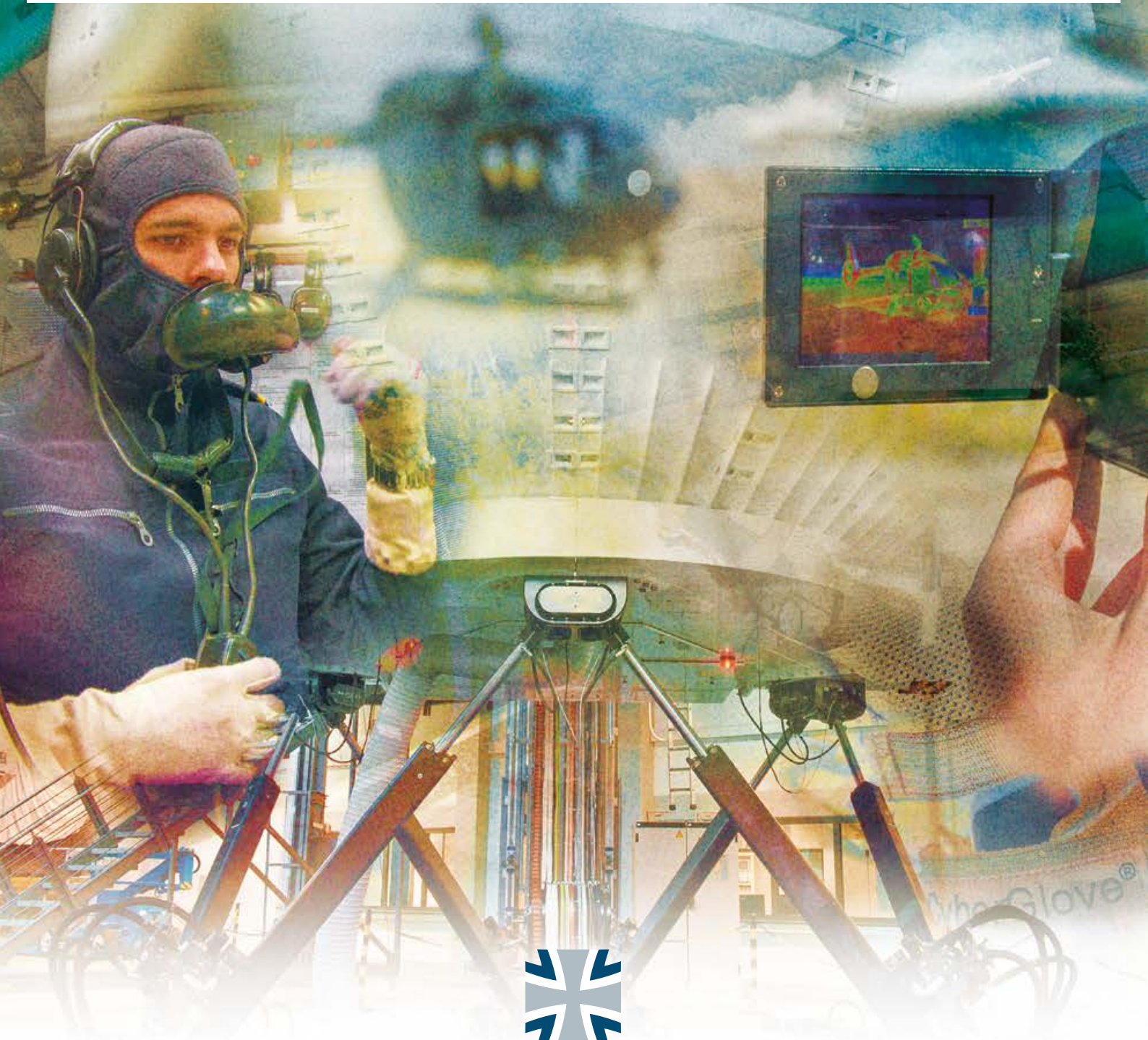




Federal Ministry
of Defence

Military Scientific Research Annual Report 2018

Defence Research for the German Armed Forces



BUNDESWEHR

Military Scientific Research Annual Report 2018

Defence Research for the German Armed Forces

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- Controls the training
- Initiates attack phases
- Supports the participants
- Evaluates the teams
- Assesses the scenarios (Debriefing)

- Observes the training
- Possible purposes:
 - Learn about the roles
 - Study strategies
 - Observe the teams and participants



Realistic network environment

Network traffic generator

Attack generator



- Attack generator
- Finds and exploits vulnerabilities
- Finds and exploits weaknesses
- Implements exploits
- Explores and exploits
- Denial of Service





Ministerialdirigent Ralf Schnurr

Unterabteilungsleiter A II und Forschungsbeauftragter
Bundesministerium der Verteidigung

Defence Research for the German Armed Forces

Germany faces a wide range of security challenges, which need to be met responsibly and with the long term in mind.

From Africa to Kosovo, on two oceans, and in Afghanistan – every day our soldiers serve in diverse theatres of operation.

As the demands on the Bundeswehr grow in variety and volume, what is expected of our servicemen and women will also increase.

The Bundeswehr needs the best equipment and sustainable funding in order to deal with challenges such as hybrid warfare, transnational terrorism, cyberattacks and pandemics effectively as well as meet the necessities for stronger national and collective defence.

It will be required to have a full, modern range of capabilities at its disposal in future. It must also be a driver of innovation and a reliable and constant partner for our allies.

With every emerging demand and need, the strategic orientation of defence research and technology is also continuously reviewed and adjusted.

In this latest issue, the Federal Ministry of Defence presents selected contributions from the fields of

- defence technology research,
- military medical and military psychology research,
- military history and social science research,
- geoscientific research, and
- cyber and information technology research.



Ralf Schnurr



Access directly by clicking on the item

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1

Defence Technology Research

Defence research and technology (R&T) is the first link in a value chain, at the end of which should be the equipment needed by the Bundeswehr, on time and in compliance with mission requirements.

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

The analysis and assessment capability necessary to do so involves studying civilian research findings and evaluating technological developments for their future military usefulness or their threat potential.

To evolve Bundeswehr capabilities further, strategic fields of interest are identified and pertinent emerging technologies advanced in a timely manner to production maturity. In the course of doing so, it is important to maintain and strengthen our own technological sovereignty in key national military-industrial areas.

The ultimate objective is to safeguard and improve the Bundeswehr's capacity for action and its performance capability through greater cultivation of new ideas and rapid implementation of innovations.

In Germany, defence R&T activities are conducted

- at Bundeswehr research institutes and technical centres,
- within the scope of shared government funding, by 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 awarding of R&T contracts and grants to third parties, i. e. to industry and business, universities and institutes of further education, and non-university research institutes.

