (Source: Fraunhofer IOSB and OHB System AG)


Fig. 2: MODISSA – vehicle-based multi-sensor platform

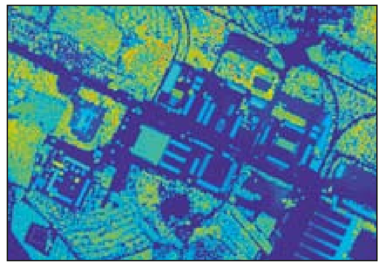
Fig. 3: Airborne laser scanning with Fraunhofer IOSB multi-sensor platform

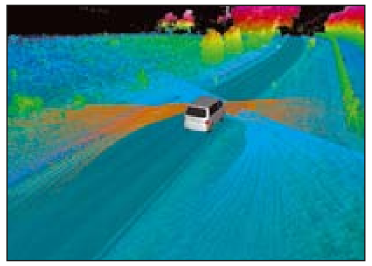
Fig. 4: Laser scanning images from mobile MODISSA vehicle


Fig. 5: Densified 2.5D surface model


Fig. 6: Simulation terrain database derived from ad hoc-generated 3D reference data

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On the way to a millimetre-wave camera

Information superiority is an important prerequisite for successful mission accomplishment and for protecting military personnel and civilians when in theatre. Imaging techniques have proven particularly effective for this purpose in the past. However, optical systems tend to fail in dusty or smokey environments. In future, this capability gap can be filled by high-frequency millimetre-wave radar systems.

Stirred-up dust, sand, snow or smoke is composed of particles with a size distribution which strongly scatters visible light and infrared radiation. Neither the human eye, nor cameras, nor sophisticated thermal imaging systems can therefore penetrate them. The wavelengths used in these systems lie in the range from around 0.4 µm to 12 µm.

Conventional radar radiation with its comparatively much greater wavelengths in the centimetre range is hardly affected, however, and is consequently able to penetrate numerous media and materials. But the size of a radar system directly scales with the wavelength used, i. e. in the centimetre range the systems are very large. A compact, lightweight, highly mobile system is hence not possible.

Compound semiconductor technology developed to an advanced stage at Fraunhofer IAF in Freiburg meanwhile makes it possible to produce radar systems that operate at frequencies of 100 GHz and well beyond. The wavelength of the radar beam is only some 3 mm or less. The size of the systems also decreases accordingly. The frequencies around 100 GHz are particularly of interest because that is where there is a “window” with particularly low attenuation of the atmosphere.

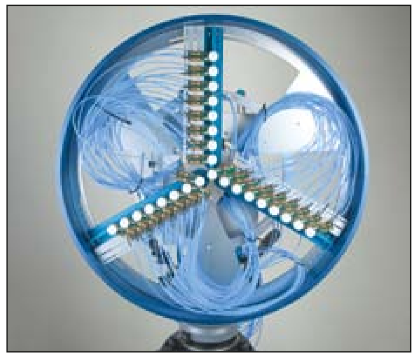

Fig. 1: Prototype of the millimetre-wave camera with a diameter of around 50 cm. Direct view of the antenna with 24 receivers and one transmitter

Fig. 2: Electronics developed in-house for the data processing

Where an imaging radar system is concerned, it would be desirable to build a matrix comprising as many individual detectors as possible, similar to the “megapixels” familiar from digital cameras. That is not possible, however, due to the some 5000-fold greater dimensions compared with optical wavelengths. Cost, weight, energy consumption and data processing also play a crucial role in the system’s design.

The theoretical concept of a sparse matrix offers a promising solution approach in this regard. It is not absolutely necessary to fill the entire aperture of a planar radar receiving antenna with sensors. It is also theoretically possible to achieve quite satisfactory spatial resolution with only a few sensors. Figure 1 shows the prototype of a first millimetre-wave camera from Fraunhofer IAF. The diameter of the antenna is 50 cm and it is occupied by only 24 receivers in a Y-configuration. The transmitter is located in the centre. As is the case with conventional radar systems, the detectors receive the radar echo. The distance from the object can be calculated from the time shift. Since the individual detectors are located at different positions within the antenna, they receive the reflected signal with a certain phase shift, depending on position. Further information about the scene is thus collected, it being possible to calculate additional image information using a complex algorithm. The symmetrical Y-configuration of the detectors simplifies the data analysis in this respect.

The analogue signals of the 24 individual detectors are digitised, it being necessary to process a data rate of 1.2 gigabits per second. A resolution matching that of simulation calculations has already been achieved at a distance of 15 m. Figure 3 shows a comparison of a simulated point reflector and a corresponding test measurement.

Figure 4 shows the transmitter and one of the 24 receiver modules used. These are each only 60 mm x 20 mm x 25 mm in size. The “white ball” is an inexpensive polyethylene lens used to increase the antenna gain (directivity) of the underlying planar broadband antenna.

The first experiments involving this prototype have already proven very promising. It should therefore be possible to develop a compact dust- and smoke-penetrating imaging radar system to meet the future needs of the German Bundeswehr. The use of even higher frequencies around 300 GHz would further reduce the system dimension. Sophisticated concepts such as gated viewing or frequency modulation of the transmitter represent interesting options for successively improving the quality of the image information.

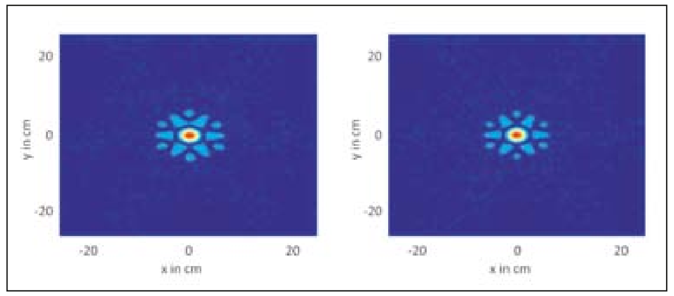

Fig. 3: The signal from a point reflector, comparing simulation (left) and measurement (right), demonstrates the effectiveness of the novel concept under real conditions

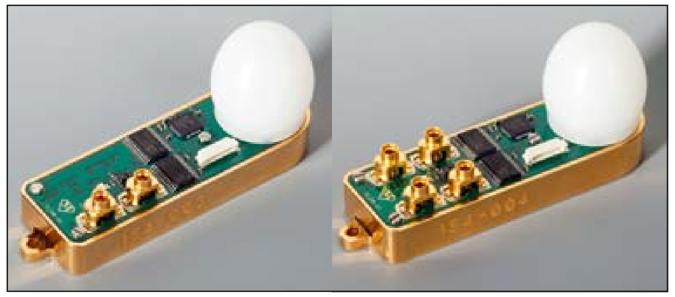

Fig. 4: Detail of the transmitter (left) and the receiver (right), as used in the camera. Usable frequency range 87 – 103 GHz

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Power electronics for Europe's defense industry improved with gallium nitride: MANGA

New developments for gallium nitride-based electronic components for use in radar applications and electronic warfare systems are helping Europe's defense industry to move towards independence: a multinational project under the leadership of the European Defense Agency (EDA) has succeeded in implementing the entire supply chain for power electronics components for high-frequency applications in Europe.

Researchers and industry partners from five European countries are working together to optimize techniques for developing and manufacturing power electronics based on gallium nitride (GaN) with the aim of producing high-quality GaN-based electronic components in Europe.

In the past ten years, mainly in the USA, GaN-based electronics has evolved from a research topic into a technology commercially available for military applications. Because of the semiconductor's high performance capability and robustness, GaN-based power electronics components are already replacing established technologies for electronic counter and warfare measures. In future this technology will find increasing application in radar systems and broadband amplifiers thanks to its excellent electronic properties and efficiency.

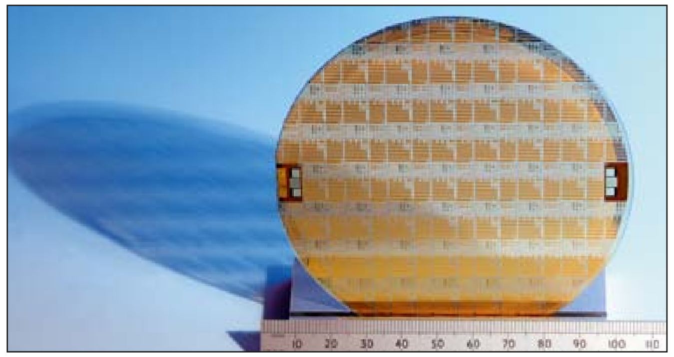
Where the increasing use of efficient components is concerned, the European defense industry is facing growing demand for the reliable supply of power electronics parts. In March 2010, therefore, a dedicated research program was launched with the aim of reducing the dependence of Europe's defense industry on suppliers outside Europe and of avoiding possible international delivery restrictions. Under the guidance of the EDA, leading research institutions and universities, as well as defense industry enterprises from Germany, Sweden, France, Italy, and the United Kingdom have been working together for the past four years on Project MANGA (Manufacturable GaN: SiC substrates and GaN-based heterostructures supply chain) to advance gallium nitride technology in Europe.

In order to establish a European GaN technology at the industrial level, it is first of all necessary to make semi-insulating SiC substrates available for the epitaxial growth of GaN-based heterostructures. Then, the entire supply chain, ranging from the SiC substrates to the industrial manufacture of high electron mobility transistors (HEMTs), needs to be implemented within Europe to facilitate independent production of GaN-based electronic components for military applications. Within the scope of the project, GaN-based heterostructures have been generated epitaxially on newly developed, high-quality SiC substrates. These heterostructures and use of established manufacturing technologies have culminated in the production of completely European, state-of-the-art power electronics components.

Both the quality of the SiC substrates and the performance of the components are on a par with comparable components from the USA that are currently setting benchmarks for modern GaN technology. One of the main things which this has demonstrated is that there are the capacities within Europe for the industrial production of high-quality 100 mm-diameter semi-insulating SiC substrates.

The goal of the EDA, also in future projects, will remain the further loosening of international trade constraints for Europe's defense industry. Having now succeeded in independently developing and producing militarily suitable, state-of-the-art GaN-based transistors completely within Europe, the project partners wish to focus in future on improving the reliability and material quality of components.

Data from the universities which have participated in Project MANGA and have studied the impacts of transistor layer variations on the performance of HEMTs will help to further optimize the HEMT technology. In a follow-on project the project partners also wish to achieve the qualification of a European industrial wafer supplier for the realization of state-of-the-art power electronics components.



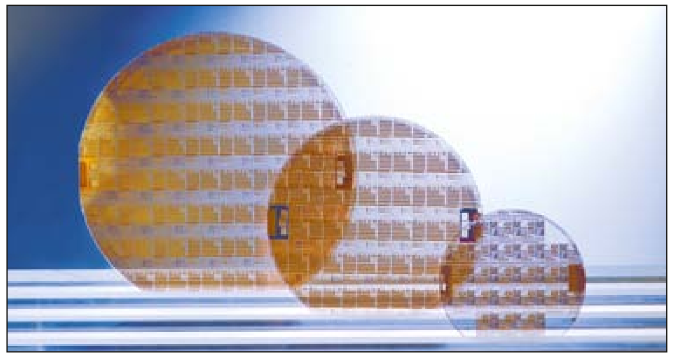


Fig. 1 to 3: Image of a processed GaN-based heterostructure on a 100 mm semi-insulating SiC substrate. Also shown are processed and packaged integrated circuits for use in long-term reliability testing of high-frequency power electronics applications

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Lithium-ion batteries safe for military use

High-performance electrical energy storage devices are elementary to meeting the basic military requirements for high mobility, autonomy and security of supply. A core aspect in this connection is the development of suitably efficient and portable energy sources. Lithium-ion batteries have meanwhile found a broad range of civilian applications because of their higher energy and power density, and the aim now is to make them fit for military use.

The use of high-performance lithium-ion batteries can bring with it the danger of cell-internal events developing which, through the occurrence of a cell-internal short circuit, results, in the worst case, in a thermal runaway (TR) of the cell. Under unfavourable conditions this can lead to complete destruction of the battery. It is possible for a cell-internal short circuit to remain undetected when the battery management system on that cell measures the voltage and temperature, and for the cell to spontaneously develop a TR. So that such cases do not occur in military use, there is need for a better understanding of the mechanisms underlying an internal short circuit. To achieve this, it is necessary to be able to generate cell-internal short circuits directly in specially prepared test cells and to analyze their development during the operation of that cell. Non-destructive computed tomography (CT) is an imaging method suitable for this purpose. The testing, however, calls for special miniaturized test cells, such as are developed and manufactured by the Fraunhofer Institute for Chemical Technology ICT in Pfinztal. Recordings of such special cells are then made with corresponding resolution at Fraunhofer EMI. To display even the finest structures in the micrometre range

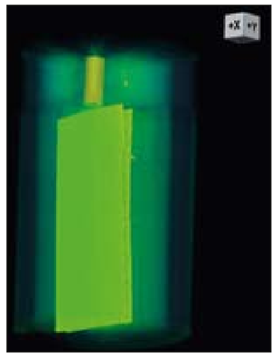

Fig. 1: Computer tomographic image of a miniaturized lithium-ion cell (2 mm diameter, 10 mm long)

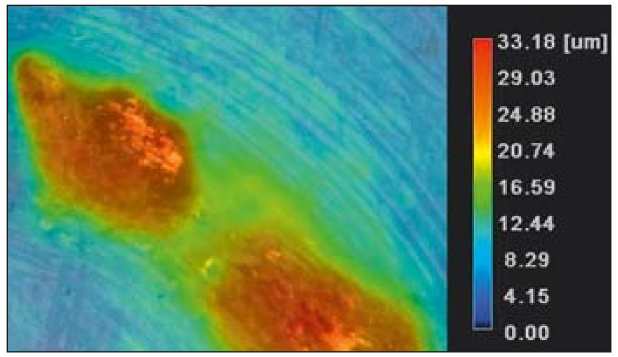

Fig. 2: Light microscopy height profile of a metal particle through a lithium-ion separator (cell- internal short circuit)

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in the separator and in the electrodes of a lithium-ion cell with sufficient contrast, it is necessary to increase the X-ray contrast. As the electrolyte solution permeates the entire pore system of the electrodes and of the separator material, it is advantageous to increase the X-ray absorption of the electrolyte solution. At Fraunhofer ICT, numerous electrolyte solutions are being synthesized and tested electrochemically for their suitability for use in lithium-ion cells. Filling the miniaturized test cells completely with these special electrolyte solutions presents itself as a particular challenge.

Numerical simulations are performed using the Finite Element Method (FEM) in order to estimate the impacts of different short-circuit scenarios on the cell as a whole. A variety of material-specific parameters such as electric resistance, heat conductivity, heat capacity, etc. is necessary to achieve the most realistic simulations possible. These values are determined on components of commercial lithium-ion cells and supplemented with values taken from literature.

Measuring the electrical resistance of a cell-internal short circuit occurrence caused, for example, by a metal particle represents a special challenge. Special test setups are used for this purpose and, besides determining the electrical resistance of the cell-internal short-circuit location, it involves measuring the depth of penetration of the metal particle into an active layer of a lithium-ion electrode by means of light microscopy and scanning electron microscopy (SEM). Based on all the data obtained it is possible to parameterize numerical simulation models with realistic measurement data and to acquire, with the aid of these models, a better understanding of the processes that take place during a cell-internal short circuit. It is identified, for example, that a cell-internal short circuit between the conductive metal foil of the cathode and the active layer of the anode, presents the highest risk potential for initiating a TR in a cell.

These findings are then taken directly into account in the selection and design of electrical energy storage systems based on lithium-ion batteries suitable for military applications, because protection and safety of the user are paramount.

Fig. 3: Safety test / abuse attempt by overloading a lithium-ion cell (pouch cell)

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Insensitive, high-performance explosives

Researchers at Fraunhofer ICT are looking to develop new explosives which combine high performance with low sensitivity to unintended reactions. Different approaches are being pursued to achieve this, ranging from the design of new energetic molecules, and their production and processing, through to testing within the system.

The chemical and mechanical stability of explosives depends essentially on their composition and on the bonds within the molecules, as well as on their molecular arrangement, for example within the crystals. Layered structures like FOX-7 and FOX-12 are characterised by insensitive properties and because they compensate for external stresses through movement of the layers. High-quality crystal structures with low defect concentrations also offer reduced sensitivity, since dislocations, impurities, cavities or trapped solvent can lead, under load, to the formation of initiation zones (hot spots).

These effects are being used in the particle pilot facility at Fraunhofer ICT to refine explosive particles. EHMX and RDX explosives, for example, have been coated with FOX-7 and FOX-12 in a fluidised-bed coater to achieve an overall reduction in sensitivity. The refined explosive particles have been produced on a laboratory scale and characterised with regard to their safety during processing (friction and impact sensitivity). They have subsequently been incorporated into explosive formulations, and explosive charges have been cast and cured. These trials have demonstrated the safe handling and good processability of the materials.

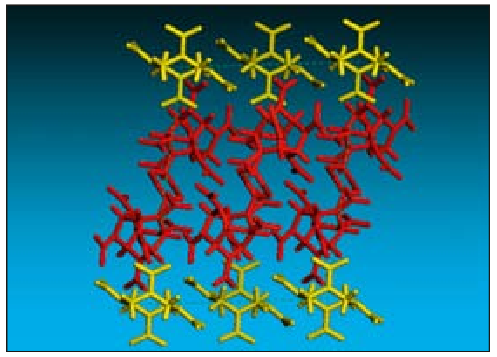

Fig. 1: Structure of HMX-CL20 co-crystals

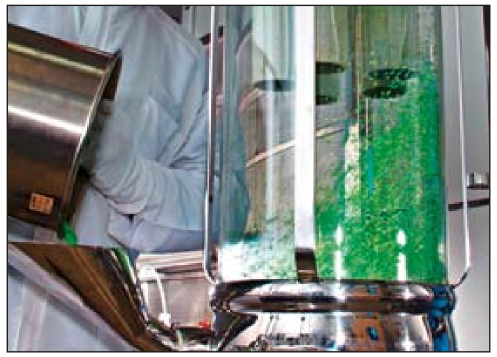

Fig. 2: Coating of explosive particles in a fluidised-bed coater

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The explosive charges were characterised with regard to performance and shock sensitivity using the gap test, plate dent test and measurement of the detonation velocity. The detonation velocity measured for the formulation based on 64 wt.% HMX/FOX, 20 wt.% aluminum and 16 wt.% HTPB binder was 7569 m/s. The charges consisting of explosive particles coated with FOX-7 and FOX-12 exhibit a lower sensitivity in the gap test. The initiation pressure of HMX-based explosives coated with FOX-7 (2.79 GPa) is higher than that of uncoated HMX explosives (2.36 GPa).

A new structural concept is also being explored at Fraunhofer ICT with the production of so-called co-crystals. This involves combining different explosive molecules in the crystallisation phase, thereby creating new crystal structures with an expanded property profile. Current research is focusing for example on co-crystallising high-performance explosive CL20 with HMX, thus coupling the good performance of CL20 with the good handling properties and the insensitivity of HMX. Initial batches of these co-crystals have been produced. After detailed characterisation and identification of the safety-relevant properties, the production technology will be upscaled in a next step in order to produce larger quantities for more extensive testing.

Structure-sensitive methods such as X-ray diffraction are being employed for the further characterisation and quality assurance of the components and products. The behaviour of explosives under extreme conditions is being investigated in a project designated „Insensitive High Explosives". The investigations will identify damage mechanisms such as crystal fracture and twinning in plastic-bonded explosives, as well as their mechanical load thresholds. This will open up new approaches to quality assurance.

The research findings will serve to develop future shock-resistant high-performance explosives, for example for penetrator and solid propellant applications.

Fig. 3: Plastic-bonded explosive based on HTPB and FOX-7

Fig. 4: Investigation of explosive crystals using X-ray diffraction

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PIO – Hazardous pilot-aircraft interaction

The term PIO (Pilot Induced Oscillations) denotes uncontrollable oscillations caused by flight mechanical and flight controller design deficiencies during challenging flight manoeuvres. DLR's Institute of Flight Systems has explored new possibilities for preventing such aircraft behaviour and researched methods for identifying these unwanted tendencies at an early stage in flight tests for newly developed aircraft.

The PIO phenomenon, an unwanted oscillatory response of aircraft to pilot input commands that can become divergent to the point of complete uncontrollability, occurred in the 1990's especially during the testing of new fighter and transport aircraft fitted with modern digital fly-by-wire flight control systems and even led to devastating mishaps. Extensive investigations into these events have revealed that, contrary to what the term PIO suggested, the root cause of this aircraft behaviour is not the pilot, but lies in disadvantageous flight dynamics characteristics which do not become apparent under normal flying conditions. One potential trigger for the abruptly changed behaviour in response to pilot inputs is a limitation in the control surface actuator rate which, once activated, causes a sudden change in the vehicle dynamics. Actuator rate limiting can occur when large control surface deflections are needed very quickly and the actuator, in the attempt to achieve them, runs up against its rate limitation. If the required actuator rate becomes greater than the maximum possible rate, the control surface is no longer able to follow the command signal, resulting in an abrupt phase delay as depicted in Figure 1. The aircraft response hence no longer matches the inputs of the pilot who, by introducing even greater control inputs in frequency and amplitude into the system, tries to enforce the desired response. Thereby inadvertently saturating the system even further and increasing the closed loop gain which, in turn, increases the phase loss and potentially makes the closed loop pilot vehicle system unstable. By integrating an anti-windup compensator into the closed loop flight control system (Figure 2), it is possible for the output (control surface deflection) signal and input signal (pilot command) to be in sync again. Even when the amplitude of the output signal is smaller than the command signal, the aircraft still generally follows the pilot's inputs, thereby precluding PIO tendencies and hazardous flying situations.

The functionality and effectiveness of the anti-windup compensator has been successfully demonstrated within the framework of the SAIFE (Saturation Alleviation In-Flight Experiment) project, involving an extensive flight test campaign (Figure 3).

An important factor which contributes to PIOs is a high pilot gain during demanding manoeuvres (Figure 4). In the last few years it has become apparent that established flight test methods have only a limited ability to stimulate representative high pilot gains which may only become apparent in an emergency situation. In spite of thorough flight testing, some PIOs only surfaced during the operational use of an aircraft – this was for example the case for C-17 military transport aircraft of the USAF during Operation Enduring Freedom in Afghanistan.