The articles appearing in the following provide examples of defence R&T activities from these three implementation levels as conducted in 2018.



Dr. Martin Schimmerohn
Fraunhofer-Institut für Kurzzeitdynamik,
Ernst-Mach-Institut, EMI
Freiburg

info@emi.fraunhofer.de

Prof. Dr. Frank Schäfer
Fraunhofer-Institut für Kurzzeitdynamik,
Ernst-Mach-Institut, EMI
Freiburg

info@emi.fraunhofer.de

Nanosatellites for military purposes

Small satellites are currently transforming the space sector. Large constellations of small satellites, produced in series and funded by considerable capital expenditures, are becoming a reality. The Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut (Fraunhofer EMI), is developing ERNST, a nanosatellite, to demonstrate the potential benefits of this emerging satellite technology for military applications.

The aerospace industry is undergoing a radical change at present due to new competitors who have attracted substantial amounts of venture capital for the development of new space systems. In the field of satellite technology such development is focusing on the concept of large swarms of small satellites. A small satellite, or smallsat, is generally defined as having a mass below 100 kg. Far from being a new invention, they have been undergoing development for decades, driven initially by radio amateurs and, later, by universities and research institutes, including in Germany. Smallsat traditionally use the free payload capacities of launcher systems, based on the rideshare principle.

An additional satellite class has established itself since the definition of the “CubeSat” standard in 1999. It consists of a standardised, cube-shaped satellite with a side length of only 10 centimetres and a maximum mass of 1.3 kilograms, or comprises multiple cube units combined as a nanosatellite. By late 2018, more than 1000 CubeSats had been launched worldwide. Record numbers of launches are meanwhile being driven by commercial providers such as Planet Labs, which



Fig. 1: Mars image taken by NASA's MarCO-B smallsat, a 6U nanosatellite with a mass of 13.5 kg built by JPL. Two of these CubeSats withstood the journey to Mars and have served successfully as the radio link to the InSight spaceprobe following its landing on Mars' surface (Copyright: NASA)

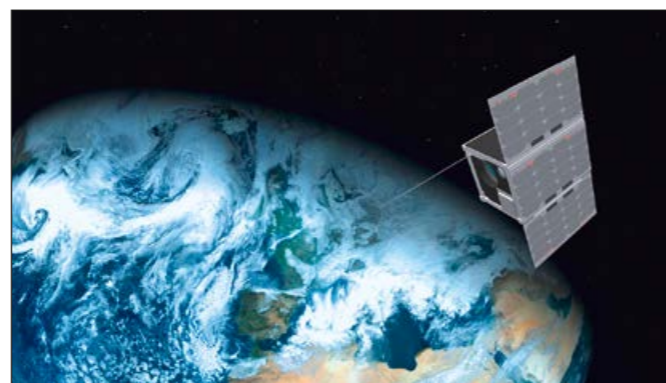


Fig. 2: Artist's impression of the ERNST 12U nanosatellite in orbit. Its launch is planned for the first half of 2021 (Copyright: Fraunhofer EMI)

has installed a constellation of over 150 CubeSats in low earth orbit for the purpose of earth observation. Smallsat have thus reached a turning point at present, evolving from mainly institutional to commercial use. Another milestone has been marked by NASA and its Mars mission InSight, which has demonstrated the technological potential of smallsat through the successful use of interplanetary 6U-CubeSats.

The emergence of smallsat is being propagated by their protagonists as part of the “New Space” industry. The highly dynamic nature of this market leads to the question whether military applications can benefit from this technology development. Although their performance is limited by their small size, they offer the essential advantage of low costs and short development times. The development of nanosatellite technology follows the premise of “validation in place of certification” and involves small, modular and robust satellite platforms assembled in series production. These systems contain a relatively high share of commercial off-the-shelf components and, because of this, are able to respond promptly to trends in technology.

Their use as part of a constellation makes it possible to realise global coverage and a low data latency. Data that is available faster and more frequently provides a more up-to-date situation picture. A further plus point is system redundancy, which is more pronounced on the US side, where the development of nanosatellites militarily is also being pursued more intensively. Compared with a single system, a constellation of satellites is very much more difficult to attack, blind, manipulate, or even destroy.

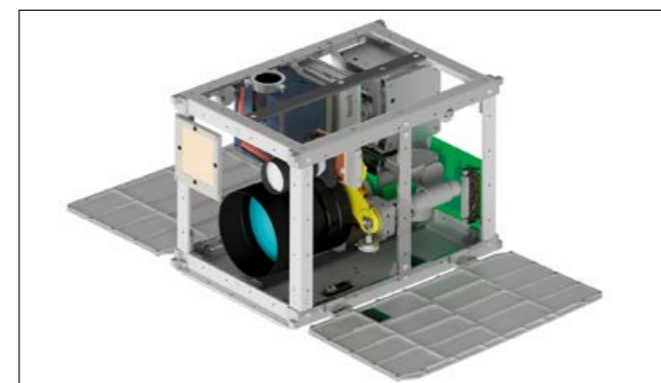


Fig. 3: ERNST engineering qualification model (without outer walls, harness and optical bench). With folded solar generators, the nanosatellite has dimensions of 236 x 236 x 340 mm³ and a mass of 15 kg to 20 kg (Copyright: Fraunhofer EMI)

Fraunhofer EMI is in the process of developing ERNST, a nanosatellite, to examine the feasibility of using smallsat to support the Bundeswehr (German Armed Forces). ERNST is a modular 12U-CubeSat platform with a volume of 236 x 236 x 340 cubic millimetres. As payloads for its demonstration mission, it carries a cryo-cooled infrared detector, for detecting rocket launches in cooperation with Fraunhofer IOSB; a camera for earth observation in the visible range, and a detector developed by Fraunhofer INT for monitoring the radiation environment in orbit. The ERNST qualification model is currently undergoing integration and testing. The launch of a flight model is scheduled for early 2021. Technological highlights include an additively manufactured optical bench and a de-orbit drag sail for accelerated re-entry of the satellite into the earth's atmosphere upon completion of the mission.

The development of nanosatellite technology can be regarded not as competition for, but as augmenting established high-performance satellites. Particularly through combination with existing systems, low-cost and highly responsive nanosatellite emissions can provide a fast and more extensive situation picture from complementary data for military remote reconnaissance applications.

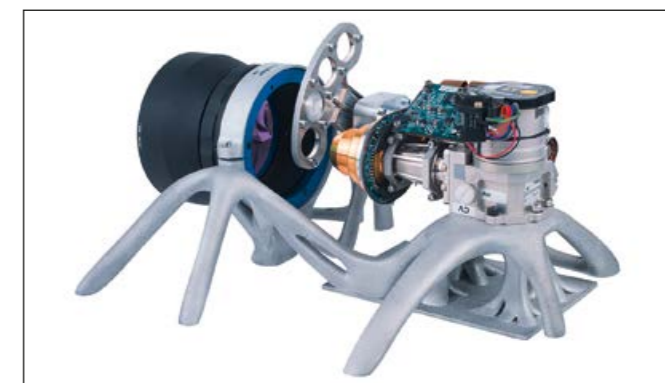


Fig. 4: Infrared main payload of the ERNST nanosatellite including filter pendulum and additively manufactured optical bench. On its underside (not shown), the optical bench has a three-dimensionally structured radiator surface that efficiently increases the emission surface area of the cryo-cooled detector while retaining a small base area (Copyright: Fraunhofer EMI)

Dr. Norbert Heider
Fraunhofer-Institut für Kurzzzeitdynamik, Ernst-Mach-Institut, EMI
Freiburg

info@emi.fraunhofer.de

Dr. Hagen Aurich
Fraunhofer-Institut für Kurzzzeitdynamik, Ernst-Mach-Institut, EMI
Freiburg

info@emi.fraunhofer.de

Mechanics of explosives – dynamic characterisation of polymer-bonded high-explosive charges

High-explosive charges for gun-launched munitions are exposed to extreme mechanical loads in the course of delivery or impact. To ensure the safety and reliability of munitions, the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut (Fraunhofer EMI) is working on methods to characterise the phenomena that occur and is evaluating the behaviour of modern polymer-bonded explosive charges under dynamic loads.

Almost exclusively nowadays, modern munitions contain insensitive polymer-bonded explosive charges, in which a crystalline explosive is embedded in a polymer matrix. Compared with charge types used in the past, the charges' sensitivity to external influences such as fire or projectile impact is significantly reduced.

Excessive dynamic loading of polymer-bonded explosives can induce changes in the internal structure of the charge, possibly altering the reaction and initiation behaviour. Such processes may need to be monitored and precluded.

With the aim of ensuring munitions safety, a method has been developed at EMI for examining the behaviour of explosive charges under high mechanical loads that typically occur during munitions use. A material model for the high-explosive charge is first of all generated which takes account of the heterogeneous structure of the charge and the different behaviour of the components. Various experimental test equipment developed at EMI (Split Hopkinson Pressure Bar, servo-hydraulic press) is used to cover the entire spectrum of occurring loads and to

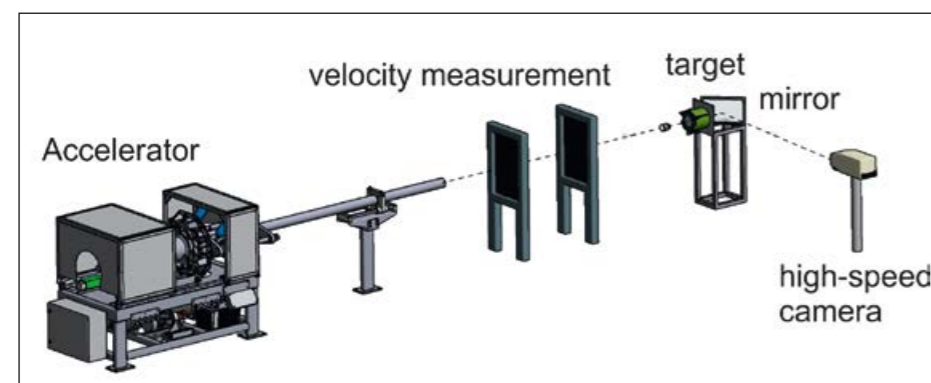


Fig. 1: Experimental set-up for characterising the reaction behaviour of high-explosive charges (safety threshold testing (STT) facility)

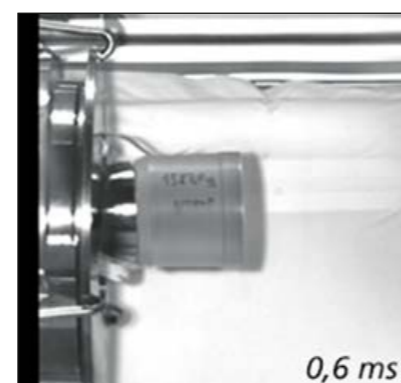


Fig. 2: Experiment (left) and simulation (right) for dynamic deformation of the high-explosive sample (magenta) after striking of the impactor

Axel Sättler
Fraunhofer-Institut für Kurzzzeitdynamik, Ernst-Mach-Institut, EMI
Freiburg

info@emi.fraunhofer.de

collect experimental material data. High-resolution X-ray computer tomography is employed to assess the mechanical condition of the explosive samples exposed to loads. The results from the experiments are used to derive suitable material model data for the highly dynamic load range.

To obtain additional information about the start of reaction processes under moderate dynamic loads, an STT (= safety threshold testing) facility has been developed with which it is possible to determine the reaction threshold of the explosive charge experimentally. It involves subjecting a confined sample to a defined deformation by shooting at it with a subsonic-velocity projectile, the size of which is varied in order to determine the start of the reaction. A reaction parameter is derived through a parallel numerical simulation of the process.

This so-called Browning parameter represents a measure of the load from which reaction processes start in the examined material. It is characteristic of the examined explosive charge and can therefore be used as a threshold value for subsequent assessments.

Once the material model for describing the mechanical behaviour and the limit value for the start of the reaction of the high-explosive charge are known, a numerical simulation of

the munitions under examination is carried out. The described process provides the possibility to perform safety assessments for dynamically highly loaded munitions (e. g. gun-fired artillery munitions), to identify critical load conditions that may occur, and to already make appropriate design changes in an early design phase.