The Workload Buildup Flight Test Technique was developed by the USAF test pilot school in 2005 and has the potential to gradually increase pilot gain up to a level previously unachievable in flight testing (Figure 5). Investigations by DLR involving 24 pilots from the German Air Force in a fixed-base simulator and 13 flying hours in a modified F-16 of the USAF test pilot school have shown that, although it is rarely possible to increase pilot gain beyond the level hitherto reached, the technique is however easier to learn, more intuitive to use, and can lead to a simultaneous increase in pilot gain and precision. It hence offers huge potential with respect to identifying PIOs and other mission-critical shortcomings in terms of handling qualities.

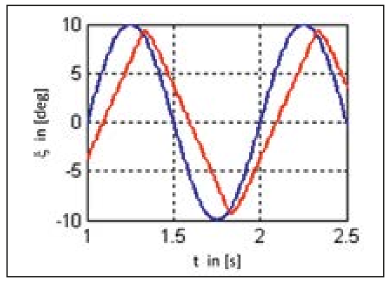

Fig. 1: Time histories of control command (blue curve) and real (red curve) control surface deflection (aileron ξ) showing the effect of rate limiting

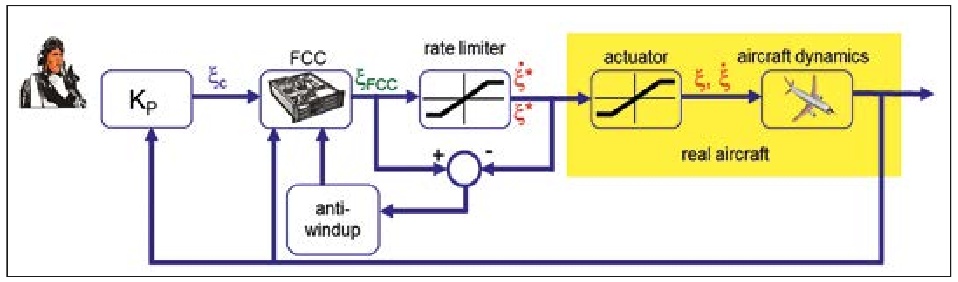

Fig. 2: Anti-windup filter integrated into the pilot-aircraft loop

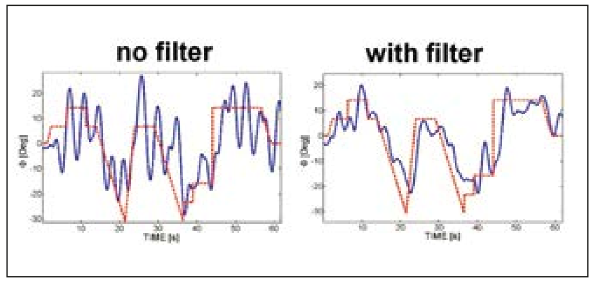

Fig. 3: Comparison of flight experiment results with and without active anti-windup filter, bank angle command (red curve), real bank angle (blue curve)

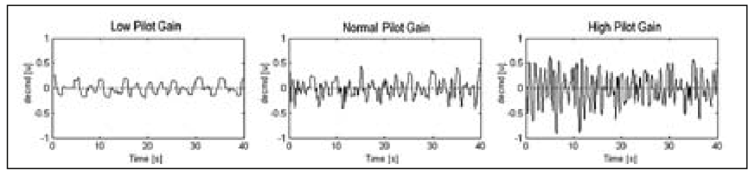

Fig. 4: Pilot control inputs for the same tracking task with an intentional pilot gain variation

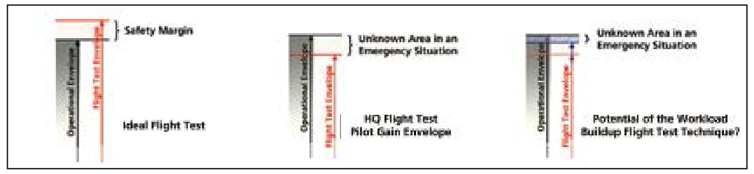

Fig. 5: Potential of the Workload Buildup Flight Test Technique

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Radar imaging of unconventional targets

Radar systems are used for many applications in which surveillance, reconnaissance, status control, or the determination of range and speed is the goal. Classical observation targets often include vehicles, urban infrastructures and nature. Even the human body in its environment is a target of interest, for which radar can deliver diverse information.

Besides the classical use of radar as a device for measuring range and speed, imaging approaches have served for decades to measure the reflectivity of objects. Particularly suitable for that purpose is synthetic aperture radar (SAR), whereby radar echoes are recorded within a certain frequency band along a certain range of aspect angles and then coherently processed to form an image. The bandwidth and the range of aspect angles define the spatial resolution, i. e. the attribute of the radar being able to discriminate spatially between smallest-sized adjacent scattering objects. The image amplitudes represent the strength of the reflectivity, in other words the object characteristic of whether it tends to reflect back or away from the radar waves under the given view conditions, or whether it even absorbs them. That circumstance determines, for instance, the way in which the radar information can be evaluated with respect to objects' surroundings. It is also of great interest, therefore, especially where safety-relevant applications are concerned, to what extent the human body displays evaluable interaction with the radar waves.

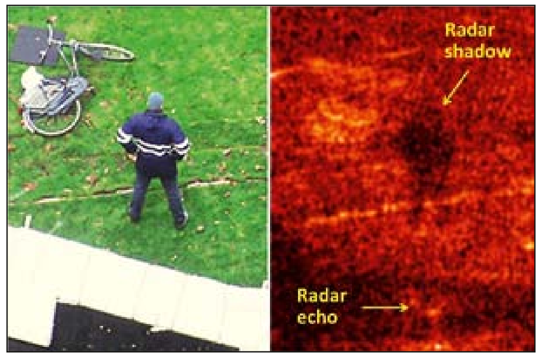

Fig. 1: 2D radar image of a standing person with around 6 cm spatial resolution. The person is undistinguishable by means of the radar echo, but clearly distinguishable by means of the radar shadow

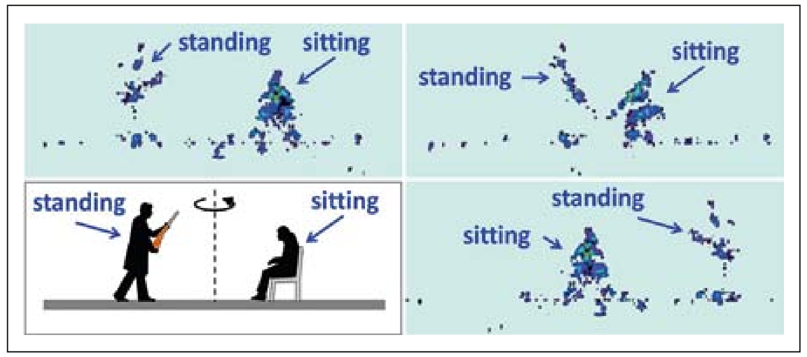

Fig. 2: 3D radar images of two persons as might be observable optically from a side view on a rotating platform from different aspect angles. One person is sitting on a chair, and the other person is standing and holding a dummy rifle. The radar echoes are here located in their correct positions. The spatial resolution is around 6 cm

Figure 1 shows, for example, the two-dimensional (2D) radar image of a standing person recorded with SAR around a centre frequency of 10 GHz (X band). The actual radar echo of the person is located in the wrong position in the image due to the person's height, and also fails to provide any information about the person. The presence of the person is made all the more visible by the person's shadow, which reproduces the projected contour very well. To achieve this, the focus has been adjusted purely mathematically to the existing geometry.

Since 2D imaging is only inadequately capable of reflecting the real three-dimensional (3D) world, a true 3D radar approach would be useful. This involves creating an additional measurement aperture in vertical direction with respect to the scene under observation, realised for instance by means of a sparse antenna array or also by using the SAR technique. Figure 2 shows X-band radar images thus taken of two persons as a side view from three different perspectives. In contrast to Figure 1 the radar echoes are now located in the right position and show the structural arrangement of each person quite clearly. A distinct difference between standing and sitting is observable, as is the elongated structure of the rifle held by the standing person.

In addition to radar imaging as a means of identifying structures and evaluating them, a temporal analysis of radar echoes is advantageous, with it being possible to make use of an object's range variation and of its Doppler frequency shift due to the radial velocities of the overall object including individual object parts. Figure 3 shows range profiles of the reflectivity of a person moving away from the radar, as a function of time. A mean linear gradient of the echo is clearly identifiable, corresponding to a constant increase in range of the torso over time. The curved echoes around that line reflect the alternating motion of the legs. Figure 4 illustrates the breathing of a person, based on the range variation of the thorax in relation to a thorax that is non-breathing. Here, too, the periodic activity is clearly visible.

Modern radar systems, besides being used for their classical functions, can also be applied to new target types as a means of enhancing the collection of information. Highest possible resolution and complex data processing, in addition to suitable radar techniques, are mandatory. A person in its environment can interact with radar waves in diverse ways and correspondingly generate different information. While X-band frequencies still offer sufficient capability to ingress or penetrate many materials, millimetre and sub-millimetre waves, for instance, can provide still significantly higher resolution.

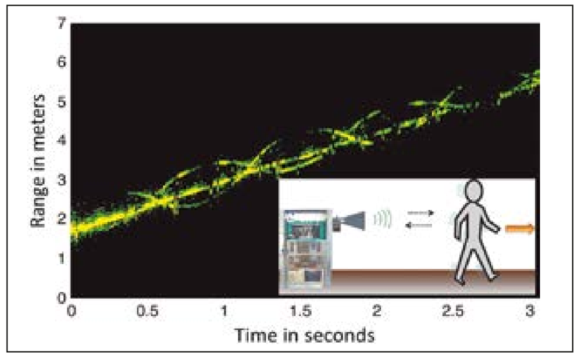

Fig. 3: X-band range profiles of the reflectivity of a person moving away from the radar position, as a function of time.
The range resolution is around 5 cm. The colour distribution of orange-yellow-green-black indicates decreasing reflectivity

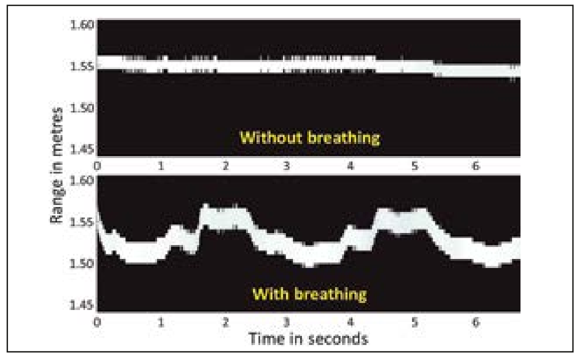

Fig. 4: X-band range profiles towards the thorax of a non-breathing/breathing person as a function of time.
The range resolution is around 5 cm

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Separation technology for missiles

During missile separation procedures, interactions occur between the individual bodies which can induce high dynamic loading. A clear understanding of these interactions is necessary in order to ensure safe separation. With this in mind, the DLR is conducting experimental und numerical studies on missile separation from jet wings.

An important aspect of operating missiles for the purpose of air and missile defence is the safe realization of separation procedures, be it during launch from the carrying platform, during stage separation of multi-stage systems, or during the shedding of protective covers that serve to enhance the aerodynamics and / or protect sensitive sensors during cruise flight. Characteristically where missiles are concerned, the separation procedure tends to take place at high velocities.

To gain a better understanding of such separation procedures and of the interactions occurring between the different bodies, extensive experimental and numerical studies have been carried out at the Institute of Aerodynamics and Flow Technology of the German Aerospace Center (DLR) as part of the government-funded Advance Missile Technologies 2 (FFT 2) research project and the follow-on Missile Technologies (FluTech) research activity.

For the experimental research on missiles separating from their carrying jets, generic wind tunnel models of a high-agility short-range air-to-air missile and of a “wing section” of a carrying jet were fabricated (Figure 1). These were then tested in the Trisonic Test Section (TMK) of DLR in Cologne, with aerodynamic coefficients being determined at flow speeds up to Mach 2.2. By using a Captured Trajectory System (CTS) it was possible to move the models in relation to one another in four degrees of freedom, meaning that the horizontal and the vertical distance as well as the angle of attack could be varied individually with respect to the oncoming flow. Parametric measurements were conducted to determine the forces and moments induced by the wing on the missile for a broad number of positions. As an example, Figure 2 shows curves of the yawing moment coefficient as a function of the horizontal position of the missile in relation to the wing (x = 0 is the start position) for different vertical distances between launch rail and missile.

In a second operating mode of the CTS, in addition to the parametric studies, simulations of complete separation trajectories have been conducted in the wind tunnel. This has involved adding a flight mechanic software module to upgrade the CTS control system, thus providing the ability to use the forces and moments measured during the testing directly to calculate the motion of the missile, and to then use this data to move the wind tunnel models suitably in relation to one another. The software adds external forces such as gravity and thrust. As an example, Figure 3 shows a sequence of schlieren images, taken during a test, for a simulated free-falling missile with limited thrust.

To complement the experiments, numerical calculations of the separation procedure have been performed at DLR in Brunswick, Germany, using the DLR TAU code, which is capable of solving the Reynolds-averaged Navier-Stokes equations for compressible and incompressible flows on structured or unstructured grids. The movement of missile and wing in relation to one another has been realized by applying the Chimera technique, i. e. the technique of overset grids. As in the experiments, coupling the TAU code with a software module for flight mechanic calculations has made the simulation of complete separation trajectories possible and, in the present case of the CFD calculations, even for movement of the missile in all six degrees of freedom. The calculations and experiments show good qualitative agreement overall. For example, the induced rolling moment measured in the experiments has been confirmed by a corresponding rolling motion of the missile in the numerical calculations. As an example of the CFD calculations, Figure 4 shows the pressure coefficient distribution on the surfaces of wing and missile in which regions of interactions are easily discernible.

Overall, the results serve to provide valuable information about the dynamic interferences occurring between wing and missile and make it possible to realize a suitable and safe design for missile control during the separation procedure. The methods developed here can, also, be applied in future to other separation procedures of interest.

Fig. 1: Wind tunnel models of wing and missile in the Trisonic Test Section Cologne (TMK)

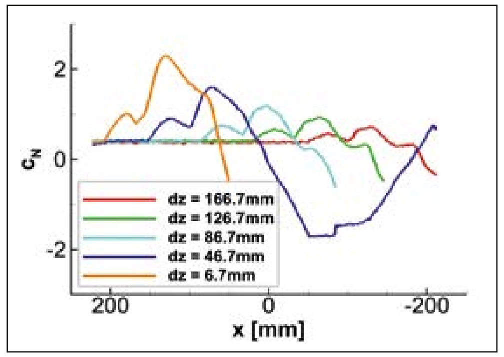

Fig. 2: Yawing moment coefficient for different vertical distances to the wing

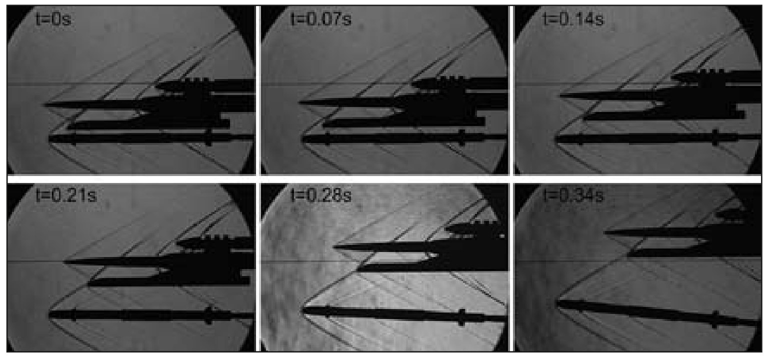

Fig. 3: Schlieren sequence of separation test with coupled flight mechanic software module

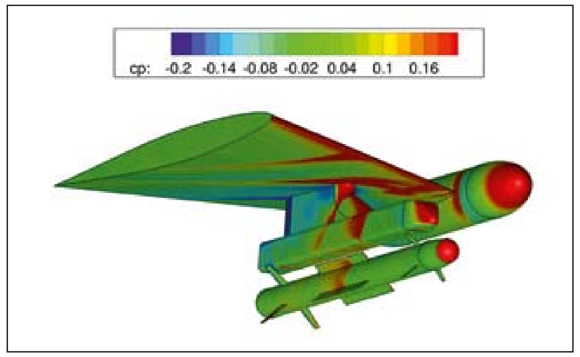

Fig. 4: Numerically calculated pressure coefficents for wing and missile

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Laser weapons

High-power lasers are potential weapons for a broad spectrum of scenarios – ranging from countering IEDs (Improvised Explosive Devices), for example, to "extended air defence applications", or also the protection of maritime assets. Research at the Institute of Technical Physics of the German Aerospace Center (DLR) in Stuttgart is focusing on laser sources, beam control, pointing and tracking components, and their evaluation on a laser test range.

Diode-pumped solid-state lasers – especially slab lasers, fibre lasers and thin-disk lasers – are seen as the best-suited sources with regard to focusability, compactness and high efficiency by today's standards. The thin-disk laser concept is the key technology undergoing research at the Institute of Technical Physics as it combines power scalability with excellent brightness and high efficiency. One elegant solution for power scaling is the master-oscillator power-amplifier (MOPA) concept, where a multi-kW thin-disk laser oscillator with excellent beam quality is amplified by a chain of high-power thin-disk amplifier modules. This approach has already been demonstrated for fundamental research in the past using pulsed lasers. Current experiments have demonstrated its feasibility also in continuous operation at the multi-kilowatt level. For these experiments an amplifying setup has been developed which realizes a high number of amplification passes through a thin-disk laser module.

The Institute of Technical Physics operates a laser test range to investigate the propagation and target effects of high-power laser radiation under realistic atmospheric conditions. Constant monitoring of the atmospheric conditions (turbulence, precipitation etc.) allows correlation with experimental results. Following the operation of a chemical oxygen iodine laser for several years on this test range, an industrial-grade thin-disk laser has recently been installed. This laser delivers several kilowatts of output power with high beam quality. Delivery of the beam by means of optical fibre cable makes the system quite versatile and, being an industrial-grade laser, 24 / 7 operation would be possible, the switch-on time being negligible. A dedicated beam control platform has additionally been developed and installed for this laser. This platform provides the capability for tracking experiments involving moving targets, and it is possible to integrate a fine-tracking system to compensate for beam jitter caused by atmospheric turbulence. First target engagements using high-power laser radiation over a distance of around 130 m have been successful.

In case of moving targets, turbulence effects and the motion of the target tend to interfere. These effects must be separated to be able to evaluate coarse and fine tracking systems systematically. A high-precision translation stage has been installed at the laser test range to simulate target movements. This agile target platform is able to emulate typical angular speeds as are expected for RAM targets; the angular position can be determined with a precision better than 1 μrad. In parallel with this, a passive tracking test platform (i. e. an agile computer-controlled telescope mount with a camera system) has been developed to evaluate tracking algorithms. The tracking platform has been successfully tested on the laser test range.

The experimental work is being accompanied by studies and surveys concerning potential engagement scenarios, laser safety and international laser weapon projects.

Fig. 1: High-power thin-disk laser amplifier with high number of amplification passes

Fig. 2: Laser test range

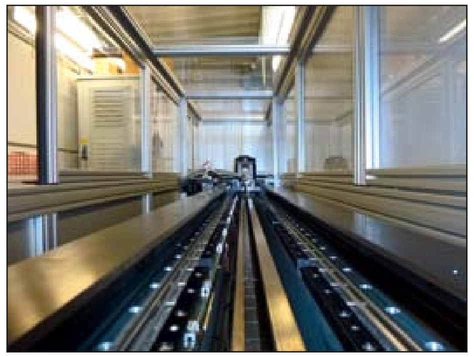

Fig. 3: Agile target platform (translation stage)

Fig. 4: Passive tracking test platform

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Magnus effect – experimental and numerical investigations into supersonic flows

Slender flying bodies such as projectiles or rockets are launched with spin in order to stabilize them. The fluid-mechanical phenomena that occur in this connection are known as the "Magnus effect" and can destabilize the flight behaviour. The investigations being conducted at the French-German Research Institute of Saint-Louis (ISL) to explore the phenomena caused by the Magnus effect are fundamental to evaluating the flight behaviour of highly agile projectiles.

Slender free-flying models such as projectiles or rockets not fitted with suitably dimensioned fin assemblies display statically unstable behaviour. These are, for this reason, dynamically stabilized by using a spinning motion around their longitudinal axis.

In the process, however, complex fluid mechanical interactions arise between the moving body's surface and the oncoming flow. This leads to changes in the body's boundary layer and its displacement, primarily generating side forces and corresponding yawing moments in a spinning model (Figure 1). The phenomena generally occurring in the case of rotating bodies in cross-flow are referred to as the "Magnus effect".

Having knowledge of the phenomena occurring in connection with the Magnus effect is essential for predicting the flight behaviour / stability of novel, highly agile guided projectiles as early as the design phase. Particularly the combination of high angles of attack and high spin rates has yet to be investigated in supersonic flow regimes. In that context the experimental and numerical studies being conducted at ISL are of fundamental interest for understanding the phenomena caused by the Magnus effect.

The Magnus effect occurs primarily due to pressure differences that are caused on both sides of the spinning free-flying body as a result of rotation about the longitudinal axis and manifests itself as a side force and a yawing moment. The structure of the flow topology and, thus, the resulting aerodynamic coefficients are strongly dependent in a non-linear manner on the angle of attack between the model's longitudinal axis and the direction of the oncoming flow (Figure 2).

In conformity with the predominant phenomenological flow patterns, the development of the Magnus side force can be classified into five characteristic sections:

1. Attached boundary layer ($\alpha < 3°$): The spinning motion of the model causes a uniform shift of its boundary layer in the spin direction, thereby generating a linear increase in the side force for higher angles of attack.

2. Development of attached vortices ($3° < \alpha < 15°$): Due to the development of attached vortices on the downwind side of the model and an associated expansion of the flow around the maximum thickness of the model, the flow field becomes highly asymmetric, leading to a strong nonlinear increase in the side force.

3. Transition to the complex multiple vortex system ($12° < \alpha < 25°$): The occurrence of secondary vortices generates a force counteracting the primary Magnus force direction. This causes a slight decrease in the side force coefficient.

4. Detachment of vortices ($20° < \alpha < 35°$): The successive detachment of the vortices from the model reduces the asymmetries in the flow pattern and leads to a decreasing side force coefficient within this angle of attack range.