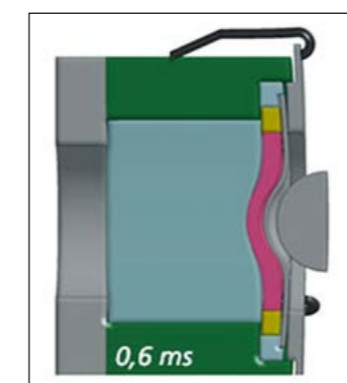


Fig.2 (right)

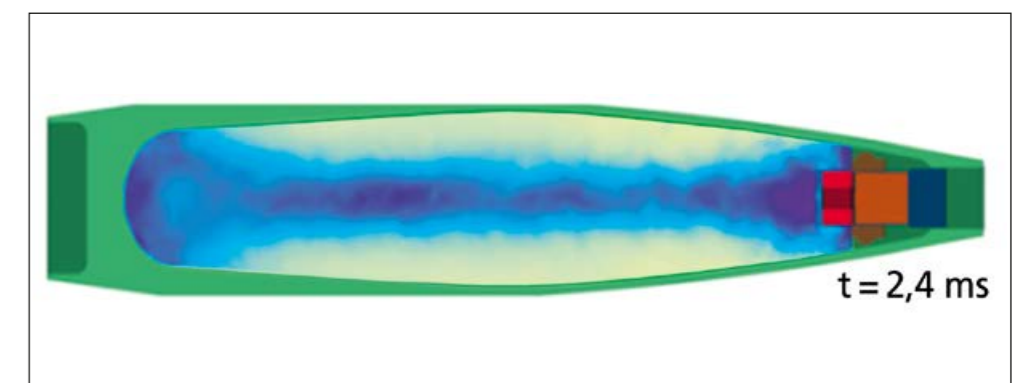


Fig. 3: Numerical simulation of the Browning parameter during firing of an artillery projectile

Dipl.-Ing. Thorsten Brehm
Fraunhofer-Institut für Hochfrequenzphysik und Radartechnik FHR
Wachtberg

info@fhr.fraunhofer.de

Dipl.-Ing. (FH) Daniel Janssen
Fraunhofer-Institut für Hochfrequenzphysik und Radartechnik FHR
Wachtberg

info@fhr.fraunhofer.de

Radar image-based navigation for drones affected by GPS signal interference

The reliability of existing navigation systems is essential for reconnaissance drone navigation. In the event of interference affecting the global navigation satellite system (GPS), a radar-based navigation method can support drones' inertial navigation systems and improve their accuracy, thus enabling successful completion of reconnaissance missions.

Since global GPS systems are often affected in conflict areas by local interference, they can prove useless for navigation. In poor visibility conditions, drones can then navigate only on the basis of their inertial navigation system. Such systems consist of laser gyros and acceleration sensors, which calculate the position from the information at their disposal. Although these systems operate with high precision nowadays, there is always a residual error which, over time, accumulates to cause a larger positional deviation.

Military reconnaissance drones often have an all-weather, imaging radar system that is used primarily for reconnaissance. Because of the computing power now available, reduced-resolution radar images can be processed on-board drones in real time and matched against digital maps. When distinctive features such as road crossings or rivers are detected, they can be superposed against digital maps and used for the exact position of fixed points. If several of these fixed points are available, it is then possible to deduce the current position of the drone based on the known measuring geometry.



Fig. 1: MIRANDA-35 radar sensor mounted under the wing of an ultralight DELPHIN aircraft

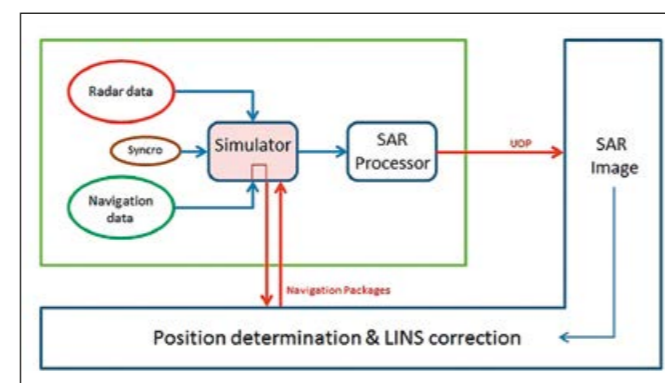


Fig. 2: Extract from the real-time radar image (Quicklook) from a measurement flight with a reduced resolution of approx. 2.7 metres

By filtering the navigation data and the information on the fixed points generated by matching radar images with the digital maps, it becomes possible to correct the drone's inertial navigation system.

Although this method cannot achieve the accuracy of GPS systems, it does provide the ability to carry out a mission with sufficient precision in areas where there is GPS signal interference. The accuracy of the navigation is dependent on the precision of the real-time radar image generation as well as on the number, position and positional accuracy of the fixed points that are found.

Used as the basis for radar-based navigation is an imaging SAR sensor with real-time evaluation. In the present case it is the MIRANDA-35 radar system of the Fraunhofer Institute for High-Frequency Physics and Radar Techniques (FHR), which operates at a centre frequency of 35 GHz and a bandwidth of up to 1500 MHz. It also has a data link to a ground station to control the radar and transmit the images from the on-line processor.

To test the method of radar image-based navigation, which is being financed by the Bundeswehr Technical Centre for Aircraft and Aeronautical Equipment (WTD 61) in Manching, suitable data was recorded over air routes of approximately 100 km, along with associated navigation raw data. Using these data records, the further processing initially took place off-line to be able to test the procedures and routines extensively and repeatably. This meant excluding the GPS signal from the navigation raw data, which is equivalent to a failure of the GPS system. Two navigation data sets were thus available for

each SAR data record, the one being the original data record and the other the modified data record without usable GPS signal.

The adjusted navigation data sets together with the radar raw data were subsequently re-fed into the SAR processor and processed. The SAR images were then transmitted to project partner Airbus Defense and Space GmbH in Manching, where matching against the digital maps and position fixes took place. The calculated position data, together with the navigation data, was transferred to a filter, which corrected the navigation data accordingly and, in turn, fed the corrections into the SAR processor.

It has been demonstrated that it is possible to support the on-board navigation system with the aid of radar images. Although the accuracy of a GPS system is not achievable, a steady drift of the position is effectively prevented. The achievable positional accuracy is more than sufficient for smooth mission accomplishment and can be guaranteed over the entire mission duration.



Fig. 3: Schematic representation of the offline data processing used

Dr. Svenja Sommer
Fraunhofer-Institut für Hochfrequenzphysik und Radartechnik FHR
Wachtberg

info@fhr.fraunhofer.de

Monitoring the re-entry of Tiangong-1 with the aid of TIRA

China's space station, Tiangong-1, re-entered the Earth's atmosphere, attracting great international attention and, ultimately, crashing. The Fraunhofer Institute for High Frequency Physics and Radar Techniques (Fraunhofer FHR) supported the German Space Situational Awareness Center (GSSAC) in Uedem and the European Space Agency (ESA) during this re-entry with up-to-date, highly precise orbital parameters and spacecraft rotation data.

Tiangong-1, China's first space station, was launched in 2011. From the spring of 2016 onward, the station was judged to be out of control and steadily lost altitude over a period of two years. Ultimately, on 2 April 2018, Tiangong-1 re-entered the Earth's atmosphere and crashed. Large parts burned up in the atmosphere, while some fragments may have survived, plunging into the Pacific Ocean.