5. Analogy to the behaviour of a cylinder in cross-flow ($35° < \alpha$): Even higher angles of attack have no further influence on the magnitude of the Magnus side force. Up to the limiting case of a 90° angle of attack (analogous to the behaviour of a spinning cylinder in cross-flow) the side force coefficient displays a relatively constant value.

The Magnus effect can, in the case of slender flying bodies such as projectiles, significantly degrade hit precision as a result oft the Magnus side force causing a shift from the original flight trajectory. Also, the Magnus yawing moment can destabilize the flight behaviour and consequently lead to the loss of the projectile. Both the experimental and numerical studies performed by the Aerodynamics Group at ISL give a detailed insight into the influence of the fluid-mechanical phenomena caused by the Magnus effect. The capability to calculate and evaluate the flight behaviour of novel, highly agile flying bodies as early as the design stage can lead to greatly increased stability and a higher hit accuracy for such spinning projectiles.

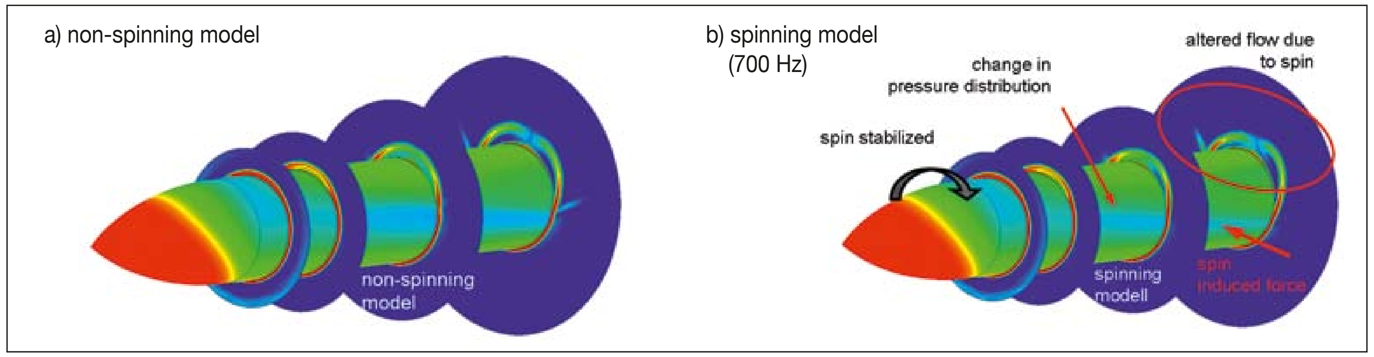

Fig. 1: : Influence of the model spinning motion on the boundary layer and the vortex system for projectiles with angle of attack (Mach number 3, angle of attack of 9°, pressure distribution on the model surface, density gradient in the contour planes)

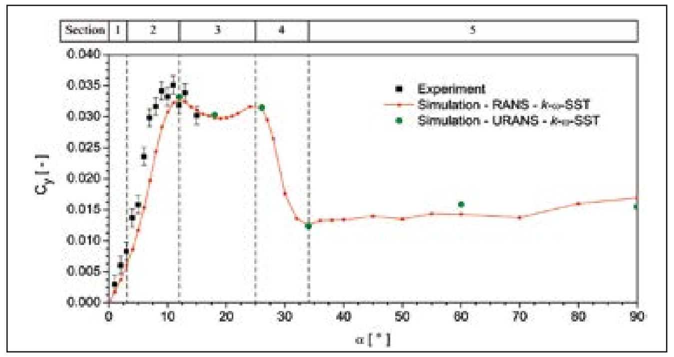

Fig. 2: Side force coefficient versus angle of attack for Mach number 3 and a spinning frequency of 700 Hz. Classification of the side force evolution as a function of the characteristic fluid-mechanical phenomena

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Analysis of the shielding effectivity of metallic rooms as part of a complex system

Strong external electromagnetic fields can lead to malfunction or even damage of electronic devices within a complex system, e. g. a ship. The risk is particularly high, if resonant frequencies of a metallic, cubic room are met. A higher electromagnetic immunity can be achieved by applying absorber materials.

Metallic rooms within a complex system, like the CIC (Combat Information Center) in a ship, are necessarily connected to each other via cables and apertures like ventilation slots and door gaps. Thus the inside cannot be shielded entirely against external electromagnetic fields, especially with high frequency components. Therefore, a metallic room without any leaks would be necessary.

The threat consists of nuclear electromagnetic pulses (NEMP) or HPEM sources (High Power Electromagnetics) and appears as sinusoidal HPM-fields (High Power Microwave) or UWB pulses (Ultra Wide Band) with a broad bandwidth. Their spectral density is depicted in Figure 1 qualitatively.

The resonant frequencies of a resonator depend on its dimensions. For a room with a size of 4 m x 3 m x 2.6 m (length x width x height), the first resonance is at 62.5 MHz. There, the occurrence of a standing wave inside causes the shielding effectiveness to collapse. The electric field of this resonance inside a room with a door gap as aperture is shown in Figure 2. The E-field of the illuminating TEM-wave (Transversal Electromagnetic) has an amplitude of 50 V/m. The field inside peaks at 1.35 kV/m in the center of the room, which corresponds to a factor of 27.

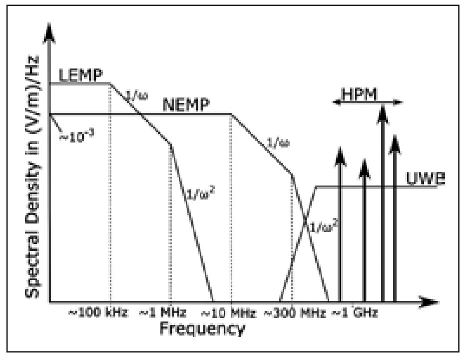

Fig. 1: Comparison of the spectral density of different signal types

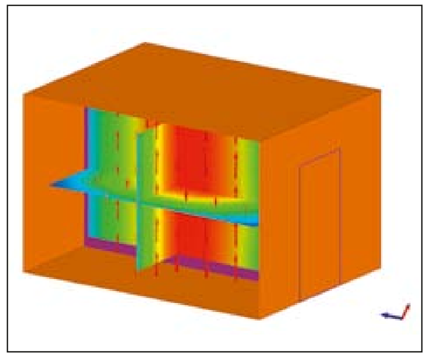

Fig. 2: Electric field strength inside the room at the first resonant frequency of 62.5 MHz

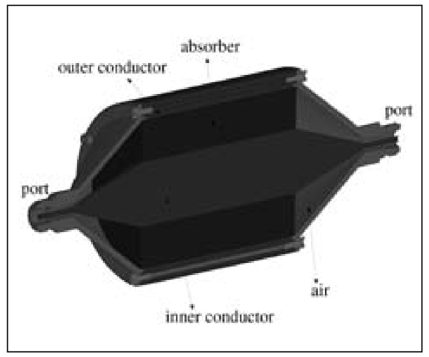

Fig. 3: Setup of the coaxial line experiment for measuring the electromagnetic properties of the absorber

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In order to improve the EMC (Electromagnetic Compatibility) properties, the use of absorber materials is analyzed in a cooperation of the Bundeswehr Research Institute for Protective Technologies and NBC Protection (WIS) and the University of the Federal Armed Forces Hamburg. These are already applied in anechoic chambers for free-field measurements. Therefore the walls are lined with a combination of ferrite tiles and dielectric pyramid absorbers made of polyurethane-carbon-foam, in order to cover a broad frequency range.

The improvement in shielding effectiveness by applying absorbers is analyzed with measurements inside the GTEM-cell (Gigahertz Transverse Electromagnetic) as well as CEM (Computational Electromagnetics). Therefore, knowledge about the electromagnetic properties of the absorber is necessary. These are determined with a coaxial line experiment, in which the reflection and transmission of EM-waves at the boundary absorber-air is measured. The employed coaxial line is shown in Figure 3, the samples of different absorber materials in Figure 4.

With the knowledge of the electromagnetic properties the numerical calculation of the shielding effectiveness with and without absorber is possible. The frequency dependent result is shown in Figure 5 with the rear side of the room lined with a layer of polyurethane-carbon-foam of variable thickness. 10 cm are sufficient to improve the minimum from – 26 dB to – 10 dB. This corresponds to a factor of 6.3.

Fig. 4: Absorber samples for the coaxial line experiment. From left to right: polyurethane-carbon, ferrite, silicon-ferrite, polyethylene-ferrite absorber

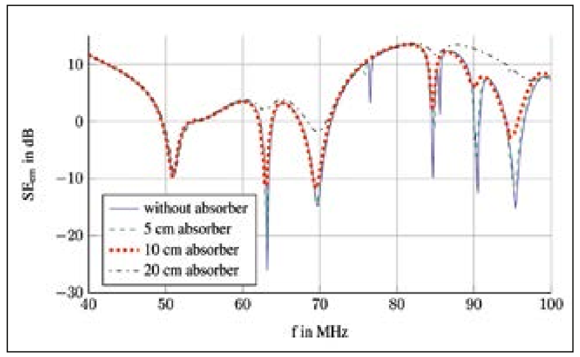

Fig. 5: Shielding effectivity with and without an absorber layer of variable thickness on the rear side of the room

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Technical evaluation and development of military communication systems

Military communication systems continue to evolve in view of changing mission types and requirements. The research being conducted by the University of the Bundeswehr, Munich (UniBwM), in the field of radio and satellite communications, as well as its outstanding technical equipment, are ultimately proving to be key in the successful cooperation with the German Bundeswehr on recent satellite ground station and VHF radio system projects.

Future tactical radio communications systems of the Bundeswehr are subject to the same rising demand for increased data rate availability and a higher number of supported users or user groups, comparable to civil mobile communication systems, for example. The University of the Bundeswehr, Munich (UniBwM) has been addressing this topic in close cooperation with Directorate I of the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw), giving special consideration to UHF SATCOM and VHF radio systems.

Knowledge about the propagation conditions for electromagnetic waves that serve to transmit information is a fundamental requirement for the development or installation of any new radio communication systems. Against this backdrop the UniBwM has been analysing the propagation conditions for satellite signals in the so-called P-band, i.e. the UHF range (0.23 – 1 GHz) to ensure smooth operation already in advance of installing any new ground station. Measurement of the transmission characteristics via a real satellite link involving the two communication satellites operated by the Bundeswehr (COMSATBw) has taken place using dedicated measuring equipment developed and used by UniBwM. Unlike satellite communications at higher frequencies for which only the propagation of waves on a direct path from transmitter to receiver is relevant, in the P-band surrounding buildings or the terrain might additionally cause a signal to be reflected and also received.

Fig. 1: UHF satellite antenna used for the measurement of the signals from the COMSATBw satellites

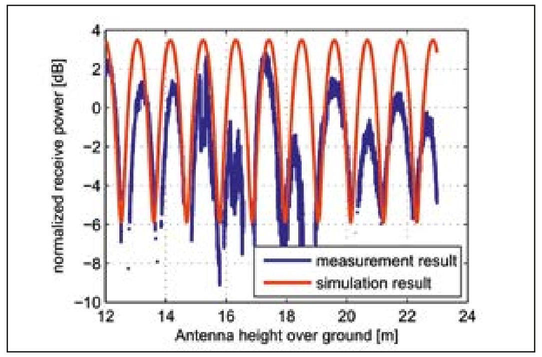

Fig. 2: Measured relative received power of the satellite signal using a directive antenna at different heights; comparison with a simulation result from a theoretical model

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Such signal interference can lead to system performance reduction or total failure of reception. The collected data and deliverables from the measurements will be used further in the setting-up of a new ground station in Gerolstein for communication with the two COMSATBw satellites.

Another focus of the cooperation between UniBwM and BAAINBw has been research into novel waveforms for data transmission by tactical VHF radio at 30-80 MHz. The internationally regulated narrowband channels of 25 kHz allow the current systems of the Bundeswehr to transmit only a few kBit per second. More novel waveforms for future systems may be suitable for transmitting at considerably higher rates, depending on the required range (and transmit power). So-called CPM (Continuous Phase Modulation) waveforms are the best suitable choice for this because of their favourable characteristics with regard to low transmitter power consumption and component quality requirements. Although they have been in existence for several decades now, the use of such modulation methods in conjunction with modern channel codes has become possible only due to the capacities offered by contemporary signal processors.

The research activities of the UniBwM on this topic are focusing on the development and improvement of waveform modulation methods with respect to achievable data rate, resistance to adjacent channel interference, and reduction of receiver complexity for demodulation and decoding. Furthermore, the UniBwM has flexible modem platforms at its disposal to perform realistic waveform evaluation in practical field tests. In 2013 and 2014, test campaigns were conducted in different scenarios. The results from these tests and the underlying research have been presented to the NATO standardization committees and compared against the findings from proposals submitted by other nations, thus revealing significant potential for future optimizations that are expected to have an influence on future national systems operated by the Bundeswehr.

Fig. 3: Measurement setup comprising a fixed and a mobile antenna for the practical evaluation of waveforms for data transmission via tactical VHF systems

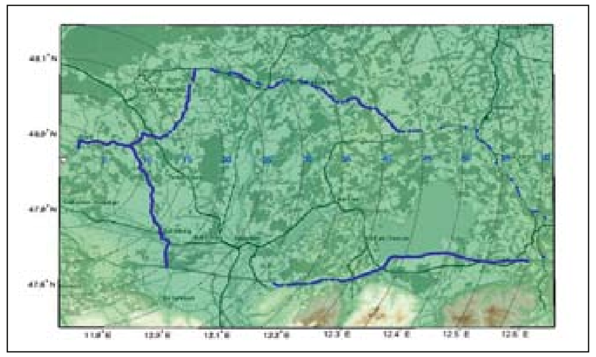

Fig. 4: Test result regarding the range of a very robust VHF waveform. At the locations marked in blue, error-free transmission was possible using the mobile receiver

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Testing of SATCOM on-the-Move systems

SATCOM on-the-Move (SOTM) systems are small vehicle-mounted terminals enabling communication via satellite while the vehicle is in motion. Dependent on the technology and size of the antenna, these systems offer the user data rates of several Megabits per second. A test supported by the University of the Bundeswehr, Munich (UniBwM), demonstrates their performance capability and provides the possibility to assess limitations and constraints.

The mobile transmission of high data rates is a capability urgently required by the Bundeswehr for connecting forces in theatres of operation where there is no terrestrial infrastructure. SOTM terminals are not only capable of transmitting high-resolution video data but also serve as a mobile connecting node for strategic connections between tactical mobile wireless networks over the “last mile” in theatres of operation. R&D study activities have been initiated by Directorate I of the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw) with the aim of evaluating the performance capability of SOTM systems in the Ku- and Ka-band and of assessing their suitability for use in the Bundeswehr. DIRACON Innovation Consultants GmbH, as the main contractor, is conducting these studies, supported by the Fraunhofer Institute for Integrated Circuits (FhG-IIS) and UniBwM.

The main components of a SOTM system are the antenna unit, which is mounted externally on the vehicle roof, and a satellite modem. While conventional satellite modems are often installed which are commonly used in fixed satellite service applications as well, the antenna unit is characterized by a dedicated automatic tracking and pointing mechanism. The antenna has to be capable of focusing permanently on the required geostationary satellite and of compensating for the motions and vibrations of the vehicle. This minimizes undesirable adjacent satellite interference and also enhances the link budget. Used as antenna technologies are either phased array antennas, i. e. antennas with electronic beam forming, or traditional reflector antennas. Hybrid systems are also available, with the tracking of the antenna being either mechanical, electronic, or a combination of both.

The studies are focusing on the practical laboratory testing of several commercially available SOTM systems. Three systems in the Ku-band were already tested in 2013, and three more in the Ka-band are currently undergoing evaluation. Laboratory conditions are achieved in FhG-IIS’s unique “Facility for Over the Air Research and Testing“ (FORTE) in Ilmenau; a test range specifically designed for testing SOTM systems. FORTE provides the possibility to measure the performance capabilities of different SOTM systems under predefined and reproducible conditions and, thus, an ideal test environment for putting the systems most suited for the Bundeswehr through their paces.

The transmit power is a key performance parameter for high data rates. The maximum permissible radiated power is dependent on the frequency band in use and on the shape of the antenna pattern. Small antennas forming broad antenna beams with usually large side lobes are generally limited more than antennas with sharper beams so as not to interfere with adjacent satellite systems, with stringent power density limits being defined especially in the Ku-band. In this connection the UniBwM has developed a novel frequency coordination approach that permits optimized transmit power utilization especially for small SOTM antennas. Depending on the antenna characteristics, it has been possible to achieve gains of up to 2.4 dB. The research findings have been presented to an expert audience at this year’s Military Communications Conference (MILCOM) in Baltimore, USA.

Fig. 1: Ka-band SOTM antenna from EM Solutions; parabolic reflector antenna depicted without a radom (Source: © EM Solutions)

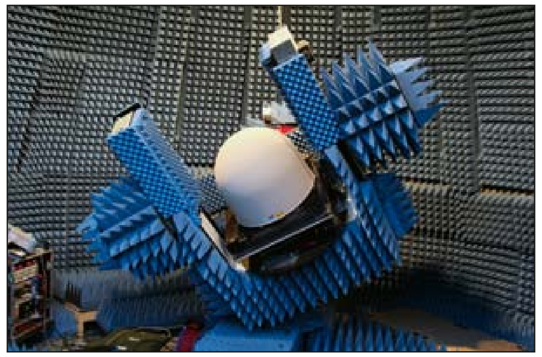

Fig. 2: FORTE test facility measurement chamber for OTMs, showing a SOTM antenna on the motion emulator

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Fig. 3: SOTM terminal mounted on a vehicle

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Detoxification of surfaces with air and sunlight

Surfaces exposed to biological and chemical warfare agents have to be decontaminated with the greatest possible consideration for resources and the environment and without endangering personnel. The long-term goal is to carry out detoxification with absolutely non-toxic methods. The Bundeswehr Research Institute for Protective Technologies and NBC-Protection (WIS) is looking into the use of photocatalysts as an alternative.

Detoxification, ideally, is not limited to removing a hazardous substance from a surface but also includes its destruction by chemical reaction. Over time, many different chemicals have been scrutinized for their ability to break down warfare agents. Aside from reaction with added chemicals there is reaction with atmospheric oxygen as a way of transforming toxic substances into less hazardous compounds. Since the latter reaction is quite slow under normal ambient conditions, it is necessary to add suitable catalysts. Catalysts accelerate the chemical reaction without being consumed themselves. Titanium dioxide has long been a focus of civil research in this connection. Irradiation with light can transform this compound into an electronically excited state and thus activate it. The activated catalyst is capable of interacting with atmospheric oxygen to produce very reactive oxygen compounds that, once formed, then react with the hazardous substance. The final degradation products from this reaction are carbon dioxide, water and non-toxic inorganic salts (Figure 1).

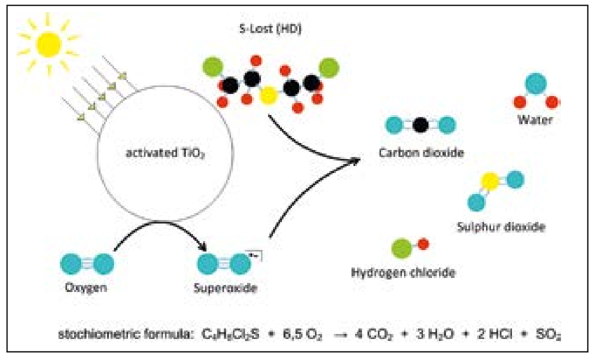

Fig. 1: Simplified schematic of the process of photocatalytic oxidation for sulphur mustard (HD) as an example of a chemical warfare agent

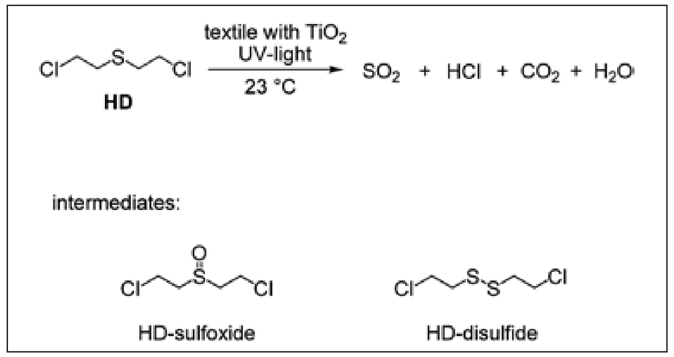

Fig. 2: During the degradation of sulphur mustard (HD), two intermediates are formed. Compared with the starting material both intermediates are less toxic

The complete process is referred to as photocatalytic oxidation and offers the crucial advantage of being effective against a broad variety of hazardous substances. TiO_2, for example, catalyzes the oxidation not only of chemical warfare agents but also of toxic industrial chemicals (TIC), and it also successfully supports the decomposition of microbiological pathogens such as viruses, bacteria and toxins. Despite such a broad spectrum of activity, however, there are also drawbacks to be considered because, although the catalyst significantly accelerates the reaction with oxygen, the complete decontamination of a surface still requires several hours. Furthermore, the reaction only takes place in the presence of light. This is, however, offset by the fact that, in case of exposure to biological or chemical agents, the decontamination takes place fully automatically, thus rendering any additional personnel, tools or systems unnecessary.

The research at WIS is focusing on the issue of permanently fixing the catalyst directly to the surface of different materials that are used militarily. Since the photo-catalytic oxidation goes through several intermediate stages, the thus formed intermediate products also have to be characterized and evaluated with respect to the hazards they pose (Figure 2). For this purpose, samples of paint-coated plates and modified textiles are placed in specialized measuring apparatus at WIS, contaminated with warfare agents and then irradiated with light. The measuring setup makes it possible to trace the degradation of the applied toxic substances (Figure 3) and, through careful analysis of the data thus obtained, the formed substances can be determined. Diversely modified materials are also examined at WIS for their general catalytic activity with the aid of rapid tests. This is done, firstly, by measuring the carbon dioxide produced and the oxygen consumed during reaction (Figure 4) and, secondly, by means of specific colour reaction tests (Figure 5).

Photocatalytic oxidation is to be regarded primarily as a complementary method to technologies already in existence. Where photocatalysts can be integrated successfully into paints or textiles, the modified surface has a latent capability for self-decontamination. This kind of "passive decontamination" can be put to use in scenarios where the cleaning procedure is neither time-critical nor feasible within the time given. It would thus be possible to provide critical infrastructure such as bridges, buildings or essential large equipment, whose "active decontamination" would tie down major material and, especially, personal resources, with a TiO_2-coating to create additional resilience against warfare agents.