Despite the advanced state of research today, it is still hard to forecast when and where an orbiting spacecraft will crash to earth. Low-Earth satellite orbits are subject to strongly fluctuating external influences. The Earth's atmosphere, which is still present at these altitudes, slowly decelerates orbiting space objects. The deceleration causes the orbit to degrade. Because of the denser atmosphere at lower altitudes, the decelerating force increases further so that the rate of descent is accelerated with decreasing altitude. Atmospheric drag and the atmospherically exposed cross-sectional area play an important role in this regard, along with the density of the atmosphere, which, for its part, is strongly influenced by the greatly fluctuating and difficult-to-predict solar activity.



Fig. 1: Radom of the TIRA system at Fraunhofer FHR in Wachtberg, near Bonn



Fig. 2: The 34 m antenna of the TIRA system

Towards the end of the re-entry phase, the fast-changing influences make more frequent observations necessary for reliably forecasting the time of re-entry.

A Tracking and Imaging Radar (TIRA) provides highly precise orbital data on re-entering space objects and additionally images the objects by means of the inverse synthetic aperture radar (ISAR) technique. Using this system, Fraunhofer FHR regularly supports agencies and international organisations with up-to-date information. In the case of Tiangong-1, Fraunhofer FHR worked closely together with GSSAC and ESA. It also conducted its own observations for research purposes.

The orbit parameter calculations and latest re-entry predictions for Tiangong-1 were sent within minutes to GSSAC, which incorporated the data in its own re-entry forecasts. During this campaign, Fraunhofer FHR calculated the orbital data and also regularly checked the status of Tiangong-1 with the aid of radar images. Fraunhofer FHR is currently the only one able to deliver such radar images of space objects for the public domain, with the images of Tiangong-1 published by FHR receiving worldwide acclaim.

TIRA, furthermore, was the first to systematically analyse the rotational behaviour of a space object during its (uncontrolled) re-entry. The atmospherically exposed cross-sectional area can vary with time due to possible rotation, which can affect the temporal and spatial point of re-entry. Only by means of radar imaging techniques is it possible to determine the full rotation vector, i. e. the rotation axis and rotational velocity. By iteratively matching a 3D model of the object to a series of images for each observed pass, the rotation vector can then

be estimated for each pass. Figure 3 shows a radar image with a transparent image of the 3D model superimposed. Fraunhofer FHR tracked Tiangong-1 for more than a year, during which 24 observations were performed and the rotation vectors analysed for each one.

Figure 4 shows the rotation velocity as a function of the orbital altitude. A significant increase in the rotation velocity becomes apparent with decreasing orbital altitude, especially toward the end of the re-entry phase. Figure 5 shows the orientation of the rotation axes relative to the object coordinate system. During a large part of the re-entry phase the rotation axes are perpendicular to the solar panel plane.

In future, research is to focus on the extent to which the consideration of space objects' own rotational behaviour can improve the forecasting of upcoming re-entry events.

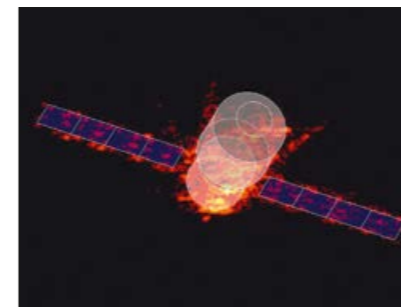


Fig. 3: An ISAR image of Tiangong-1 with 3D model superimposed

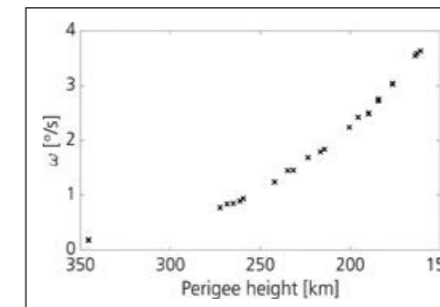


Fig. 4: Rotational velocity as a function of perigee height

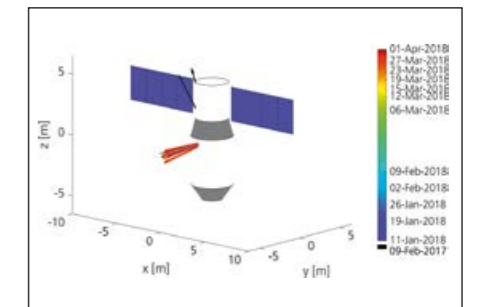


Fig. 5: 3D model with rotation axes in object coordinate system.

Marcel Baltzer
 Fraunhofer-Institut für Kommunikation,
 Informationsverarbeitung und Ergonomie FKIE
 Wachtberg

Konrad Bielecki
 Fraunhofer-Institut für Kommunikation,
 Informationsverarbeitung und Ergonomie FKIE
 Wachtberg

kontakt@fkie.fraunhofer.de

kontakt@fkie.fraunhofer.de

Cooperative automation and remote controllability of land-based weapon systems

Future weapon systems will not only have to strike a balance between protection, firepower, agility and controllability, but also take account of data links and automation. Multi-platform systems, such as the Future Combat Air System (FCAS) or Main Ground Combat System (MGCS), include manned, unmanned and optionally unmanned subsystems, with partially and highly automated components as well as closely intertwined data links. The long-term development of these systems should be discussed and communicated clearly through the use of roadmaps.

Unmanned or optionally unmanned systems, including partially and highly automated variants, are being established in every domain: in the air, on land, at sea, in space, and in cyberspace. Both lines of technology influence one another. Non-automated systems require a high data link to be available and sufficient bandwidth for reliable remote controllability. Interference with the data link (through hostile intervention, for instance) can render these systems non-functional. Partially and highly automated systems require less bandwidth, and subsequently are more resilient to interference and more effective, through skilful human-machine interaction.

Aspects such as reliability, usability and cybersecurity become increasingly important. The Fraunhofer Institute for Communication, Information Processing and Ergonomics (FKIE) has, as part of its research for the German Federal Ministry of Defence, pre-structured this complex set of circumstances in terms of cooperative guidance and control. In this article, a first overview is provided for ground-based weapon systems.

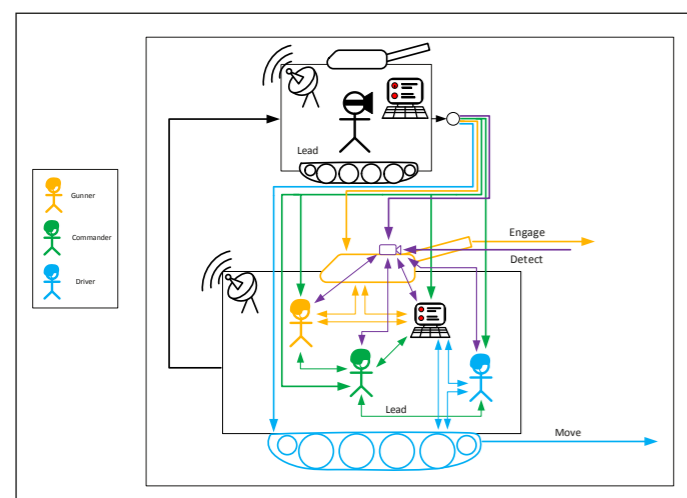


Fig. 1: Relation between automation, crew and remote operator

Prof. Dr.-Ing. Frank Flemisch
 Fraunhofer-Institut für Kommunikation,
 Informationsverarbeitung und Ergonomie FKIE
 Wachtberg

kontakt@fkie.fraunhofer.de

Dr.-Ing. Marc Adrat
 Fraunhofer-Institut für Kommunikation,
 Informationsverarbeitung und Ergonomie FKIE
 Wachtberg

kontakt@fkie.fraunhofer.de

Concepts for cooperative motion guidance and control can be realised through different subsystems, such as an on-board operator, automation, or a remote operator and be evaluated in relation to their effects on performance, safety and usability.

Apart from the different relations (see Fig. 1), it is necessary to address questions regarding a balance of skills and autonomy authority and authorisation, controllability, and responsibility.

For a multitude of reasons (technological, social, economic, and legal), presently there are few fully automated functions available but that might change dramatically in the future. A suitable roadmap for achieving higher levels of automated functionality and remote controllability (see Fig. 2) will be used to keep humans in the loop at critical junctures, applying to both mobility and intervention capabilities. The relation between automation and remote controllability at a given time on the displayed roadmap is described in a degradation and transition matrix (left).

The vertical positions pointing downward in the capabilities matrix denote variable assistance and automation functionality in combination with variable availability of a human on board. The horizontal positions pointing to the right show the possible levels of remote control. This creates numerous

possibilities whereby, with full availability and bandwidth for example, a remotely controlled system (level 3) remains reliably mobile for each level of automation. If remote controllability degrades, as indicated by the yellow arrow, while automation remains fully available (level 5), the system would still remain fully mobile.

If, however, this degradation of remote controllability occurs as indicated by the blue arrow, at a level where automation has no control (level 0), the system could quickly become immobile. An on-board service member capable of taking over partial or full guidance or control, as indicated by the black arrow, can be a significant factor for enhancing the resilience of such a system.

Such a matrix allows a risk assessment regarding which relations and links need improvement or require special attention when designing land-based weapon systems. In combination with the roadmaps, it also provides the possibility to estimate when unmanned components of new multi-platform systems such as FCAS or MGCS will not only be ready for demonstration but also be realistically mature enough for performant and usable operation in a military environment.

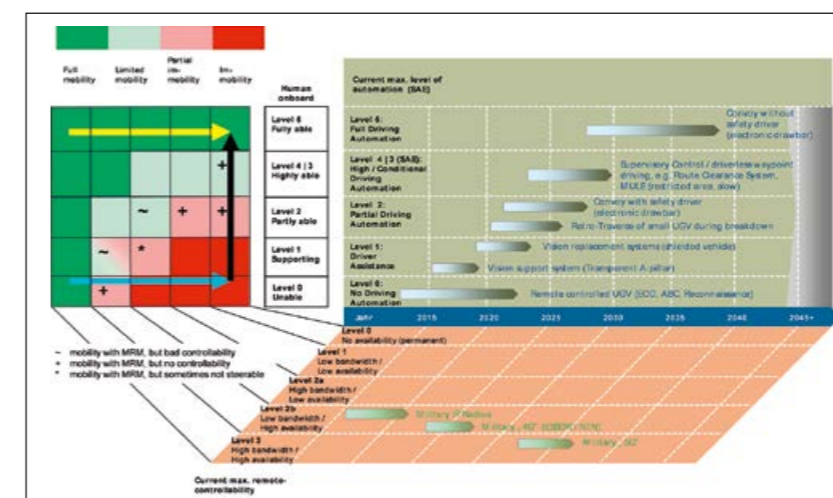


Fig. 2: Relation between automation and remote controllability for the mobility of cooperatively piloted systems (example)

Dr. Hanna Geppert
Fraunhofer-Institut für Kommunikation,
Informationsverarbeitung und Ergonomie FKIE
Wachtberg

kontakt@fkie.fraunhofer.de

LRDir Dipl.-Inform. Thomas Schulte
Zentrum für Softwarekompetenz der Bundeswehr
Euskirchen

ZSwKBw@bundeswehr.org

Project-independent integration environment

In order to avoid incompatibility issues when creating sub-components for its IT system, it is necessary for the Bundeswehr to have a high-standard integration capability available “in-house”. Through its Bundeswehr Centre for Software Expertise and a tactical-level analysis and test environment (“AuT”) as an integration system, a germ cell exists for a “Battle Lab” to pool integration and test expertise as well as project-independent material and personnel resources.

In the military domain, networked IT systems are used to support complex command and decision-making processes. These systems can seldom be procured as global solutions. Instead, subcomponents generally have to be realised and integrated individually, leading to the involvement of various major organisational elements. Often, it is not possible to adequately synchronise the timing and content for their development or for subcontractors. As there are currently no cross-project technical “quality gates” for contributions to the Bundeswehr IT system, incompatibility issues and semantic inconsistencies frequently become apparent only after the systems are in use in the field, making complicated (and expensive) workarounds necessary. By applying systematic requirements engineering and “method architecture”, it is possible to define critical boundary conditions for implementation. However, the gap between the ‘drawing board’ and reality also has to be bridged.