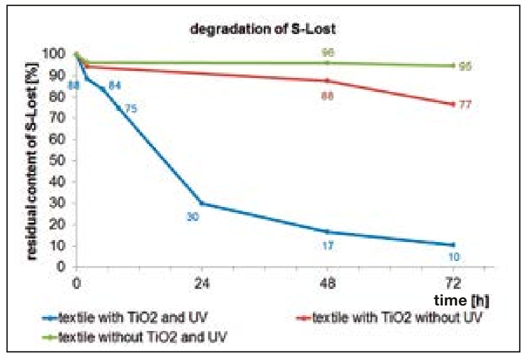

Fig. 3: Degradation of sulphur mustard (HD) on textiles modified with TiO_2, as a function of irradiation time (blue). Plotted as a comparison are the residual contents of HD in textiles without TiO2 after UV irradiation (green) and in textiles with TiO2, but without UV irradiation (red). The initial concentration of HD was always 0.5 µl / cm²

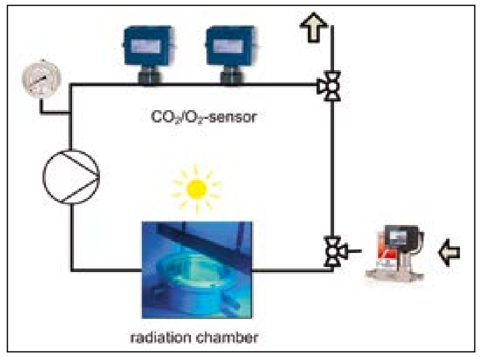

Fig. 4: Measurement setup for investigating the photocatalytic oxidation of chemical substances with titanium dioxide. In this arrangement the carbon dioxide and the oxygen content can be measured during the irradiation

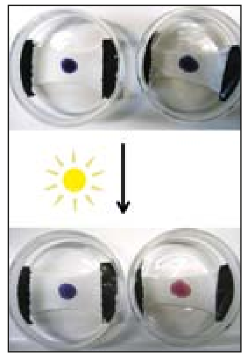

Fig. 5: Textile samples with applied coloured test substance (resazurin) before and after 30 minutes of irradiation with UV light. Left: without TiO_2; Right: with TiO_2. The photocatalytic reaction can easily and quickly be tracked visually.

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Synthetic fuels for the Bundeswehr

Detailed chemical and physical analyses as well as investigations into interactions with elastomeric materials have been undertaken with the aim of developing a fundamental understanding of the properties of synthetic fuels. The insights gained will serve as a basis for adopting synthetic fuels in the Bundeswehr.

Against the background of a foreseeable shortage of fossil fuels, the Bundeswehr and the armed forces of other NATO members are seeking alternative products. The US military, in particular, is strongly promoting the use of synthetic fuels. Armed forces are reliant on high mobility even in remote and poorly supplied theatres of operation and for that reason require energy sources with energy densities close to those of fossil fuels. Because military weapon systems have very long life cycles, the alternative energy sources need to be compatible with existing drive and propulsion systems (drop-in fuels). For several years, the Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB) has been extensively evaluating the properties of various synthetic fuels. The findings from this work will serve as the basis for selective testing and ultimately be used for their approval for weapon systems in service with the Bundeswehr.

Synthetic fuels in neat form as well as mixed with selected fossil aviation fuels have been subjected to detailed characterisation as part of a study. The synthetic fuels under consideration were produced by various methods, such as the catalytic conversion of synthesis gas (Fischer-Tropsch process), catalytic hydrogenation, and the hydrothermolysis of fats, as well as biotechnologically from renewable sources. Despite the production routes being different, all the products have in common that their chemical composition largely resembles that of the fossil fuels. Only the content of aromatic compounds differs strongly from that of the fossil fuels, yet is vital for certain fuel properties and also has a major impact on compatibility with elastomers.

Detailed chemical analyses of synthetic fuels (cf. 2D gas chromatograms) and determination of all the relevant physical-chemical fuel parameters are essential for any sound understanding of the product properties. Correlation of the composition and properties reveals trends and allows identification of critical parameters. These, in turn, need to be evaluated in partnership with Bundeswehr technical centres and system manufacturers and, where applicable, considered in selected tests.

WIWeB is pursuing a similar approach in work aimed at assessing the compatibility of synthetic fuels with elastomers. Investigations into the interaction between materials and synthetic fuels are helping to identify those fuel components which significantly influence material properties. Interactions regarded as critical need then to be evaluated within the approval process.

A comprehensive report on the results of the study will be released in 2015. It will show that some synthetic fuels resemble the fossil products closely with regard to composition and properties and could, therefore, be used even in neat form. Others, however, are suitable only as blend components to fossil fuels, in which respect the maximum blend ratios have been assessed. Furthermore, it has been possible to identify distinct fuel properties which need to be considered in the process of approving synthetic fuels as drop-in alternatives. Where compatibility is concerned, the content of aromatic compounds proves to be crucial for some seal materials. Systematic variation of the aromatic content in model fuels and the analysis of their interaction with materials have revealed relationships that can be applied to numerous synthetic fuels.

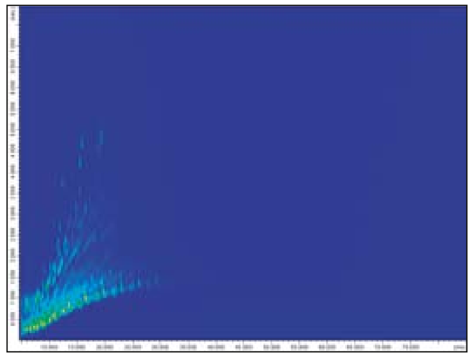

Fig. 1: 2D gas chromatogram of a conventional aviation turbine fuel (F-34)

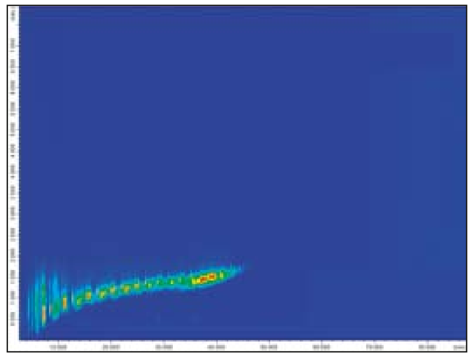

Fig. 2: 2D gas chromatogram of a Fischer-Tropsch fuel produced from coal. The sample consists of n- and iso-alkanes and lacks aromatic compounds

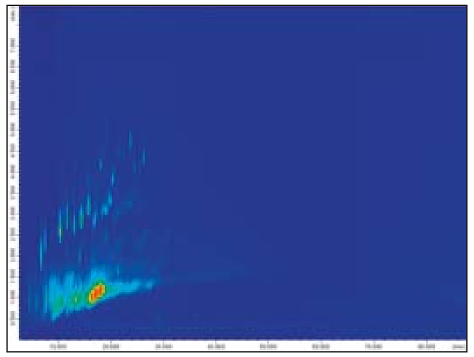

Fig. 3: 2D gas chromatogram of an alcohol-to-jet fuel with n-, iso-alkanes and aromatic compounds. The starting material (alcohol) can be produced biotechnologically

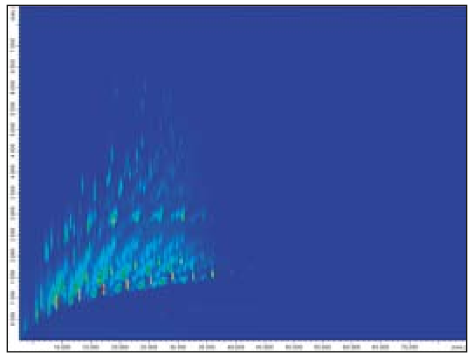

Fig. 4: 2D gas chromatogram of a fuel produced through the catalytic hydrothermolysis of fats. In terms of composition it closely resembles a conventional fuel

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Fuel fire effects on carbon fibre composites

The research project has as its aim to determine the influence of short-duration fuel fires on carbon fibre composites and, in particular, the correlations between the energy input and the mechanical properties of those materials. The Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB) has been working on this topic over several years in cooperation with the Wright-Patterson Air Force Base (WPAFB) in Dayton Ohio/USA.

Knowledge about the relationship between energy input, thermal degradation and the loss of mechanical strength in carbon fibre composite materials is of major interest, especially in the aircraft industry. Possible causes of thermal overloads include events such as heating-pipe bursts, malfunctions in electrical equipment, engines overheating, lightning strikes or fuel fires. For fuel fires typical heat fluxes range from 50 kW/m² to 80 kW/m², as a function of the fire's development.

To simulate the effect of such radiated energies on carbon fibre composites, a cone calorimeter (Figure 1) has been used to irradiate panels of varying thickness almost up to ignition (Figure 2). The homogeneous heat flux can be varied according to typically expected fire conditions. The maximum temperatures achieved on the material surfaces ranged between 125 °C and 470 °C depending on the irradiation time, the heat flux and the thickness of the material.

Figure 3 shows a carbon fibre composite sample after irradiation with a heat flux of 50 kW/m² for 40 seconds. It is clearly

Fig. 1: Cone calorimeter

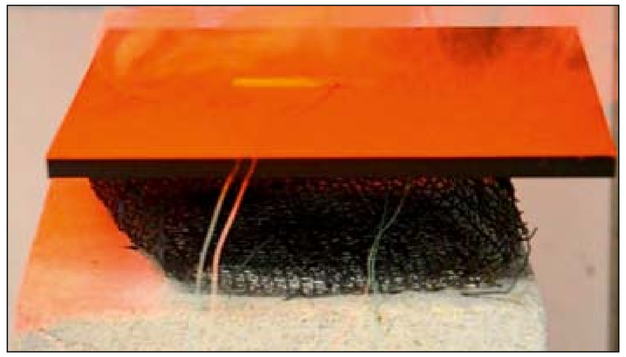

Fig. 2: Irradiation of a composite sample (10 cm x 10 cm) with a cone heater

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visible that the thermal degradation on the sample surface is unevenly distributed despite the homogeneous energy input. This damage development typical for carbon fibre composites leads to the observation that residual strength of individual specimens from the same sample can vary considerably, this applying particularly to relatively high energy inputs.

The interlaminar shear strength (ILSS) test results show that a decrease in mechanical strength is observed with increasing irradiation time (Figure 4). The thickness of the carbon fibre composite has a clear influence because of the increasing thermal capacity, i. e. the strength levels increase less with increasing thickness. In addition, due to the higher thermal capacity, the moment of ignition of the carbon fibre composite shifts toward higher heat energies (longer times).

Based on the calculation of the energy applied per unit of volume (Figure 5) it can be illustrated that up to a maximum energy of approximately $6 \cdot 10^5$ kWs/m³ there is no observable influence either of the different carbon fibre composite thicknesses or of the different applied heat fluxes on the measured strength. The influence of different applied heat fluxes and sample thickness is observable only with higher energy inputs. Using this graph it is quickly possible to estimate whether, under the real conditions of a fuel fire, thermal degradation is accompanied by an ILS strength decline of the material (carbon fibre composite thickness of 2 to 6 mm, various heat fluxes). In particular, it is thus possible to define a universally applicable energy input maximum for the carbon fibre composite material up to which it withstands thermal loading.

Infrared spectroscopy is used for the non-destructive characterisation of thermal damage caused to the matrix of carbon fibre composites. With the aid of multivariate data analyses it is quickly possible to predict both the temperature and the residual strength for samples of unknown thermal history and, in the event of damage, to promptly estimate whether the carbon fibre composite material has adequate strength for further use.

The findings expand the fundamental knowledge for estimating and assessing the risks posed by thermal events to carbon fibre composite structures. They also form a basis for further experimentation under more complex mechanical loading conditions.

Fig. 3: Irradiated sample after 40 s at 50 kW per kw/m²

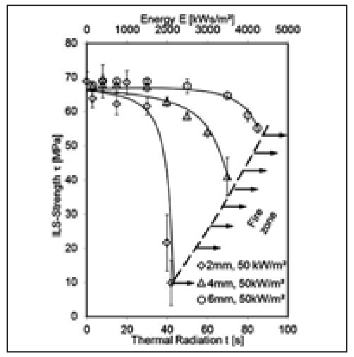

Fig. 4: Thermal radiation vs. ILSS strength

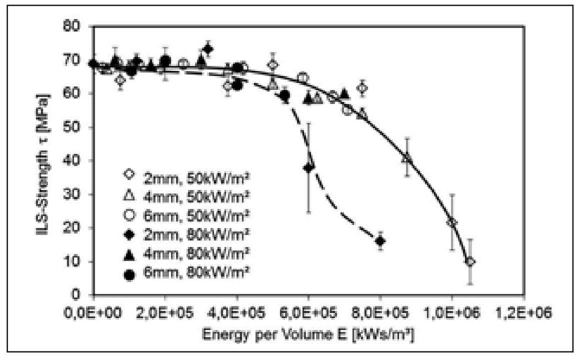

Fig. 5: Energy per volume vs. ILSS strength

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EnergyCamp, generic test bed for smart grid technologies

The deployment of Bundeswehr forces worldwide involves the need to establish and operate mobile base camps. While simultaneously reducing the consumption of fossil fuel energy sources and their ecological footprint, it is important to achieve the largest possible benefit from utilizing innovative technologies and renewable energies. Meaning better performance with less fossil energy!

At present, supplying energy for mobile base camps is dependent on conventional power generator units operated on liquid fossil fuels. These, besides producing the electric power for direct consumption, also generate the energy required for heating, cooling and service water warming. This project is examining the utilization of renewable energies as well as of the waste heat from power generators for heating and cooling, for instance. It is also taking a look at technologies capable of efficient thermal energy transformation and storage for the purpose of fossil energy conservation and thus emission minimization.

Further activities include the integration of hybrid and battery-operated electric vehicles as well as of fuel cells / range-extended electric vehicles into the energy network of an EnergyCamp. Supported by modelling and simulation, the civil “Vehicle-to-Grid” concept (dual-use) is under consideration for future smart energy networks operated by the Bundeswehr.

The objective of the R&T project is to achieve the largest possible benefit from utilizing innovative technologies and renewable energies while at the same time reducing the consumption of liquid fossil fuels and their ecological footprint.

Mobile base camps are generally to be understood as complex, interconnected / -related, environmentally compatible systems comprising infrastructure, erected buildings and operation. To ensure the energy supply, smart monitoring of consumption as well as energy management are necessary, supported by usage profiles and prognoses, so as to balance energy generation, storage and consumption.

Intelligent integration of all subsystems is essential, along with centralized closed-loop control of energy flows to cater for the most varied requirement profiles and environmental conditions, including the requisite algorithms.

The potential for saving / substituting liquid fossil energy sources on operations is being evaluated by means of demonstrators, modelling and simulation of technologies / processes for use of tri-generation and renewable energies. The dimensioning of the energy storage devices for short- / long-time storage, as well as the choice of storage technology (sensible, latent, adsorption) are an essential focal point in the optimization of the overall system (heating, air conditioning, service water warming, process heat / cold) .

The expertise is to be built up in conjunction with the generic EnergyCamp test bed for all the relevant technological aspects of energy generation, transformation, storage, usage and Vehicle-to-Grid. Verification of distributed (virtual) systems requires the high degrees of freedom offered by the generic electrical / thermal energy distribution system demonstrator.

Components, meanwhile, have been realized / ordered for the following systems: central energy distribution, photovoltaics and solar heat, battery container, electric mobility, charging stations for electric vehicles, central process control station (steering, control, visualization of energy fluxes), power generator station with heat exchanger (utilization of waste heat), adsorption cooling system (heating, cooling, air conditioning), evaluation block heat and power plant (solar thermal, tri-generation, adsorption cooling system, sensible heat storage), latent heat storage, accommodation containers with PCM storage heating / cooling system, and service water warming via PCM heat storage.

To summarize, it is essential to consider energy generation, transformation, storage, distribution and sustainable supply in base camps as one complete system.The R&T project, therefore, is focusing on the intelligent control / regulation of all energy flows under the most varied environmental conditions / requirement profiles and on the implementation / verification of the required algorithms in the generic test bed system demonstrator. In this regard the EnergyCamp of the Bundeswehr Technical Centre for Automotive and Armoured Vehicles (WTD 41) is of central importance as the technical reference, test and integration environment for all aspects of verification, integration, obsolescence, regeneration and sustainability.

Fig. 1: Evaluation block heat and power plant

Fig. 2: Adsorption cooling system

Fig. 3: Photovoltaics and solar heat

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STANDCAM test bed – an example of project-related standardized cross-sectional technology

In 2006 the Standard Decoy for Camouflage Materials (STANDCAM) test bed vehicle was put into service by the Bundeswehr Technical Centre for Protective and Special Technologies (WTD 52) and has since progressed to become the quasi-international standard.

Testing and evaluating new technologies and subsystems play a prominent role throughout the life cycle of defence projects. Standardized cross-sectional test bed vehicles such as STANDCAM, presented below, serve to keep abreast of the state of the art as regards research or projects in support of studies relating to integrated compliance demonstration.

Novel ideas are often born out of problems confronting more than one nation. A NATO committee had also identified the problem that, for the purposes of testing future camouflage systems, a common test bed vehicle with reproducible signatures was lacking. Proper vehicles for international research purposes were either not available or their signature data were classified information. The solution to this problem has been found to be a surrogate vehicle which, although capable of generating typical vehicle signatures, does not exist in any army around the globe.

Fig. 1: Convertible test bed vehicle

This surrogate vehicle is today referred to as STANDCAM and has meanwhile become a quasi-standard through its application in numerous international cooperation projects on camouflage technologies, among others.

During the search for a partner to implement the STANDCAM project, the Technological Base for Camouflage and Concealment in Storkow, a Bundeswehr agency which had practical experience in the fabrication of high-end camouflage decoys in the past and continues to be an international leader in this regard, was selected.

Despite the STANDCAM being close to reality, it does have some peculiarities: One of its most important features is its capability to imitate both a tracked combat vehicle and a wheeled AFV. This design provides the possibility to test, explore and research camouflage technologies for different applications at the same time economically.

As military vehicles can be identified on the basis of their multi-spectral signatures and then attacked, these signatures are normally classified information. This does not apply to STANDCAM, whose signatures are open-source information that can be exchanged between the Bundeswehr and its partners.

Figure 2 shows the wheeled aspect of STANDCAM in simulated „combat move“ status. Thermally conspicuous are a gun hot from firing, the exhaust area, and wheels that have run hot.

Figure 3 shows STANDCAM‘s radar cross section (RCS) diagrams with their typical fish shape, together with inverse synthetic aperture radar (ISAR) sites. Clearly identifiable (red) are the high reflection values generated by the track chassis.

Similar and other signature management problems are also to be found with many vehicles, including more recent designs. It will, for this reason, remain a long-term task of Bundeswehr Technical Centre 52 to reveal the signature weaknesses of combat vehicles and to reduce them by retrofitting mobile multi-spectral camouflage kits.

Especially where mobile multi-spectral camouflage kits are concerned, there have, and continue to be, constant material and technological innovations which need to be examined and evaluated, so as to ensure that the state of the art can be made available, if required, during the production phase of CPM (Customer Product Management (amended)) projects.

Such a need arose, for example, as part of an immediate operational requirement for mobile multi-spectral camouflage kits for the deployment of MARDER 1 A5A1 infantry combat vehicles in Afghanistan. Only the persistent fundamental testing conducted with the STANDCAM test bed vehicle made it possible to meet the requesting authority’s requirements following adaptation of an existing system.

Fig. 2: STANDCAM‘s active thermal signature

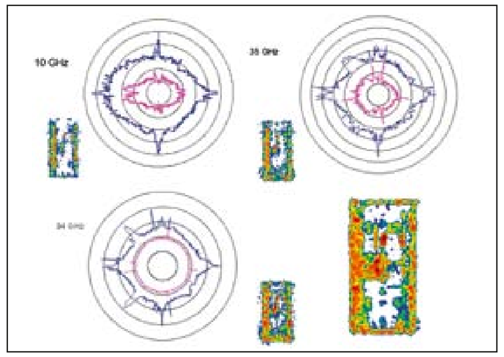

Fig. 3: RCS and ISAR signatures

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Bi- and multistatic antisubmarine warfare

Modern submarines are locatable over large distances only by means of active sonar, in which respect antisubmarine warfare (ASW) as a joint operation is more effective than when conducted by a single hunter. Bi- and multistatic sonar signal processing methods, which are being examined by the Bundeswehr Technical Centre for Ships and Naval Weapons, Maritime Technology and Research (WTD 71) and tested during ASW exercises in cooperation with the German Navy, help significantly to make this more effective.

Nowadays, modern submarines with air-independent propulsion systems and optimized acoustic signatures are practically no longer locatable by means of passive sonar. Also, the already demanding task of locating submarines under adverse environmental conditions is set to become even more challenging in future because of new submarine coating materials, for instance.

One possibility for increasing the effectiveness of ASW operations compared with those of a single ASW unit is to use bi- and multistatic sonar methods. Bistatic sonar involves the active sonar signal of a transmitting ASW platform being received and processed by a secondary, covertly operating unit. The basic prerequisite for bistatic processing is the relaying of source parameters (location, sonar signal, transmit trigger) to the receiver (Figure 1). The covertness of the passive "spotter" then yields tactical advantages over the hunted submarine. An extension of this is a multistatic ASW operation (Figure 2), in which transduced signals from several units are used jointly and results are not only shared but also combined or "fused". Methods necessary for fusing data from different displaced

sensors have been undergoing study and development at the Research Department for Underwater Acoustics and Geophysics (FWG) of Bundeswehr Technical Centre WTD 71.

A submarine acting as a hunter in a joint ASW operation is in an exceptional position, as (covert) communication of source parameters to the submerged submarine is not readily possible without the risk of exposing the covert hunter. In recent years FWG has developed methods to automatically determine the source parameters (location and transmit trigger) required from the received sensor / antenna signals onboard a submarine for deep water scenarios. In combination with the passive sensor system that is already installed on the German U212A class submarines and is also outstandingly suited to bistatic processing, completely new operational perspectives open up for antisubmarine warfare, while retaining the possibilities for passive sonar detection. It has been possible to demonstrate this for the first time in a live experiment onboard a German submarine against a hunted submarine during an ASW exercise in deep waters off the east coast of the USA. Figure 3 shows an extract from a bistatic display as seen onboard the German submarine.

In shallow waters, different approaches for estimating the source parameters are necessary due to the diverse sound propagation and environmental conditions. For that case, too, FWG is working on methods that during the receipt of an active sonar signal allow the build-up of a bistatic display picture through georeferencing of the received antenna signals to known topographic structures and implicitly locate the source. Figure 4 shows first results for sea data post-processed in a laboratory.

Following the successful demonstration of the bi- and multistatic signal processing methods, the question regarding further research is, logically, how are the capabilities offered by the different sensors, platforms and the communication network to be combined under the given environmental conditions and adapted in response to changes in situation (e. g. loss or addition of a sensor) so that operational goals can be achieved as effectively as possible.

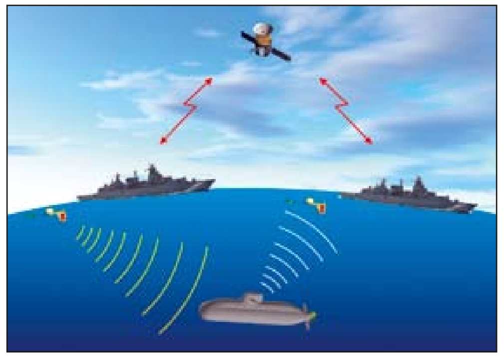

Fig. 1: Bistatic ASW scenario. One frigate transmits active sonar signals. The second frigate operates covertly as a bistatic receiver

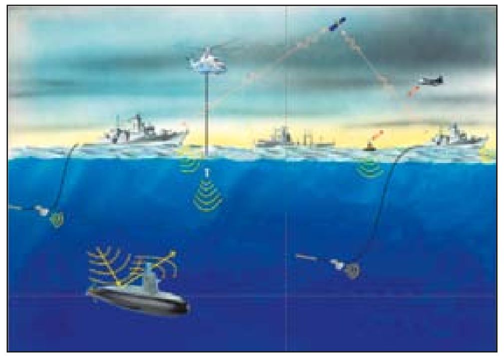

Fig. 2: Multistatic ASW scenario. Different units hunt the submarine in a joint operation

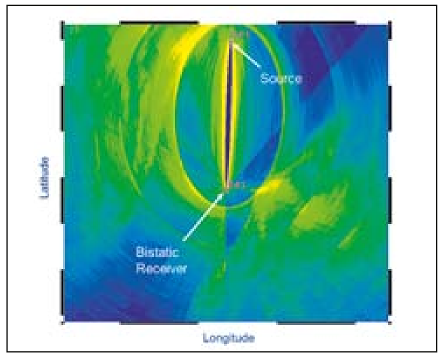

Fig. 3: Bistatic geographic raw data display.
The elliptic structures originate from reflections of the active sonar signal at the sea bottom in deep waters

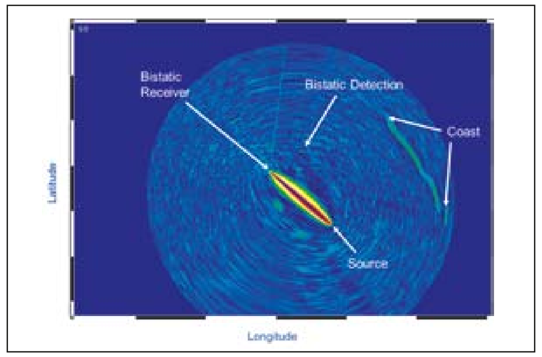

Fig. 4: Bistatic geographically referenced raw data display.
This picture is generated by georeferencing the received antenna signals to the known coastline. The method implicitly locates the source

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Semiconductor laser emitter for military sensors

Lasers have a wide range of applications in the military domain. Semiconductor lasers, in particular, are low-maintenance and conducive to military use because of their high power efficiency and compact design. Laser technologies for applications such as night reconnaissance, disruption of enemy optics and detection of explosives are the subject of ongoing research work.

Semiconductor lasers can be designed to operate in a range from the ultraviolet to the far-infrared, in some cases with a high output. Especially in the militarily relevant mid- and long-wave infrared range (MWIR and LWIR), they are meanwhile so advanced that they offer far more than just an alternative to the established, mainstream solid-state lasers. Due to fundamental physical differences, semiconductor lasers have many advantages over other types of lasers when it comes to designing multi-band laser systems – the emission wavelengths can be adjusted over a wide range through selective modification of the semiconductor structure and thus optimized for various applications. They have a higher power efficiency and require a lesser amount of cooling, being of small size. It is therefore possible to realise extremely compact, powerful and more cost-efficient laser systems for military applications such as defence against guided missiles (Figure 1).

Militarily utilised infrared sensors such as in seeker heads of guided missiles do not cover the entire spectrum, but can only scan greyscale values sequentially in individual, separate spectral

infrared bands. It is consequently sufficient to illuminate them with laser irradiation of a suitable wavelength and pulse rate to effectively interfere with the seeker head sensors or to present false targets. Optronically guided missiles thus lose their effectiveness through a relatively simple measure and are diverted from high-grade platforms.

The Fraunhofer Institute for Applied Solid State Physics (Fraunhofer IAF) has been commissioned to study and conduct research on highly efficient semiconductor disk lasers and quantum cascade lasers for the mid- and far-IR range with a view to developing powerful and compact multiband laser systems for optronic countermeasures in the relevant IR wavelength range. These laser arrays consist of a semiconductor structure whose core is formed of as many as one thousand III-V semiconductor layers in thicknesses of only a few atomic layers in some cases. Figure 2 shows laser chips typically a few millimetres in size which are integrated into special suitable heat sinks. High-output power quantum cascade lasers in the relevant medium- and long-wave infrared range are the topic of research, especially as a protective measure against the threat potential posed by IR seeker heads.

The aim is a new generation of compact, modular and affordable laser emitters for use by the Bundeswehr.

A miniaturized multiband laser demonstrator developed in a previous study (Figure 3) shows the potential of this compact and modular laser technology. Besides the laser modules with their specially adapted beam forming and combining optics, this prototype contains the electronic drivers for the laser current and for temperature stabilization (Figure 4). The interfaces for external digital control and for the power supply are also already implemented.

Since, unlike with destruction lasers, there are no challenging requirements concerning the beam shape, several single emitters or laser modules can be cascaded and a significant increase of the coverage range achieved through superposition of the laser beams in the far-field.

Individual requirements regarding laser systems ensue for the following operational scenarios:

- Optronic self-protection systems: high output power and rapid pulse timing, short operation cycles
- Laser-based reconnaissance systems: low output power and long operational life, eye-safe IR scene illumination
- Detection of hazardous materials: spectral analysis through precise tunability of the wavelength of the emitted laser irradiation.

Modular, adaptable and multi-functional demonstrators that meet these seemingly conflicting operational requirements will be striven-for in a follow-up study in the foreseeable future.

Fig. 1: Possible application scenario as a disruptive laser to ward off infrared-guided missiles (Source: Diehl BGT Defence)

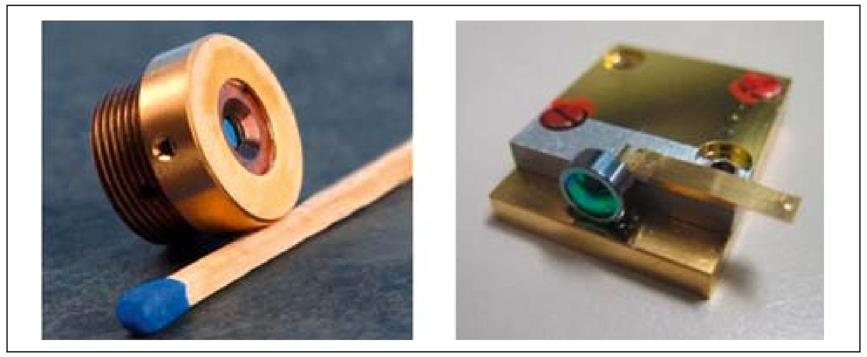

Fig. 2: Semiconductor disk laser heterostructure and quantum cascade single emitters with integrated collimating lens (Source: Fraunhofer IAF)

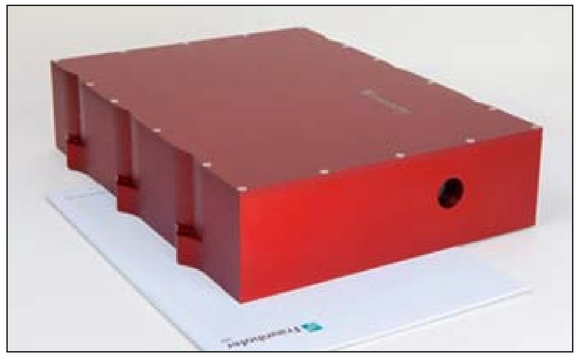

Fig. 3: Miniaturized multi-band laser head with a volume of only 32 x 25 x 7 cm^3

Fig. 4: Internals of the multi-band laser head with integrated cooling assemblies, electric control units and optic components for beam forming

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Hyperspectral sensor systems for detecting challenging targets

Homemade explosives constitute a major threat in Bundeswehr areas of operation. As most of the so-called roadside bombs are buried, detection is very difficult. Aerial reconnaissance using hyperspectral sensors will facilitate large-area detection based on surface structure changes.

In long-range reconnaissance, hyperspectral sensors are defined as sensor systems which can record images over many narrow and close bands of wavelength intervals. These wavelengths can range from ultraviolet to long-wave infrared, depending on the sensor. Hyperspectral sensors are generally deployed on aircraft or satellites. The sensors originally used in mining and geology to identify different minerals, ores and oils have undergone further development and are nowadays being used in the environmental field as well as to assess vegetation. Further miniaturization is making them attractive for additional uses such as surveillance and reconnaissance, particularly in the military domain.

In early July of last year, hyperspectral data concerning different ground targets in the surroundings of the Bundeswehr Technical Centre for Information Technology and Electronics (WTD 81) in Greding were collected in the context of German-Swiss cooperation. The two sensors manufactured by company AISA and provided by the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB together cover the wavelength spectrum between 400 and 2500 nm and

store the data from a total of 367 channels. The hyperspectral sensors are designed as line scanners, each with a different number of pixels per line; the AISA Hawk has 320 pixels, and the AISA Eagle as many as 1600 pixels. These detector lines in combination with the unsteady movement of the small aircraft deliver an irregular pixel pattern above ground. The pattern is corrected geometrically and georeferenced. Through combination with a radiometric correction to minimize atmospheric influences, an informative picture of the flown-over target area is created. The spatial resolutions on the ground vary and naturally depend on the optical equipment in use as well as on the flight altitude. The Cessna 208 Caravan used as the sensor carrier aircraft flew at around 950 m above ground. The tests yielded pixel sizes on the ground of roughly a quarter of a square metre to one square metre. The question thus arises as to how large an area of a pixel the material to be detected must fill to be able to be clearly identified, and the answer lies in the calculation of the performance limits of the hyperspectral sensors. During multiple flyovers, further sensors were used to collect additional information about the target area, these include a Light Detection and Ranging (LiDAR) system, a high resolution RGB camera and a thermal sensor.

Switzerland, our partner nation, laid out different camouflage nets. The aim was to identify not only the artificial materials themselves but also the different types of nets. The German side positioned a variety of material samples including an MBT and an inflatable MARDER mock-up. Also, the surfaces of different fields consisting of sand, humus and gravel were altered by means of digging activities and irrigation.

The military objective is to detect artificial camouflage materials, man-made objects and excavation activities. This could lead to the development of a large-area reconnaissance method for detecting buried booby traps, or so-called Improvised Explosive Devices (IEDs), using the changes in the surface structure of disturbed soil as a basis. Lessons learned from military operations in Afghanistan are leading to further tasks such as the identification of poppy fields based on the state of the vegetation, or detecting bushes which may have been moved and planted in front of possible tunnel entrances. Both nations are currently working intensively on processing the recorded sensor data in order to optimize their own algorithms and thus ultimately improve their classification capabilities.

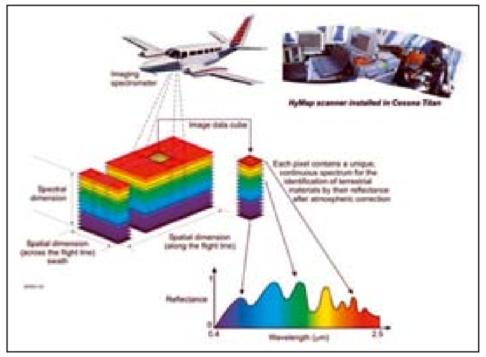

Fig. 1: The principle of hyperspectral data recording (Source: www.ivvgeo.uni-muenster.de)

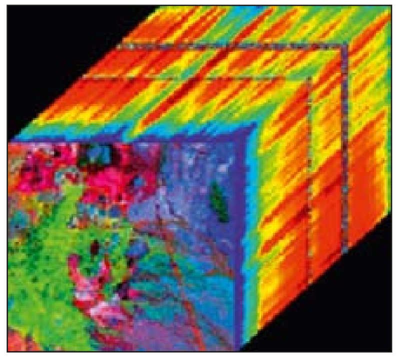

Fig. 2: The so-called "HyperCube" is created (Source: www.math.duke.edu)

Fig. 3: Camouflage nets during spectral measuring

Fig. 4: Main battle tank (MBT) and mock-up

Fig. 4: Fields consisting of sand, humus and gravel

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New V_0-measurement system for gun muzzles

Programmable ammunition incorporating target information and permitting precise intervention within predefined target perimeters is finding successful use in ground-based air defence systems as well as on combat vehicles. In 2014 the first steps were taken within the scope of an R&T project to create a new, compact V_0-measurement and programming basis unit for deployment on Armoured Infantry Fighting Vehicles (AIFVs) to measure the muzzle velocity (V_0) of projectiles.

The use of programmable ammunition incorporating target information permits precise effects within predefined target areas. The principle of programming ammunition is currently employed successfully for guns in ground-based air defence systems as well as for combat vehicles (CV) and armoured personnel carriers. Immediately a projectile has left the gun barrel, it receives information on the time of flight. Once the programmed time of flight has elapsed, the projectile becomes active in the target area in the manner required. It is imperative to measure the muzzle-velocity (V_0) of each fired programmable projectile exactly in order to determine the optimum time of flight. The relevant data also have to be communicated to the projectile as it leaves the gun barrel. To do so a velocity measurement and programming basis unit (VMPB) is mounted on the muzzle of the gun barrel.

The requirements that apply to the velocity measurement and programming basis unit vary according to application. For use on armoured personnel vehicles the basis unit needs to have the shortest possible overall length and a low weight. These characteristics improve the gun dynamics. Besides

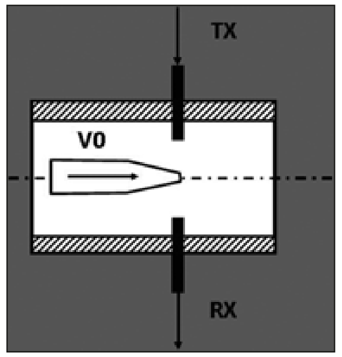

Fig. 1: The WBV measurement principle

Fig. 2: WBV technology demonstrator No. 1 (2009)

full-calibre ammunition, the basis unit must also be able to withstand the use of subcalibre ammunition. When a projectile is fired, vibrations, shocks, pressure and heat must not influence the velocity measurement accuracy. Nor must electromagnetic interference impair the quality of the velocity measurement. The same requirements also apply to the programming.

Since 2006 Rheinmetall Air Defence AG (RAD), Zurich, has been testing a new muzzle velocity measurement method that meets the requirements mentioned above. The new V_0 measurement method is based on the "Waveguide Below cut-off frequency Velocity Measurement“ (WBV) principle. The V_0 measurement section consists of a waveguide and, within that, two coupler units which serve as transmitter and receiver sensors. The transmitting coupler unit is fed with a carrier signal TX and generates an electromagnetic field distribution within the waveguide. The peculiar feature is that the carrier signal frequency is set below the cut-off frequency of the waveguide. This leads to the establishment of a characteristic electromagnetic field distribution in the waveguide, thereby ensuring robustness against electromagnetic interference. The moving projectile passes through the waveguide and influences the electromagnetic field distribution in a characteristic manner. The receiving coupler unit picks up the time-varying field distribution and generates a receiving signal RX, which is fed to an analyzer to determine the V_0. Ammunition type detection is also possible.

The new V_0 measurement method was tested successfully in 2009 (Figure 2) and in 2011 (Figure 3) using technology demonstrators in 35 mm calibre. To construct the technology demonstrator, a ceramic material was also used for the coupler mount, which is exposed directly to the hot combustion gases. The WBV measurement principle is suitable not only for medium-calibre but also for large-calibre ammunition.

To test the suitability of the WBV measurement method for use on armoured personnel carriers, the first steps have been taken within the scope of an R&T project to construct a measurement and programming basis unit as a technology demonstrator in 30 mm model calibre. The V_0 measurement section as well as the programming unit have been realized using WBV technology, thereby achieving a compact design. The fabrication of technology demonstrators is planned for 2015, and extensive proof firing involving the technology demonstrators for the year thereafter.

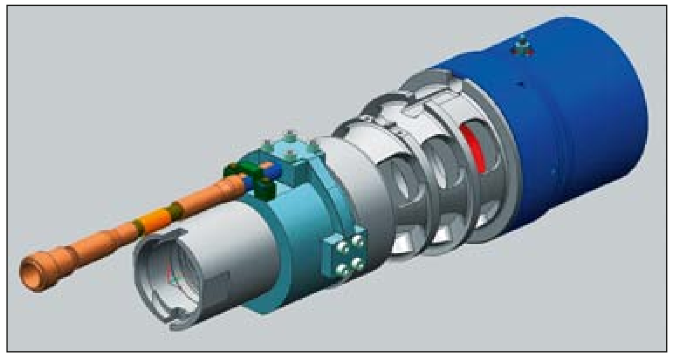

Fig. 3: WBV technology demonstrator No. 2 (2011)

2

Military Medical and Military Psychology Research

The utmost priority of the Bundeswehr Medical Service is to protect and maintain the health of the military personnel entrusted to its care. Potential health threats during service in the armed forces are manifold and range from severe physical and mental stress as early as during exercises and routine duty, to the danger of being badly wounded on operational deployment, to the risk of exposure to biological and chemical agents or ionising radiation. In the light of changing risks and the state of advancing medical science, the Bundeswehr Medical Service conducts a variety of research activities at its own departmental research establishments and in cooperation with partners at universities to provide the best possible prevention, diagnosis, therapy and aftercare.

Particular aspects of theatre medical support form the focus of clinical medicine and CBRN medical defence. The challenges of Bundeswehr-specific working conditions and associated individual, personnel-related performance requirements are the central topic where military ergonomics and occupational physiology are concerned, while the field of preventive medicine and hygiene covers specific aspects of preventive health care. The departmental research establishments of the German Air Force and Navy examine the special problems and issues that arise in aviation, diving and maritime medicine from the viewpoint of the particular demands on health resulting from such assignments.

The articles hereinafter present examples of current research projects conducted by the military medical departmental research institutes. The Bundeswehr Institute of Microbiology deals with diseases caused by infectious pathogens and, especially in that connection, the development and advancement of methods for identifying particular in-theatre needs. This includes the preparatory collection of epidemiological data as well as investigating outbreaks of a molecular-genetic nature, and bioforensic challenges. Presented in this regard are examples of the research on state-of-the-art microbiological detection and identification methods.

The articles contributed by the Bundeswehr Institute of Pharmacology and Toxicology and by the Bundeswehr Institute of Radiobiology are dedicated to the continuing threat posed by chemical agents, ionising radiation and radionuclides and, in particular, the necessity for suitable diagnosis. With regard to Bundeswehr-specific working conditions and associated individual performance requirements, the Central Institute of the Bundeswehr Medical Service is working on the development of a test procedure to prepare for operational deployments.

The articles contributed by the Air Force Centre for Aerospace Medicine and by the Naval Institute of Maritime Medicine highlight the particular challenges of providing medical support for the special assignments of aircrews and seagoing units.

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Identification and differentiation of *B. anthracis* from closely related members of the *Bacillus cereus sensu lato* group by means of MALDI-TOF mass spectrometry

Reliably differentiating the highly pathogenic *B. anthracis* bacterium from closely related species remains very challenging. Matrix Assisted Laser Desorption / Ionization-Time of Flight (MALDI-TOF) is a mass spectrometry-based method that is also found its application for the identification of bacteria nowadays. The use of MALDI-TOF MS to differentiate and identify *B. anthracis* has been significantly improved with the aid of a dedicated in-house database that has been specifically augmented and adapted.

Fast and reliable differentiation of *Bacillus anthracis* from closely related species of the *B. cereus sensu lato* group and, especially, of *B. anthracis* from *B. cereus*, is essential for clinical diagnostics. While *B. anthracis* often causes the fatal anthrax disease, *B. cereus* is mainly associated with non-lethal food intoxications or associated toxin-induced diarrhea or emesis. Infections with *B. cereus* are mostly self-limiting, but an infection with *B. anthracis* needs to be treated with antibiotics in time.

Bacterial species identification in diagnostic laboratories is mostly based on biochemical or molecular-biological methods. However, differentiating between the species of the *B. cereus sensu lato* group by, for example, sequencing the gene for the 16S small ribosomal subunit is insufficient, as these *Bacillus*-species exhibit very high sequence similarities in that gene. MALDI-TOF MS is increasingly used for species identification in routine diagnostics for species identification, because the method is simple, inexpensive, and fast.