For integration to be successful, experts are, firstly, needed who are familiar both with the operational requirements and with the technical and organisational structures of the IT



Fig. 1: “The deep integration of all relevant systems into a powerful network is necessary so that the whole can be more than the sum of its parts.” (Source: Kdo Heer, Thesenpapier III – Rüstung digitalisierter Landstreitkräfte, 2018)

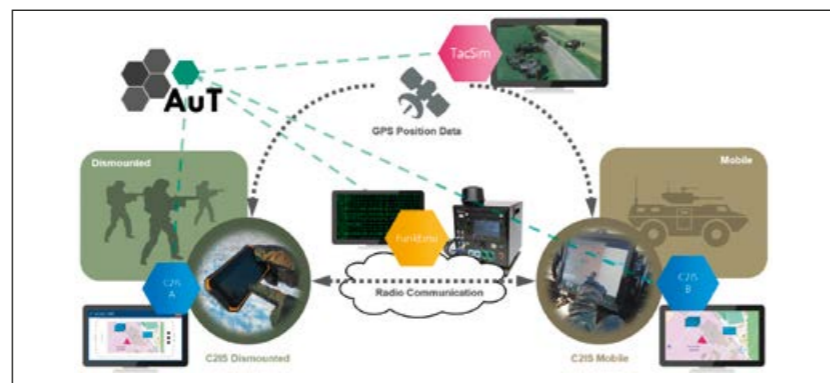


Fig. 2: AuT simulation and modular principle: Original C2IS and tactical router software is run by virtual machines. Radio communication is emulated, based on stochastic and functional modelling. The tactical environment and operational processes, e.g. GPS position data for tactical movements, are simulated in real time

systems. Where system integrators in an industrial environment are concerned, this specialist knowledge is key expertise within the manufacturing process – suppliers are conversant with the details of the individual components, while system integrators are familiar with how these fit together, and with the higher-level constraints. For this reason, the Bundeswehr must also have the latter expertise available in-house. Secondly, an integration environment is required that includes permanent project-independent personnel who pool know-how on operational, functional and non-functional requirements as well as expertise on methods and testing beyond project boundaries. The environment must encompass the entire military decision-making process chain and accompanying information and have the technical components continually at its disposal. Its personnel should not just integrate technology but also act as the organisational anchor point for Bundeswehr-internal and -external teams involved in system design, procurement and development.

One example of a technical integration system is the ‘AuT’, a tactical-level environment which attempts to combine the advantages of laboratory and field testing with one another and to achieve a compromise between cost, time and resource efficiency, on the one hand, and reality, on the other. Through the virtualisation of IT systems, emulation of communications systems, and real-time simulation of the tactical environment, it provides the ability to carry out network testing with, at present, up to 50 instances in a virtual testbed. The components to be tested are combined with one another virtually according to the modular system principle, for which various command and control information systems, tactical routers and communication emulators are available. New components

can be added quickly, as only software adaptors have to be developed for the automated system configuration, system control and data capture. The AuT is also able to integrate real components symbiotically into tests.

Effective 1 April 2019, the Bundeswehr Centre for Software Expertise (BwCSE) will form part of the Cyber and Information Domain Service (CyberInfoDS) – a major organisational element of the Bundeswehr – and be staffed with project-independent personnel. It already provides high-standard technical integration and testing expertise for Germany’s armed forces based on many years of experience. With the BwCSE serving as the organisational element and the AuT as the technical integration system, a germ cell exists for a “Battle Lab” for the pooling of expertise, responsibility and technical equipment independently of any specific project. From this, one of the first additional benefits for the armed forces as a whole can ensue, having an impact for the field units beyond the bilateral agreement existing between the defence ministry’s Directorate-General for Equipment, Information Technology and In-Service Support and the Cyber-InfoDS.

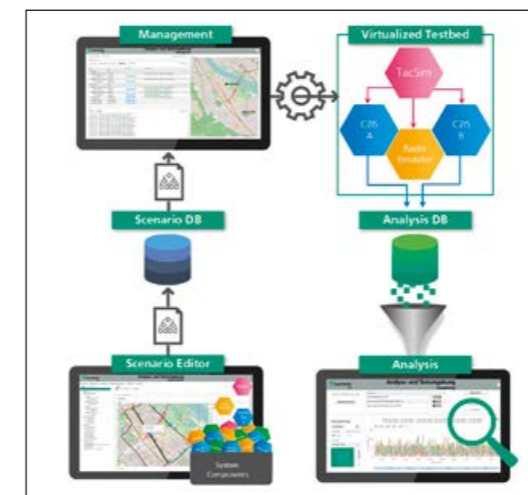


Fig. 3: AuT structure: Operational and technical scenarios can be created using the scenario editor or are loaded from the scenario database. The AuT management configures the corresponding test components in script-driven fashion and runs the operational scenario in a virtual testbed. An analysis component provides the possibility to subsequently evaluate the system behaviour

Dr. Ulrik Neupert
 Fraunhofer-Institut für Naturwissenschaftlich-Technische
 Trendanalysen INT
 Euskirchen

info@int.fraunhofer.de

Hans-Martin Pastuszka
 Fraunhofer-Institut für Naturwissenschaftlich-Technische
 Trendanalysen INT
 Euskirchen

info@int.fraunhofer.de

Technology foresight in support of long-term R&T planning

For the Federal Ministry of Defence (FMoD) and the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (FOBwEITISS), the Fraunhofer Institute for Technological Trend Analysis (Fraunhofer INT) conducts technology foresight on long-term technological developments and trends, which are identified, analysed and assessed continuously with regard to their potential future defence-technological and military relevance. Through its analyses, Fraunhofer INT contributes to the planning of long-term defence R&T.

Within Fraunhofer INT, the “Defence Technology Foresight” business unit pursues research on future technologies relevant for the Federal Ministry of Defence (FMoD) and its subordinate agencies and offices. Its central product is its “Defence Technologies Forecast” (German acronym: WTV), which, through quarterly technology and system concept analyses, supports the FMoD, its agencies and offices in their analysis and assessment of new technologies and technology-driven military capability developments.

The WTV focuses on current technology topics and visionary system concepts identified for their dynamic scientific nature, potential defence-related relevance, and/or an expressed need for acute planning action or consultation from a technological viewpoint. The topic identification process is based on a continuous technology scanning and monitoring approach established at Fraunhofer INT. This “360° technology radar” is managed by an interdisciplinary team comprising natural scientists and engineers, who observe and analyse information sources that are open to the public, such as scientific journals, defence literature, research conferences, etc.

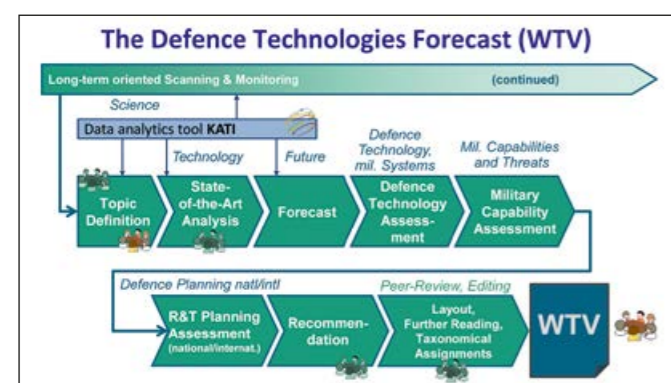


Fig. 1: WTV – multi-perspective technology foresight including INTernal (green) and contractor (coloured) workshops as well as IT support tool KATI (Source: Fraunhofer INT)



Fig. 2: Title page reflecting WTV topic 2018-1 “Architected Materials” (Source: Fraunhofer INT; cover picture adapted from COULAIS, Corentin: As the extension, so the twist. In: Science 358 (2017), No. 6366, p. 994–995)

This expert-based, qualitative approach is complemented quantitatively by state-of-the-art IT support techniques, among them the KATI (Knowledge Analytics for Technology and Innovation) tool applied by, and continually evolved at, Fraunhofer INT. From the technologies identified in this way, a list of candidate topics is drawn up for the WTV. The final selection of WTV topics to be addressed in the year thereafter is then made together with defence planning and armaments representatives, who also nominate their own topics for the process.