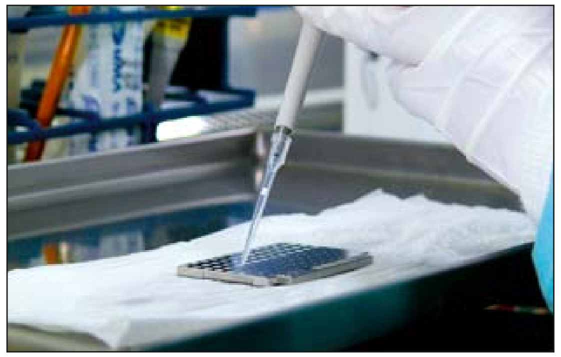

Fig. 1: Spotting of a sample on a steel target plate for MALDI-TOF MS analysis

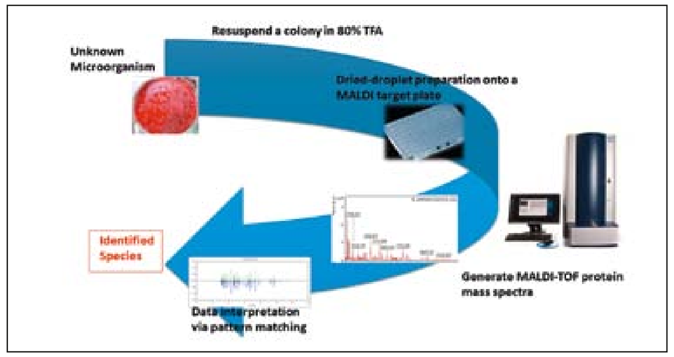

Fig. 2: General workflow for identification of bacteria by means of MALDI-TOF MS

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The identification of bacteria by means of MALDI-TOF MS is based on matching specific patterns in experimentally obtained protein / peptide mass spectra against a variety of corresponding mass spectra stored in databases. Commercial databases, however, are not yet sufficiently developed for unambiguous differentiation of highly pathogenic bacteria from closely related species. The goal of this project has been to generate a dedicated database to improve differentiation of the species within the *B. cereus sensu lato* group, especially focusing on reliable identification of *B. anthracis*.

A verified selection of 189 strains from the *B. cereus sensu lato* group has been analysed by means of MALDI-TOF MS with the aim of identifying specific protein biomarkers in the spectra of *B. anthracis* in comparison with closely related *Bacillus* spp. This involved the examination of statistical methods such as principle component analysis (PCA), and shrinkage discriminant analysis (SDA) to initially determine unique and heterogeneous strains for each of the different *Bacillus* spp. investigated. Subsequently, data relating to these strains were statistically compared using SDA in order to identify specific peaks in the mass spectra that can help to improve species differentiation.

In this way 7, 10, 18, and 14 *B. anthracis*-specific biomarker candidates were identified in comparison with *B. cereus*, *B. mycoides*, *B. thuringiensis* and *B. weihenstephanensis*, respectively. However, not a single unique biomarker emerged for *B. anthracis* in the spectra.

All the spectra of the specific strains were integrated as main spectra (MSP) in the in-house database. After subsequent validation of this database with 15 *B. anthracis* and 14 *B. cereus* strains, strongly improved results were obtained. The reliability of identification, expressed as a score which, at values ≥ 2.3, is indicative of unambiguous species identification, was improved with the in-house database. For example, all the *B. cereus* strains tested were correctly and reliably identified as such by matching their protein profiles against the in-house database, while the same strains were incorrectly identified as *B. anthracis* using commercial databases.

Owing to the enhanced database of the Bundeswehr Institute of Microbiology it has been possible to significantly improve the differentiation of *B. anthracis* by means of MALDI-TOF MS and to reduce the probability of false-positive diagnostic identification.

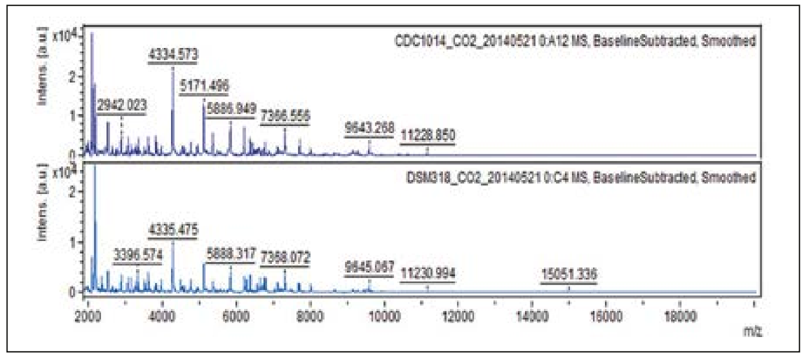

Fig. 3: Comparison of *B. anthracis* with *B. cereus*. At first glance the individual spectra suggest a high degree of similarity and cannot be differentiated further

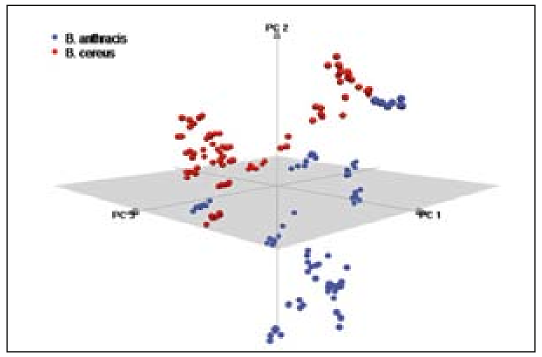

Fig. 4: Comparison of *B. anthracis* with *B. cereus*. PCA shows that the spectra take up distinct areas in the analysis, thus enabling safe differentiation

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Challenge of whole genome sequencing – bioforensics of the future

Whole genome sequencing is an emerging tool that is proving indispensable for the bioforensic analysis of biodefence-relevant pathogens. Taking the example of the Q-fever bacterium *Coxiella burnetii*, the challenges associated with pre-analytic and subsequent bioinformatics significantly influencing the quality of whole genome projects and the interpretation of their data are demonstrated.

To differentiate whether an infectious disease outbreak is a natural or a deliberate occurrence (e. g. in an act of bioterrorism), it can be helpful, in addition to epidemiological analyses, to have exact identification and classification of the pathogen along the lines of genetic finger printing, including dataset matching for comparison. This young area of research is referred to as microbial bioforensics. In the early days of this discipline, the whole genome sequencing of a multitude of anthrax strains delivered crucial pointers to the origin of letters filled with anthrax spores in the 2001 "Amerithrax" incident. More recently, in 2011, the rapid clarification and subsequent attribution of the German enterohemorrhagic *Escherichia coli* (EHEC) outbreak also demonstrated the significance of such advanced analytical methods.

The core element of this approach is whole genome sequencing, in other words determining the exact base sequence of any genome being investigated. Due to the enormous technical progress in recent years it is now possible to generate a multitude of whole genome sequences in parallel within hours. The growing spread of such affordable "Next Generation

Sequencing" (NGS) platforms, however, has also meant that the number of bacterial whole genome sequence datasets has multiplied more than hundredfold in the past few years.

The goal of determining exact genome data is influenced to a major degree by the pre-analysis, i. e. the quality of the pre-sequencing material, and has to be adapted as a function of the selected NGS platform (Figure 1). But the advancements in post-sequencing analysis of the generated data (i. e. bioinformatics) can also lead to a considerable improvement in the quality of previously published datasets. Our studies involving *Coxiella burnetii*, a potential bioterroristic agent, revealed that, depending on the DNA extraction methods and the quality of the primary sample, not all technical platforms are unreservedly suitable for sequencing (Figure 1).

An important criterion for obtaining a complete dataset is a minimum amount of pathogens in the primary material. However, not all NGS techniques are equally capable of identifying certain sequence peculiarities (repetitions, duplications, base composition) within a genome correctly. Only the combination of optimum DNA preparation and sequencing technique yields reliable bioforensic results (Figure 2).

Even more critical, however, is the post-sequencing analysis of the NGS data generated. Depending on the mathematical algorithm applied, differing gene and thus protein predictions may occur (Figure 3). But unequivocal results that do not give rise to any doubts are required for bioforensic analysis. Using published whole genome sequences of *Coxiella burnetii*, we were successfully able to verify the analysis protocols we had optimised (Figure 4) and consequently arrive at and publish several corrections (curations) of existing datasets. Thus far, five whole genome sequences of Coxiella have been curated, and 13 more are in progress.

The lessons learned and the findings from our methodical studies can also be applied to other bacterial pathogens, thus laying the foundations for a whole genome database that will comprise high-quality genomes and be a role model for integrating other pathogens. Only thus is it possible in the context of clarifying infectious disease events and outbreaks to make precise statements as a basis for taking epidemiological and operational / tactical decisions.

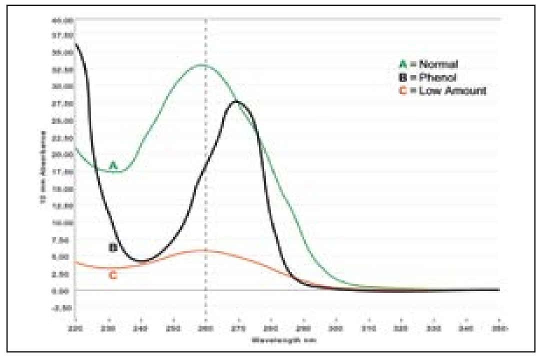

Fig. 1: Quantification and quality control of the extracted DNA by means of spectrophotometric analysis. The green curve (A) indicates good extraction and purification. The black curve (B) has shifted to the right and has a high absorbance at 220 nm, suggesting contamination with phenol. The red curve (C) indicates an insufficient amount of DNA

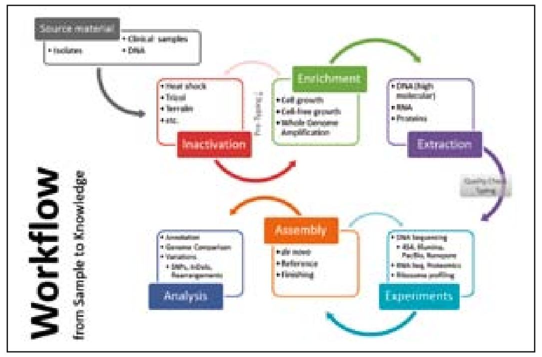

Fig. 2: : Workflow showing the individual steps from starting material, to pre-analysis, to various experimental techniques for data acquisition and analysis, to detailed knowledge about the pathogen

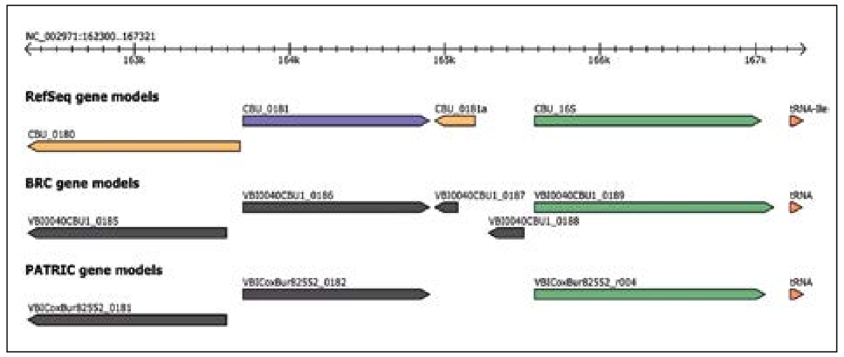

Fig. 3: Varying gene models (alternative gene start of CBU_0180, length of the 16S rRNA, missing genes) predicted by three different systems

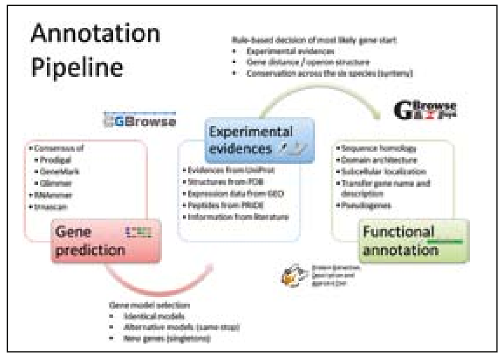

Fig. 4: The analysis of a whole genome sequence begins with the modelling of genes and proteins. Their function is then predicted using algorithms or is determined by means of experiments

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Sulphur mustard: new findings through resistant cells

The use of chemical warfare agents has a long history, one example being the Peloponnesian War of 431-404 BC. Even today, in spite of the Chemical Weapons Convention, they are still a real and existing threat. Sulphur mustard, in particular, is easy to produce and available in many crisis regions. Notwithstanding its long history, there are still only inadequate possibilities for treating exposure to it.

Sulphur mustard, or mustard gas as it is commonly called, is the world's most famous chemical warfare agent, known throug its use in the First World War. Less well known is the fact that modern chemotherapy for cancer originated from sulfur mustard in 1946. Even today, eight of the drugs currently approved and used for chemotherapy are derivatives of mustard gas.

The actual cytotoxic effect of sulphur mustard comes about through binding to the chromosomal DNA (alkylation), thereby causing irreversible cell damage and, ultimately, cell death. This process, after exposure to sulphur mustard, still cannot be stopped, mitigated or reversed today. By contrast, however, it is known that cancer cells are able to resist chemotherapy and develop a resistance. This also applies to those alkylating drugs derived from sulphur mustard.

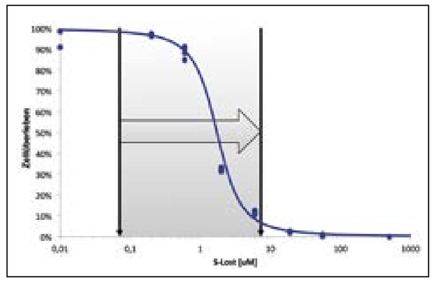

Fig. 1: Before the continuous treatment with sulphur mustard the IC50 of the keratinocytes was 1.8 µM sulphur mustard. At present the cells are being treated with 7.2 µM sulphur mustard. This corresponds to a concentration at which 95 % of the original cells would have died

Fig. 2: Slide chip array for the determination of 275 cytokines in only one sample

If the theory generally accepted in oncology is adhered to that a cancer cell does not acquire any new capability but only activates capabilities that are chromosomally encoded, then the capability to defend itself against alkylating agents must basically exist.

Building upon this consideration, we have examined the question whether it is possible to grow cells in the laboratory to the point that they become resistant to sulphur mustard. For this purpose we selected human keratinocytes. Keratinocytes are horn-forming cells of the epidermis and those which are damaged most when exposed to sulphur mustard.

In 2011 we began to acclimatise human keratinocytes slowly to the presence of sulphur mustard. Twice a week a concentration of 0.07 µM was added to the cells in culture. This corresponded to an original lethal concentration of 10 (IC10), meaning a single dose over a period of 5 days caused 10 % of the cells to die. Gradually, this concentration was increased very slowly. After a period of 137 weeks, or 33 months, the cells are now incubated twice weekly with 7.2 µM. This represents a more than 100-fold increase.

In relation to the initial situation the cells are now being exposed to a lethal concentration of 95% – in other words the concentration at which 95 % of all cells die off with a single dose within five days (Figure 1). But the cells today, at this concentration, are not only surviving but even multiplying. If the amounts of sulphur mustard administered until today were added together and applied to a human, they would come to a theoretical total amount of around 1.16 kg pure sulphur mustard.

These sulphur mustard-resistant keratinocytes are now the starting point for further research work on sulphur mustard resistance. The aim is to identify mechanisms whereby cells or tissue may escape destruction by sulphur mustard. This should yield data which can then be used for medical treatment.

The secretome has already been tested for 275 different cytokines in a first study (Figure 2). It was possible to show that sulphur mustard-resistant cells produce and secrete significantly more of the signal molecules TIMP1 and TIMP2, ANG, MMP10, and PDGF-AA (Figure 3). Further detailed work is now being carried out to study the cellular regulation. Particular attention is being paid in this respect to the miRNA, the short, non-coding, interfering RNA elements that intervene essentially in the translation and protein production. Where cancer cells are concerned, it is known that there are significant changes in the miRNA distribution which are responsible for the changed capabilities of the cancer cells.

In further work, these and other findings are currently being applied to the use of stem cells. Conditioned stem cells offer the possibility of selectively influencing tissue or of replacing damaged tissue.

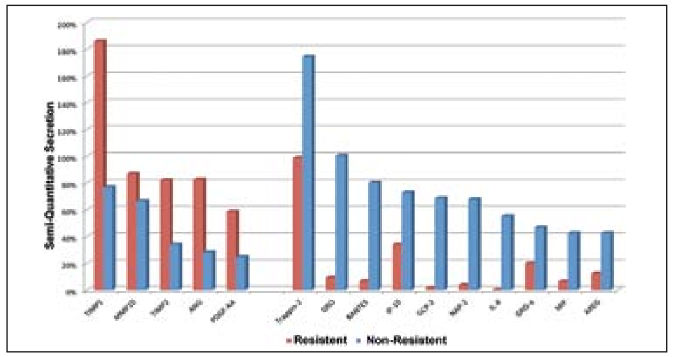

Fig. 3: Secretome of the keratinocytes. Of the 275 surveyed, in the resistant cells (red bars) 5 cytokines (TIMP1, MMP10, TIMP2, ANG, PDGF-AA) are being significantly up-regulated, while 10 cytokines (Trappin-2, GRO, RANTES, IP-10, GCP-2, NAP-2, IL-8, GRO-a, MIF, AREG) are being significantly downregulated

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Detection of acute partial body exposure to ionizing radiation in Med A scenarios

Accidental radiation exposure represents a challenge for diagnosis and therapy decision-making in the medical management of radiological incidents. Rapid estimation of the absorbed dose(s) and exposure geometry is critical in medical RN management for therapy planning.

Radiological incidents in military and civilian environments have shown that external exposure to significant doses of ionizing radiation (IR) in the range of several Sieverts, or the incorporation of large amounts of radioisotopes, can lead to the formation of acute radiation syndrome. Such high-dose scenarios stand in contrast to natural background radiation largely caused by radioactive nuclides in the Earth's crust, which is in the range of 0.002 Sv / year (Ø Germany). It is conceivable in potential radiological and nuclear (RN) scenarios that mass casualties, which may occur in military and civilian environments due to asymmetric threats such as orphan radiation sources, radiological or nuclear incidents, dirty bombs, Improvised Nuclear Devices (INDs), etc., will pose a challenge to the medical management of such events. Particularly the large number of "worried wells" (worried but non-exposed individuals) to be expected in such scenarios will have to be identified and counselled to be able to make adequate use of limited medical resources. It thus has to be considered that a first line dose estimate in the absence of physical dosimetry will have to depend on clinical prodromes and bioindicators. The latter, ideally, should respond to IR exposure in a dose-dependent manner and show a slow decay as is the case for chromosome aberrations and DNA-dependent changes. Recently, international efforts were undertaken with the participation of the Bundeswehr Institute of Radiobiology (InstRadBioBw) to harmonize and link biodosimetry laboratories transnationally, in order to prepare for potential mass scenarios that exceed the biodosimetry capabilities of a single nation.

The courses of radiological incidents have shown that orphan radiation sources frequently play a central role, like in 1997 during the accidental IR exposure of military guard personnel at a Georgian army training site (IAEA 2000). For this reason the planning for medical radiation accident preparedness takes account of all the scenarios that are relevant in terms of military medicine for diagnostic and therapeutic countermeasures, so as to provide the appropriate mission support capabilities.

In biodosimetry it has been observed that the focal DNA damage (i. e. damage foci) elicited in irradiated cells (Figure 1) and the statistical evaluation of the foci distribution in irradiated cells can predict partial body irradiation. It is also possible to investigate IR-exposed skin regions within minutes for long-lasting DNA damage foci in keratinocyte nuclei. However, the required biopsies of exposed skin regions make the evaluation of larger irradiated areas unrealistic. However, this can be compensated for by the analysis of DNA damage foci in nucleated peripheral blood cells (Figure 2).

InstRadBioBw has established a DNA damage focus assay for the rapid diagnosis of radiation exposure on the basis of blood samples. This test allows fast detection, within a few hours, of a radiation exposure and provides for an estimation of the approximate doses involved. InstRadBioBw has tested the capability of this foci method for detecting / predicting partial body irradiation in cooperation with the French Institut de Recherche Biomédicale des Armées (Brétigny sur Orge, France). Investigation of the DNA damage focus response revealed that the distribution and deviation of the radiation-induced focus yield in the analyzed cells can serve to predict partial body irradiation based on a deviation from a Poisson distribution (Figure 3). It became clear that blood samples for such an analysis should be recovered as soon as possible after IR exposure, since the progression of time after irradiation leads to a drop in foci values due to ongoing DNA repair processes (Figures 1 and 4). The findings from this study indicate that, during a potential RN scenario, it would be possible relatively quickly (within a few hours) to detect signs of radiation exposure and its geometry (whole or partial body irradiation) through analysis of the DNA damage foci in lymphocytes of affected individuals. The method is available as part of the mission support portfolio of the InstRadBioBw medical taskforce, where it will be put to use in medical RN accident management.

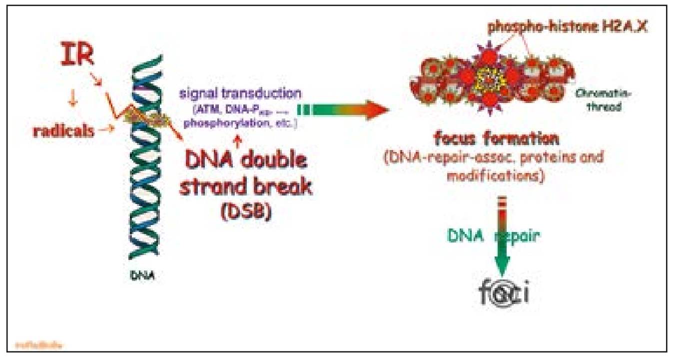

Fig. 1: Ionizing radiation (IR) can induce DNA double strand breaks (DSBs) through direct action or through radicals induced in the environment of the DNA. DSBs activate a signal cascade that, among other targets, rapidly phosphorylates the histone H2A.X. The formation of several phospho (γ)-H2AX molecules around the DSB can be visualized as a microscopic focus. The foci number and IR dose correlate linearly. With the progress of time, DNA repair leads to the decline of foci numbers (Source: H. Scherthan)

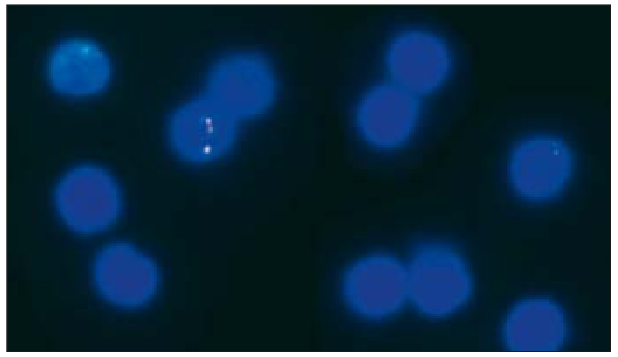

Fig. 2: DSB foci (red-yellowish) in nuclei (blue) of lymphocytes 4h after 50Gy partial body irradiation. γH2AX (green) and MRE11 DNA repair protein (red) colocalization at DSBs leads to a mixed colour. One nucleus in the image shows 3 foci, and the majority of the nuclei no foci, which can be an indication of partial body irradiation (Source: A. Lamkowski, H. Scherthan)

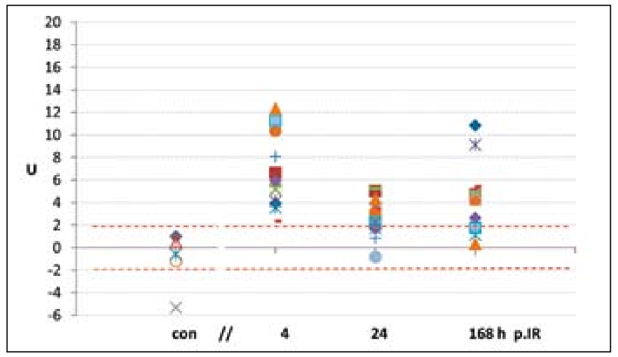

Fig. 3: Dispersion analysis (u) of foci distribution in 13 samples at time points (h) post IR. U-values outside the dotted red lines indicate over- and underdispersion, which is indicative of partial body irradiation. This is seen for all 4 h values. In vitro X-ray-irradiated blood samples (con) show a Poisson distribution, except for one (Source: H. Scherthan)

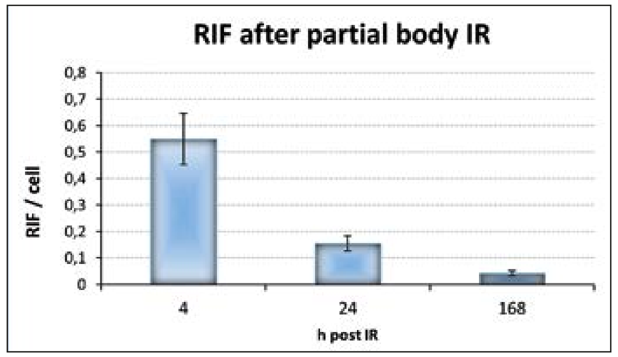

Fig. 4: Frequency of radiation-induced foci (RIF) per lymphocyte (average of 13 samples), at 3 time points past 50Gy Co-60 γ radiation exposure. The decline of the foci number indicates the progress of DNA repair (Source: H. Scherthan).

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Basic Military Fitness Tool (BMFT): Development of the exercise physiological module of a test concept for predeployment training

The individual soldier‘s ability to take part in missions abroad is ensured by means of predeployment training. To date, there has been no quality-assured method designed to monitor personnel‘s physical ability to take part in operations. In the following a newly developed tool for quantifying mission-relevant exercise physiology parameters during training is presented.

Over the past decades the mission of the Bundeswehr has changed considerably. While its main focus used to be on national defence, the daily routine of large parts of the armed forces nowadays revolves around preparing for and participating in international operations. All military personnel must generally undergo multi-stage predeployment training (conflict prevention and crisis management (CPCM) training) to provide them with the military skills and knowledge required for deployments abroad.

The conditions and required capabilities in CPCM training and missions differ greatly from civilian work processes. They are still physically challenging, despite many technical developments that make the work easier. As defined in the classification of physical fitness levels in the Bundeswehr (Directive on Training, Maintenance of Individual Basic Skills and Physical Ability, Fig. 1), these tasks are much more challenging than those at the Baseline Fitness level. The Bundeswehr, to date, has had no method comparable to the Basic Fitness Test (i. e. the physical fitness assessment required for all service personnel on a yearly base) for testing the mission-relevant performance required at the Basic Military Fitness level.

As part of a study entitled “Psychophysical Performance and Military Fitness against the Backdrop of Mission Requirements and Fitness Level of Military Personnel”, the Basic Military Fitness Tool (BMFT) has been developed as the exercise physiological module of a broader test battery for predeployment training assessment. The study has been conducted collectively between the Department for Sports Science at the University of the Bundeswehr, Munich, the Central Institute of the Bundeswehr Medical Service Koblenz, and the German Sport University Cologne.

The fundamental prerequisite has been to compile an exercise physiology requirement profile that reflects, at a joint forces level, the physical stress components that service personnel experience on deployments. This has involved conducting targeted analyses of various branches of the services towards the end of their predeployment training on site at the Army Combat Maneuver Training Center. The analyses have identified mission-typical tasks with high physical demands at a joint forces level. After conducting further analyses and incorporating lessons learned from operations, and with accentuation of the aspects movement and load, the operational requirements as regards exercise physiology were operationalised in a level-appropriate BMFT.

The BMFT consists of four consecutive modules that are performed on a 55 m x 10 m outdoor course (Figure 2) while wearing a field uniform, helmet, and protection class IV ballistic vest (20 kg total weight):

- BMFT-A: 130 m course with changes of direction, position, and speed (e. g. maneuver under fire, Figure 3)
- BMFT-B: Dragging a 50 kg load over 40 m (e. g. casualty recovery; Figure 4)
- BMFT-C: Transporting 2 x 18 kg loads over 100 m (e. g. transportation of materiel, casualty recovery)
- BMFT-D: Lifting a 24 kg load five times onto a 1.25 m-high rack (e. g. loading materiel)

It has been demonstrated that the BMFT is viable with the personnel, and time resources available in the Bundeswehr. A follow-on study will evaluate the test quality criteria of the BMFT and propose an evaluation system. With the BMFT it will be possible for the first time in the Bundeswehr to monitor the exercise physiology requirements at the “Basic Military Fitness” level (see Figure 1) and thus optimise the training.

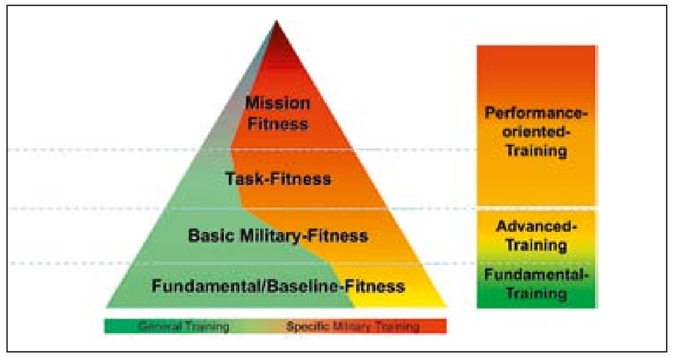

Fig. 1: Classification of physical fitness levels in the Bundeswehr (Directive on Training, Maintenance of Individual Basic Skills and Physical Ability, 2013)

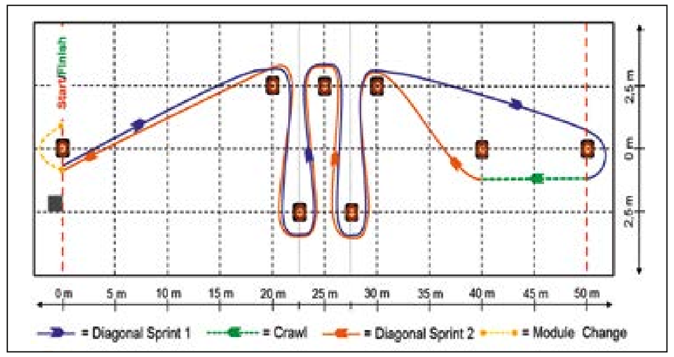

Fig. 2: Course layout and paths, taking the BMFT-A module as an example

Fig. 3: Example of how the movement aspect identified in on-site analyses is reflected in the BMFT (module A)

Fig. 4: Example of how the load aspect identified in on-site analyses is reflected in the BMFT (module B)

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Detection of molecular markers in the cerebellum after traumatic brain injuries (TBI)

Head injuries often occur during military operations. A traumatic brain injury that causes cerebral hypoxia can lead to a deterioration in the affected person's state of health. Screening methods have been selected for the purpose of detecting cerebral hypoxia.

In the current research project, biomarkers have been sought in order to estimate the extent of any cerebral hypoxia after a traumatic brain injury (TBI). These markers should be suitable especially for post-mortem and strongly degraded tissue, for instance for analyzing aircraft accidents.

When on military operations, service personnel can suffer traumatic head injuries caused, for example, by explosions, penetrations by foreign bodies, or impacts and jolts. Depending on the severity of the brain injury, it may be accompanied by memory loss, impairment of speech, vision and hearing, as well as impaired powers of judgment, self-control and movement coordination. Particularly severe TBIs can frequently be fatal. In civilian life, too, head injuries occur as a result of falls, fights or traffic accidents, among other causes. According to medico-legal autopsies, severe head injuries are among the traumas that most frequently lead to death and thus call for extensive case studies and evaluations.

As a result of a head injury, intracranial aftereffects varying in intensity can occur, including skull fractures, and hematomas around the meninges or in the cerebral tissue (see Figure 1). Concussion of the brain tissue results in tissue and cell damage, which leads locally to cell destruction, metabolic dysregulations and circulatory disturbances as well as to oxygen deficiency within the brain (so-called cerebral hypoxia), even well away from the original cortical contusion zone.

The cerebellum has been chosen for this study because it often remains intact in the event of severe accidents due to it being protected by the cerebellar tentorium, a duplication of the dura mater and, for that reason, qualifies as a subject for examination. Furthermore, the cerebellum is suitable because it seems to react vulnerably to hypoxia.

The cerebellum samples originate from autopsy material provided by the Institute of Legal Medicine, Medical Faculty, of the University of Leipzig. The cerebellum samples from humans who had died after trauma were compared against control samples (sudden cardiac death). On average, the survival time within the TBI group was 4 hours.

The complete RNA, i. e. the DNA transcriptions, was isolated from the brain samples. Afterwards, the complete mRNA (messenger RNA), which is later translated into proteins, was analyzed, for which purpose a whole genome screening was conducted.

An average of 30,218 mRNAs could be detected in the cerebellum samples. The number of mRNAs that were expressed differently between the TBI and control group and were detectable in more than half of the samples per group was 42. From these mRNA candidates a total of 14 markers was selected and additionally validated by means of another measurement method (qPCR). The correlation between both measurement methods was very high ($r^2 = 0.93$), see Figure 2.

With the aid of two mRNA marker combinations (IL6 / HSD11B1 or HSPA12B / FOSB), the TBI group can be validly demarcated from the control group (see Figure 3). Interestingly, those markers are involved in inflammatory processes (IL6), steroid biosynthesis (HSD11B1), cell death inhibition (HSPA12B) and transcription (reading of the DNA; FOSB).

It is known that the severity of a TBI correlates with the released amounts of IL6. This marker could hence be used to determine the severity.

The FOSB marker is particularly suitable for detecting TBI-induced cerebral hypoxia, as it has already been published that c-FOS, another member of the FOS family, does not increase in case of a generalized hypoxia.

In the present study it has been possible to show that there are suitable biomarkers for detecting cerebellar hypoxia after a cerebral injury.

In future it will be necessary to conduct further studies in order to examine the concentration of the four markers as a function of TBI severity. It might thus be possible to reconstruct accidents and, subsequently, develop improved protective equipment.

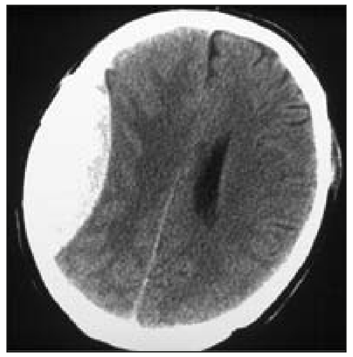

Fig. 1: Presentation of intracranial bleedings: bleeding between the calvarium and the dura mater – a so-called epidural hematoma with compression of the lateral ventricle and a starting midline shift (postmortem CT scan)
(Source: with kind permission from Prof. Jan Dreßler, University of Leipzig, Institute of Legal Medicine)

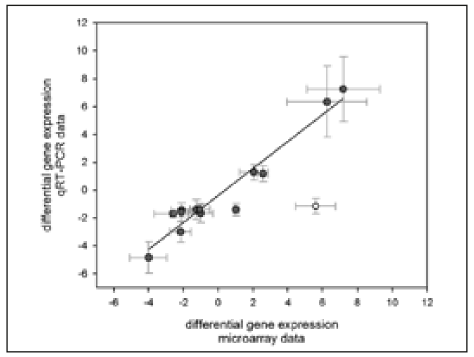

Fig. 2: Correlation between qRT-PCR and microarray data (Source: ORR Dr. Schober)

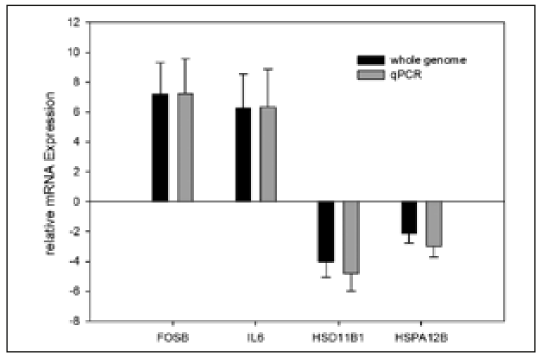

Fig. 3: Differential mRNA expression of four relevant mRNA markers (Source: ORR Dr. Schober)

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Seasickness – old problem and new challenges in the Navy

Seasickness is still an issue in the Navy. Shrinking crew sizes mean the need to achieve higher levels of performance, even in heavy seas. In a life raft study, vitamin C showed itself to be superior to a placebo in mitigating symptoms of seasickness. The new "Seasickness and Performance" project is intended to investigate to what extent a beginning seasickness negatively influences the physical and mental performance of seamen.

The highly complex workstations on board modern seagoing Navy units place high demands on crew operational readiness. The parallel trend toward reducing crew sizes is increasing the need to maintain the unrestricted performance capability of as many crew members as possible, even under adverse weather conditions.

The problem of seasickness plays a particularly important role in this connection, since it cannot always be expected that each crew member will adapt sufficiently to rough sea conditions.

Although a number of effective medications are available to ship medical officers or squadron surgeons to fight the symptoms of seasickness, it is not seldom that they also have adverse side effects which can negatively influence performance to the extent that personnel are no longer fit for duty either with or without medication.

Against this background the German Naval Medical Institute has conducted a prospective, randomized and placebo-controlled study to investigate whether prophylactically administered vitamin C might help to mitigate the symptoms of seasickness, due to an antihistaminic and, therefore, antiemetic effect of vitamin C, and constitute a potential alternative with minimal side effects to established medications for mild forms of seasickness. Earlier research has shown that relatively high blood levels of vitamin C reduce elevated histamine levels and, thus, the sickness that is felt.

Seventy volunteers took part in the study and were exposed to artificial waves in a lifeboat in an indoor pool after administration of vitamin C or placebo.

The results of this study showed that the prophylactically given dosage of two grammes of vitamin C prior to 20 minutes of exposure to waves mitigated the symptoms of seasickness to the extent that, irrespective of the expected habituation effect, the exposure was experienced to be less unpleasant after vitamin C compared to placebo.

Vitamin C showed itself to be significantly superior to placebo in this study, which was based on realistic conditions. The study findings have been published this year in the peer-reviewed Journal of Vestibular Research. Further research will need to demonstrate in future whether vitamin C administered in an adequate dosage also possesses the potential for alternative therapeutic use against seasickness at sea with minimal or no adverse side effects.

In a parallel approach it will be investigated in the next few years just how far the early symptoms of seasickness, or the so-called "sopite syndrome", are able to negatively influence parameters that are measurable for vigilance and physical performance, and when the person affected, observes a reduction in performance him- or herself.

The results of this project entitled "Seasickness and Performance" are expected to help further improve safety on board, particularly under adverse sea conditions with a difficult swell and in the face of shrinking crew sizes.

Fig. 1: "Gorch Fock" in heavy weather

Fig. 2: Life raft with participants during wave exposure

Fig. 3: Heavy swell in the pool

Fig. 4: Mobile laboratory for the study

3

Military History and Social Science Research

The Bundeswehr Centre of Military History and Social Sciences (ZMSBw) undertakes military historical and socio-scientific research on behalf of the Federal Ministry of Defence in order to actively shape the public debate about military and security issues in Germany with the scientific findings it has produced. The ZMSBw researches German military history in accordance with the generally accepted methods and standards applied in the science of history, taking account of the interrelationships between the military, politics, economy, society and culture. Through its social science research the ZMSBw contributes toward the further development of social sciences as well as toward scientifically based political consultations. The intertwining of the science of history and the social sciences broadens the options in the field of research and the application of its findings in history education.

The ZMSBw helps to promote the understanding of the role of armed forces in a pluralist society. Social sciences, being thematically intertwined with military history, feed into the research on, and interpretation of, new conflicts and special operational scenarios of the Bundeswehr.

The scientists of the ZMSBw are members of the academic community. They maintain contacts with organisations, institutions and agencies at home and abroad as well as with university and non-university research facilities. Cooperation with other Bundeswehr institutions engaged in training, research and education is increasingly important. The ZMSBw supports Bundeswehr missions through historical and social science analyses.

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German military history from 1970 to 1990

The Bundeswehr Centre of Military History and Social Sciences is conducting research on the development of the Bundeswehr and the East German National People's Army from a comparative perspective within the framework of a project titled „German Military History from 1970 to 1990". Taking an interdisciplinary approach, the project combines historical and sociological concepts, methods and analyses.

In 2015 the Bundeswehr will be celebrating the 25th anniversary of its reorganization into an „Army of Unity". The East German National People's Army (NVA) and the Bundeswehr were merged on 3 October 1990, after decades of being enemies in alliances with their respective partners. The research being conducted by the Bundeswehr Centre of Military History and Social Sciences (ZMSBw) is now focusing on the decades preceding German reunification in order to write a modern military history of both German states. As outlined in its 2014 Departmental Research Plan, the ZMSBw is examining the interrelationships between the military, state, politics, society, culture, economy, science and technology, and analyzing them on the basis of methodological standards applied in the science of history.

Preliminary theoretical considerations with regard to the project were discussed in a workshop in 2012, at which the need for a broad scientific interdisciplinary approach to the subject matter was already emphasized. The amalgamation of the Military History Research Institute and the Bundeswehr Institute of Social Sciences to create the ZMSBw has provided the

Fig. 1: The Bundeswehr in the 1970s

Fig. 2: The NVA in the 1970s

opportunity to break new scientific ground by launching a project on German military history after 1970. The outlook for this project is good. The ZMSBw has the expertise in both military history and military sociology, which is imperative for such a project. What is more, numerous fundamental publications on the military history of the Federal Republic of Germany and of the German Democratic Republic extending into the 1970s have been released within the past few years, thus priming the research environment for the upcoming project.

The availability of sources on German military history is also to be rated as favourable. In addition to files of documents on the history of the Bundeswehr and the NVA in the Federal Archives, Department Military Archives, in Freiburg im Breisgau, there are numerous sources available in various archives in Germany and abroad, such as of the Federal Foreign Office, churches, political parties and public-service broadcasters, as well as of trade and industry.

The prime objective of the project is to bring together for the first time the postwar histories of both German states and thus present a comprehensive, combined German military history after 1970, taking account of the international dimension of the alliances. This basic research project is designed to be interdisciplinary in which a multi-perspective approach based on national and international primary sources will be pursued. It will assume a comparative German-German perspective, the methodological concept of which has still to be developed.

The project will comprise several volumes dealing with subject areas such as the military as part of society, the two German states in the East-West conflict, and the arming of the two states.

Fig. 3: The Army of Unity

Fig. 4: Recent publication dealing with German-German military history

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Research on personnel and organizational issues

An „Active and Attractive Alternative". The aim of the „attractiveness" agenda is to make the Bundeswehr one of the most appealing employers in Germany, in which respect the studies prepared by the Bundeswehr Centre of Military History and Social Sciences (ZMSBw) contribute importantly to the assessment, analysis and evaluation of attractiveness-enhancing measures.

One of the six main social science research subjects in the 2014 Departmental Research Plan developed by the Federal Ministry of Defence is „Personnel recruitment and retention". A corresponding area of core competence was created at the former Bundeswehr Institute of Social Sciences as early as ten years ago and continues in existence today at the ZMSBw. Current projects cover a broad spectrum of subjects for specialist work in the field of personnel recruitment and retention for the Bundeswehr, which is one of the largest employers in Germany. The ZMSBw recently published its youth study, which gives important information about the career choices made by young people and about their opinions on the Bundeswehr as an employer.

Fig. 1: The attractiveness agenda

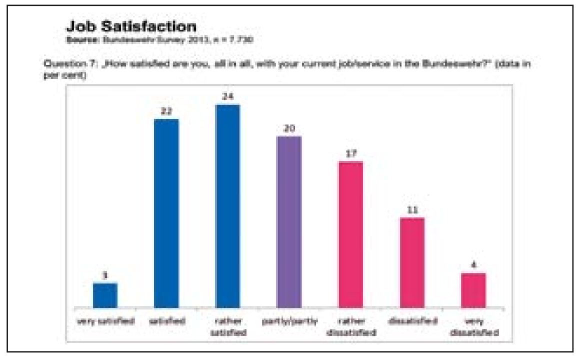


Fig. 2: Results of the interviews on the personnel's satisfaction with the service

Ongoing studies at the ZMSBw include:

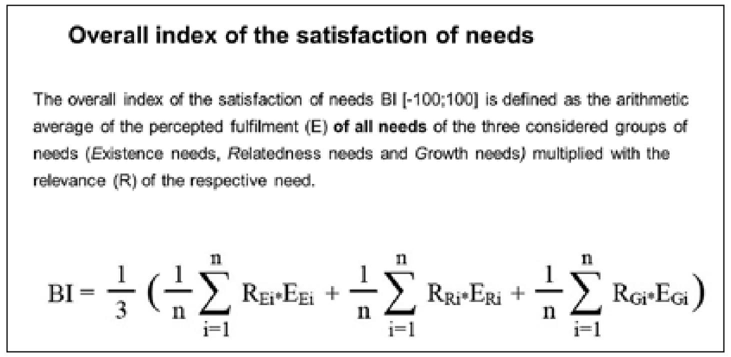
- Attractiveness of the Bundeswehr as an employer (since 2013)
- Personnel recruitment and retention in the Bundeswehr Medical Service (since 2012)
- Evaluation of voluntary military service (since 2011)
- Naval officer candidates in the first year of training (since 2013)

Where the development of the current attractiveness agenda was concerned (Figure 1), the Federal Ministry of Defence was able particularly to draw upon the findings of the first-mentioned study. From 30 January to 3 March 2013, a total of 7744 military and 3214 civilian personnel were interviewed. An explanatory model based on occupational and motivational psychology approaches was developed which shows the relation between employer attractiveness and satisfaction of occupational needs. Among other things, an instrument for measuring the Bundeswehr's attractiveness as an employer to specific target groups (Figures 2 and 3) and also, if necessary, for evaluating the agenda's package of measures was created.

In addition to Bundeswehr-wide interviews on employer attractiveness, the studies conducted at the ZMSBw are focusing on specific groups targeted by human resource management.

Particularly worthy of mention is a long-term project being carried out in cooperation with the Bundeswehr Medical Service. It is planned to hold several rounds of interviews for selected groups of medical officer candidates and (senior) medical officers concerning their professional biography, in order to determine factors which influence personnel recruitment and retention and to identify measures which may enhance career attractiveness. In this regard, too, intermediate findings have already been published.

Besides commissioned research and counselling, the social science community in the Bundeswehr actively participates in discussions with expert circles and the interested public. This is also reflected in the publications of the ZMSBw in 2014 (Figure 4). The interaction of organization and personnel will continue to be a focus of social science research for the ZMSBw in the years to come.



Overall index of the satisfaction of needs

The overall index of the satisfaction of needs BI [-100;100] is defined as the arithmetic average of the percepted fulfilment (E) **of all needs** of the three considered groups of needs (*Existence* needs, *Relatedness* needs and *Growth* needs) multiplied with the relevance (R) of the respective need.

$$BI = \frac{1}{3}\left(\frac{1}{n}\sum_{i=1}^{n} R_{Ei}\cdot E_{Ei} + \frac{1}{n}\sum_{i=1}^{n} R_{Ri}\cdot E_{Ri} + \frac{1}{n}\sum_{i=1}^{n} R_{Gi}\cdot E_{Gi}\right)$$

Fig. 3: Calculation of the overall index of the satisfaction of needs

Fig. 4: Current publication from the research field Human Resource Management and Organization

4

Geoscientific Research

The Bundeswehr Geoinformation Centre (BGIC) is responsible for "geoscientific research" as a subprocess of the FMoD's "Ensuring geoinformation affairs" performance process. Its research and development (R&D) activities are invariably geared to the immediate needs of the Armed Forces and to the missions they undertake. The global orientation of the Bundeswehr requires the Bundeswehr Geoinformation Service (BGIS) to comprehensively provide geoinfo data and products. It is therefore necessary for BGIS methods and processes to be adapted regularly to the steadily advancing state of science and technology. Only thus can the BGIS suitably accomplish its mission and at all times provide up-to-date scientifically based information for all the geospatial functions of the FMoD and the Bundeswehr.

The geoscientific research is based on the latest state of the art and involves analysing relevant scientific data in a mission-oriented manner. The range of services offered by research institutes of other federal ministries as well as by military and non-military science and research facilities is also used in terms of geoscientific information for military purposes. Geoscientific R&D projects are conducted in collaboration with appropriate partners from other ministerial research institutions, universities and universities of applied sciences, or also with commercial enterprises.

Some eighteen scientific disciplines are united under the umbrella of Bundeswehr Geoinformation Affairs, with the work taking an interdisciplinary approach geared at all times toward collective, future-oriented geoinfo support solutions for the Armed Forces. In addition to the current focus on the ongoing improvement of Bundeswehr geoinfo support, the geoscientific departmental research is understood as a linking of science, policy advice and research on areas that do not as yet show any need for action or regulation by politicians. It is hence possible to identify and adopt new developments at an early stage, and ensure advisory capacity. Furthermore, non-technical studies, research and technology projects as well as concept development and experimentation (CD&E) schemes are initiated, supported, carried out, evaluated and /or implemented.

Where topics in connection with geoinfo support are concerned, the geoscientific research may be complemented by third-party-funded research, support of doctoral dissertations, or supervision of Diploma, Master and Bachelor theses.

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Meteorological and climatological data for noise control and camp protection

Outdoor noise control and acoustic target acquisition require precise meteorological data. For this purpose the Bundeswehr Geoinformation Centre (BGIC) provides the latest world-wide weather data and climatologies of the sound propagation conditions, using meteorological model forecasts as a basis. A recent study substantiates the advantages of model data compared with measurements, but also draws attention to deficits and necessary procedural modifications.

The BGIC provides meteorological data on a daily basis from its COSMO / LME forecast model to help monitor noise control at Bundeswehr firing ranges. Combined with weapons and ammunition data, these "synthetic" yet realistic weather data can be used to match firing operations against predicted noise exposure and, if necessary, to make adjustments. The benefits of meteorological model data compared with the use of measurement data are based, primarily, on uniform coverage in terms of space and time. Added to this is a high and globally consistent quality demonstrated in several comparative tests, among others in two major NATO artillery firing exercises in Denmark and Turkey where, during live firing (of several hundred projectiles), a direct comparison was made between measurement data and model data. The BGIC provides the data from a Global Model (GME), as well as from special relocatable models, for military applications at the times of 00Z and 12Z and additionally, if required (in case of models with a higher resolution), at 06Z and 18Z, or even at 3-hourly update intervals (Figure 1). The model grid spacing varies between around 30 km for global coverage and roughly 3 km for smaller areas.

To forecast noise exposure (for noise registers), it is necessary to have climatological data. To date, this has been limited to so-called wind roses, in other words to frequency distributions of the wind speed and wind direction close to the ground (generally 10 m above ground) at a specified location, derived from many years of series of measurements. In order to obtain a more realistic picture, the University of Leipzig, working on behalf of the Bundeswehr, was the first to compute "sound climatologies" on the basis of daily meteorological atmospheric soundings taken at all German aerological stations over a period of 20 years. As the sound propagation situation was modelled with each individual meteorological profile (up to 3,000 m above ground), these sound climatologies clearly show seasonal structures (Figure 2).

In the context of the new tasks the Bundeswehr is to focus on, it has been found that the sound climatologies originally developed for noise control could also be of benefit in the use of artillery sonic / target location systems or for camp protection (sniper detection). Knowing the seasonal climatological sound propagation conditions would, in future, allow optimised installation of sound ranging sensor systems. Daily range predictions could, in addition, enhance the ongoing operation of the systems.

So far, sonic location systems (such as the sound-ranging system operated by artillery) have used their own mast measurements or standard artillery weather reports for the latest meteorological input data. In future such data could be sourced from meteorological models for world-wide use. A comparative test conducted for this field of application has yielded good results for the sound-ranging system, with the comparison between measurement data and model data showing the meteorological model data to be significantly better on average than the conventional measurement data where location accuracy is concerned (Figure 3).

There are further possibilities for optimisation and improvements in the employment of model data, always viewed from the aspect of in-theatre use, both in model development and operation at the Weather Analysis Centre (German Meteorological Service / BGIC) and in the distribution / utilisation of the computed data. Especially for regions for which little data is available, such as Afghanistan, it is imperative to strive for direct incorporation of the few high-quality soundings available locally in the model analysis (and, consequently, prediction) of the current model run. In Afghanistan this has been successfully pioneered through the real-time transmission of measurement data to the BGIC (Figure 4).

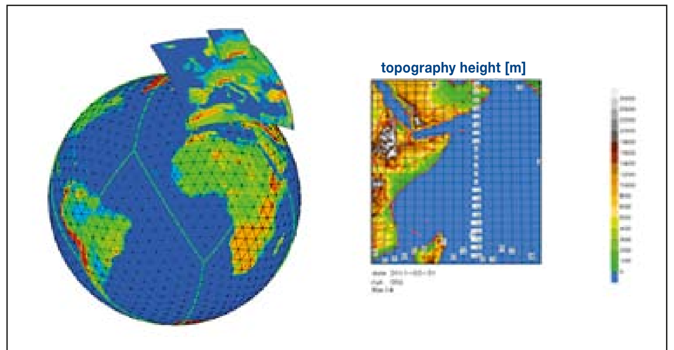

Fig. 1: Model chain of GME – COSMO / LME / RLM – LMK / RLMK (left); Example of an RLM over the Horn of Africa (right)
(Source: German Meteorological Service / BGIC)

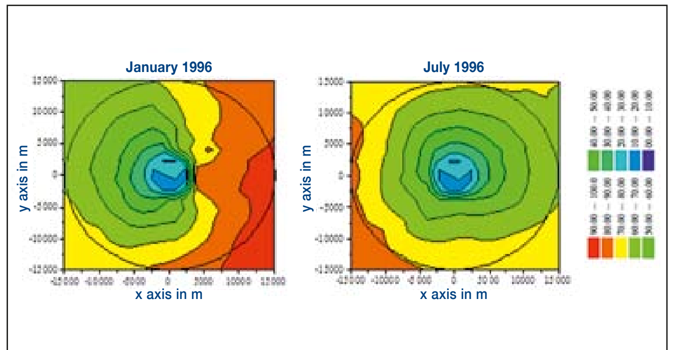

Fig. 2: Noise propagation climatologies for Meppen in the winter (left), with easterly winds and, consequently, stronger damping in the eastern area, and in the summer (right), with SW atmospheric conditions and stronger damping in the SW. Sound level damping in dB – see far right.
(Source: Institute for Meteorology, University of Leipzig)

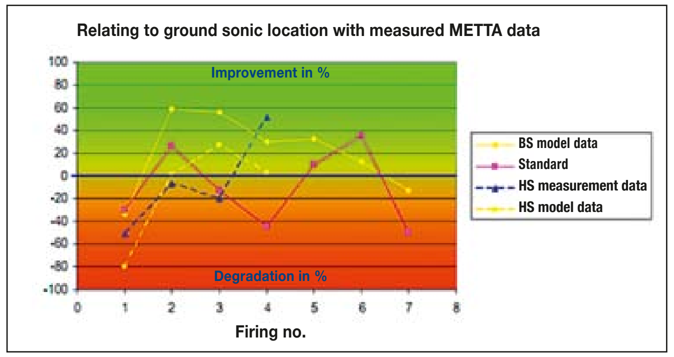

Fig. 3: Comparison of location results re-computed on the basis of different meteorological data sources. Model data (yellow) yield better results on average than conventional measurements (Source: Thales Defence DEU)

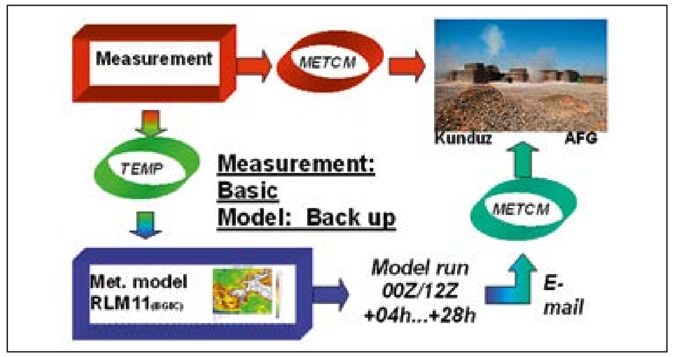

Fig. 4: Data flow implemented for the first time for AFG "mission country → WAC → mission country", resulting in the improvement of the centrally computed model forecasts (Source: BGIC)

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Study and quantification of potential multipath effects on GIBSBw

Operation of the GNSS Information and Observation System of the Bundeswehr (GIBSBw) is contingent on undisrupted reception of observation data. Interference is typically caused by objects in the vicinity of the antenna, for example. Based on "Precise Point Positioning", an analysis tool has been developed whereby it is possible to preclude significant stress caused by multipath effects.

In the 1990s the antenna of the monitoring station belonging to the GNSS Information and Observation System was installed on the highest building of the Mercator Barracks in Euskirchen. The virtually perfect free horizon there ensures undisturbed reception of the GNSS signals and, consequently, impeccable quality of the observation results. Any obstacle in the vicinity of the antenna would either directly shadow the GNSS signals or cause interference due to reflection from its surfaces. This leads to so-called multipath effects and, eventually, to imprecise or seriously flawed positioning results.

In 2012 two construction projects were realised on the site of the Mercator Barracks, in the immediate vicinity of the GIBSBw antenna location. First, a tower for the reception of signals from meteorological satellites was built north of Building A, at a distance of around 50 m. Shortly afterwards, Building "J New" was completed on the opposite side (Figure 1). As there were concerns about the quality of the data from GIBSBw being potentially compromised by the two construction projects, a tool for analysing multipath effects has been developed to be able to identify any such adverse effects.

Fig. 1: Panorama view from the antenna location of the GNSS Information and Observation System of GIBSBw in Euskirchen

Used is a diagnosis procedure developed in Sweden that, based on "Precise Point Positioning" (PPP), provides the possibility to attribute multipath effects to specific directions of the hemisphere, thereby facilitating detailed interpretation. PPP is a special analysis procedure for absolute point positioning based on undifferentiated carrier phase residuals from both frequencies and requires the incorporation of precise external information such as data on the satellite orbit and satellite clock. The application has been created by the University of Bonn, taking the "Bernese GNSS Software" as the basis. The results are shown in a raster of 5° in azimuth and 2° of elevation (Figures 2 – 4).

The multipath analysis tool used as an example in this instance for analysing the quality of the antenna location of the GIBSBw monitoring station is suitable for any location, provided sufficient data are available. In the case of GIBSBw, an observation period of six months was analysed both before (January through June 2010) and after (January through June 2013) the construction activities. Shorter observation periods would have yielded less detailed and, consequently, less reliable results. Figure 2 shows the distribution of the observations across the hemisphere. What is conspicuous is the so-called "Northern Gap", i. e. the area in the sky from where no satellite signals arrive due to the existing orbital inclination of 55°. But individual recurring satellite tracks with more than 1000 observations per raster element as well as areas for which no information is available are also identifiable.

Obtained as a result of the multipath analysis are the residuals of the PPP analysis, organised according to the direction of arrival and having sizes in the millimetre range (Figure 3) which, due to the atmospheric refraction influences, may by nature also be in the range of a few centimetres near the horizon.

If the 2010 and 2013 analyses for the GIBSBw location are compared (Figure 4), no significant multipath stress is found to affect that location.

The technical project was completed in September 2014, with the outcome that a tool is now available with which GNSS sites that have to meet high quality requirements, such as those relating to reference stations, can be analysed for their suitability.

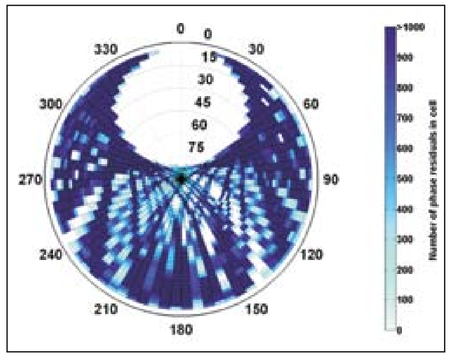

Fig. 2: Number of observations

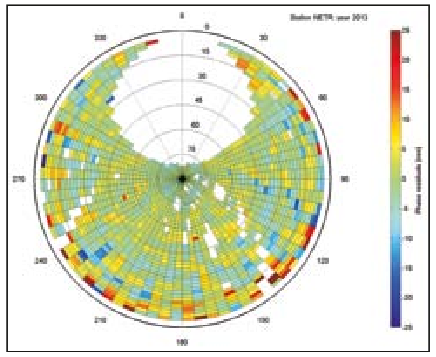

Fig. 3: Result of the multipath analysis for the GIBSBw location for 2013 after completion of the construction activities

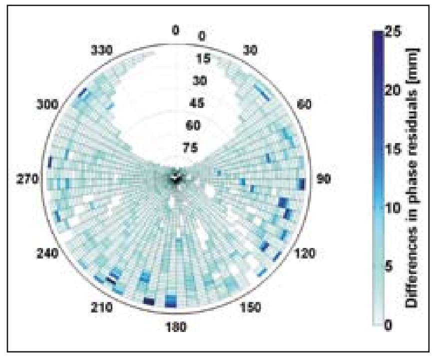

Fig. 4: Comparison of the multipath analyses before and after the construction activities (2010 and 2013) for the GIBSBw location

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Numerical modelling of atmospheric pollutant dispersion

Simulating the transport and dispersion of pollutants in the atmosphere has been part of the Bundeswehr's advisory activities for years. The HEARTS (Hazard Estimation after Atmospheric Release of Toxic Substances) model is operated by the Atmospheric Physics Branch of the Bundeswehr Geoinformation Centre (BGIC) and is constantly adapted to Bundeswehr requirements. HEARTS allows the evaluation both of acute incidents and of in-theatre and exercise scenarios.

The dispersion of (harmful) substances in the atmosphere depends on many factors, which can be represented in a model in different ways. The HEARTS system operated by the Bundeswehr uses the predictions from the weather forecast models of the German Meteorological Service, or DWD, (ICON global model, COSMO-EU European model, COSMO-DE German model, and relocatable models from deployment areas) to compute the dispersion of substances. During day-to-day operation it allows, within minutes, projections concerning the dispersion of the substance over the next few hours once a message has been received at the BGIC's Meteorological Forecast Centre. Such emergencies, fortunately, occur only sporadically, but are particularly critical precisely for the reason that any delay in the process between receipt of the message and arrival of the simulation results at the location of use is tantamount to a loss of precious time, which is why this procedure must be practised regularly.

Questions about possible scenarios are much more frequent. What would be the consequences of a sarin attack at location X? Under what meteorological conditions does ammonia from a fertiliser plant near town or city Y pose a risk to its inhabitants? These and similar questions can be answered with the aid of HEARTS.

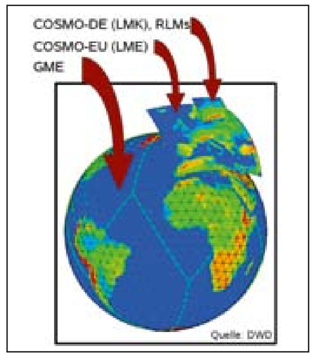

Fig. 1: Schematic representation of the DWD (German Meteorological Service) model chain including GME global model, COSMO-EU European model and COSMO-DE German model. Like COSMO-DE, the relocatable section models for the mission areas are embedded in the global model

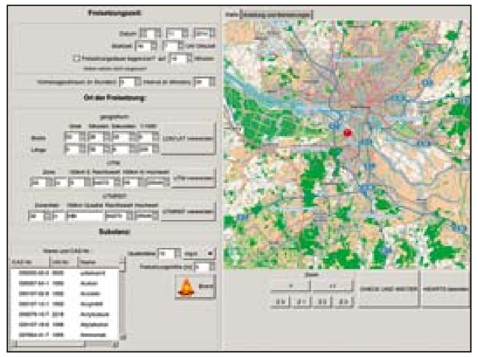

Fig. 2: The simulation parameters (source location, name of substance, amount, and period) are input via a GUI. After the simulation, the GUI is also used to specify the image format and the file names, and to send the files (screenshot)

The year 2014 was characterised by technical innovations to HEARTS: the input of data via a new GUI, the display of results and the supply of data by means of the proprietary NATO METGM format have substantially boosted product quality.

The forecasts generated by HEARTS steadily improve with the quality of the forecasts issued by the German Meteorological Service. More detailed input data, however, also require adaptation of the methods and procedures within the software. For instance, when scaling up the spatial resolution of a weather forecast model, it has to be decided whether the interpolation of the grid data for HEARTS must be changed and whether the influence of small-scale orography needs to be considered differently.

Within the Atmospheric Physics Branch the HEARTS system is undergoing constant further development which, besides the actual routines that predict dispersion, includes the data supply and the graphical user interface, such that not only meteorologists but also IT experts are a firm integral part of the advancement process.

Generally, proper simulation of incidents necessitating a large-area approach (e. g. accidents at nuclear power plants) is possible only regionally with HEARTS up to a radius of approximately 100 km and / or for a couple of hours in advance. For reasons inherent in the model, longer forecast periods and higher atmospheric layers can be dealt with only in particular cases. In this respect it appears reasonable to procure an existing model system and implement it for the Bundeswehr. There are a number of models which differ very greatly in their mode of operation. A crucial aspect for the Atmospheric Physics Branch is that the model can be developed further at the BGIC rather than be operated as a "Black Box". This has shown itself to be the best way to service user agencies.

Although from an operational point of view the system is designed primarily for use in a forecast centre, HEARTS can also be installed on laptops and used by CBRN defence forces in-theatre. It has been available for a number of years as a special "ABC-Abwehrausstattung, tragbar" (CBRN defence equipment, portable) version, as a part of the NEWS (NBC Evaluation and Warning System) software package. Soon the full functionality may also be made available in mobile form, as data supply via the internet has become feasible.

Overall, it can be said that the subject of atmospheric pollutant dispersion offers challenges both from the scientific and the technical points of view, the overcoming of which will constitute an enormous benefit in the capability spectrum of the Bundeswehr.

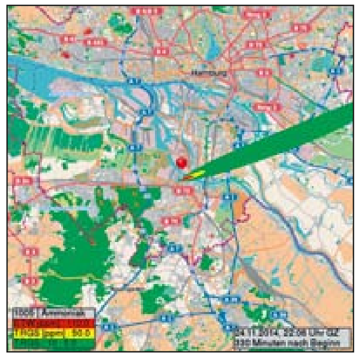

Fig. 3: Typical representation of the simulation results. The visualisation shows the spatial distribution of the pollutant concentration at a particular point in time. The threshold values for the colours red, yellow and green are derived from a pollutant database (screenshot)

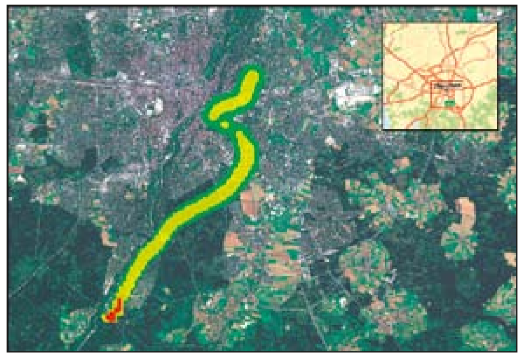

Fig. 4: Course of dispersion of a fictitious source in the Isar river valley south of Munich. While stratification is stable, the substance initially stays in the valley before it is deflected to the east, following the westerly flow (screenshot)

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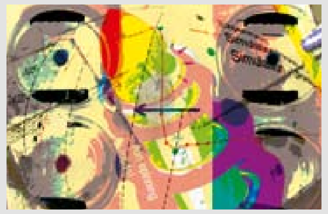

Appendix

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