Technology-driven topics covering the broadest possible spectrum are analysed in the first three quarters of a year. These are evaluated for, among other things, their technological maturity and feasibility, for possible military applications and military threat potential, as well as for relevant national and international actors and programmes. Each analysis concludes with separate recommended courses of action for defence R&T planning. In the fourth quarter of a year, the analysis perspective is reversed, and long-term system concepts are examined for their potential technical feasibility in the future. This involves identifying key technological enablers critical for their conceptual realisation as well as exploring their current state of the art and their prospective level of maturity by the time realisation of the system as a whole is predicted.

Based on these individual estimates, the technical feasibility of the explored system concepts is collectively assessed and a vision for the future developed. The WTV workflow, from scanning and monitoring through to the final article, and including the various analysis perspectives, is depicted in Figure 1.

In 2018, a total of 13 individual topics from a very wide range of scientific fields was explored in the course of the WTV. This included the analysis of future technologies across the spectrum, from basic research topics, on the one hand, to applied system innovations, on the other. One example of technologies from the field of basic research was “Architected Materials”, whose realisation starts from a desired functionality and whose requisite, highly ordered complex structures are derived with the aid of elaborate numerical methods, for example to enhance the performance of passive armour materials (see title page depicted in Figure 2).

Among the range of system innovations there was, for example, the topic of multi-domain UxS, i. e. unmanned systems capable of movement in / on different media, such as water, land and air. To be counted among these is blockchain technology, which offers potential for military applications in the fields of cyber defence, communications and logistics, etc. A long-term system concept that was also addressed was the topic of high-speed vertical lift, i.e. manned vertical take-off and landing (VTOL) vehicles.

All of the WTV topics analysed in 2018 were also addressed at the “R&T Future Situation Conference 2019”, held by the FMoD, with a view to compiling a joint picture of the future situation for the Bundeswehr, as illustrated in Figure 3.

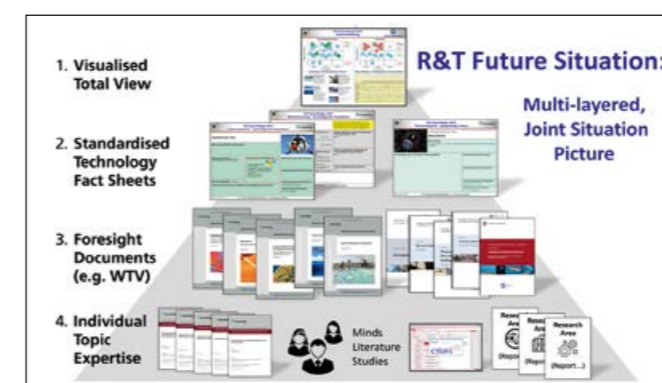


Fig. 3: WTV – a significant contribution to the FMoD’s “R&T Future Situation Conference” and to the “R&T Future Situation Picture” (Source: Fraunhofer INT)

Dr. Robert Rehm
Fraunhofer-Institut für Angewandte Festkörperphysik IAF
Freiburg

info@iaf.fraunhofer.de

Dr. Tim Stadelmann
Fraunhofer-Institut für Angewandte Festkörperphysik IAF
Freiburg

info@iaf.fraunhofer.de

Bispectral infrared detectors for situational awareness and threat warning

Colour- and spectrally resolved information, also when gathered in the infrared range, can be of crucial benefit for military core capabilities relating to reconnaissance and protection. Using antimony-based type-II superlattice technology as a basis, the Fraunhofer Institute for Applied Solid State Physics (Fraunhofer IAF) is developing high-resolution bispectral infrared detector arrays for 3-5 μm and 8-12 μm , which in some instances have already found application in defence systems.

Ultra-high performance infrared detectors are essential core components for reconnaissance and protection. Similar to colour cameras for the visible range, thermal imagers and warning sensors that capture spectral characteristics instead of monochrome information offer significant additional benefit. Fraunhofer IAF is developing such bispectral infrared detectors on the basis of antimony-based type-II superlattices. This semiconductor material comprises several hundred periodically alternating layers of InAs and GaSb, each with a thickness of only a few atomic monolayers, and uses quantum effects to achieve tailorable properties. By suitably selecting the layer thickness for the two constituents, it is possible to address both the mid- (3 – 5 μm , MWIR) and long-wavelength (8 – 12 μm , LWIR) atmospheric transmission window in the thermal infrared range.

As theoretical calculations show, type-II superlattices offer the highest performance potential of all the material systems known for these applications. In 2004, Fraunhofer IAF succeeded in demonstrating the world's first high-performance superlattice camera for the MWIR. This research work led



Fig. 1: Exterior view of a MIRAS warning sensor installed in an Airbus A400M of 62 Air Transport Wing

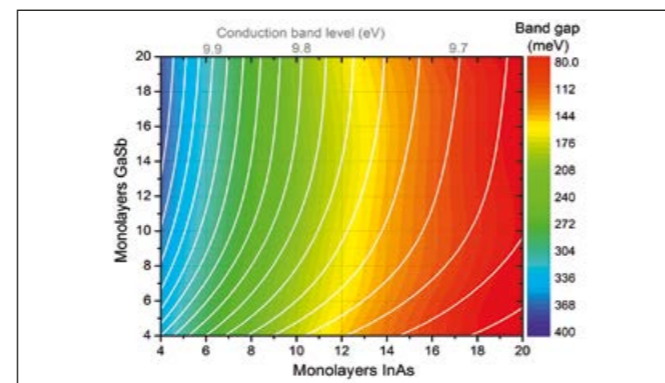


Fig. 2: Band gap and conduction band level in InAs/GaSb superlattices as calculated by the empirical four-component superlattice pseudopotential method developed for the design of heterojunctions

directly to the development of bispectral detector arrays featuring two co-located, simultaneously registered detection channels for the MWIR subranges of 3 – 4 μm and 4 – 5 μm , respectively.

Bispectral superlattice technology provides the possibility, for example, to remotely detect the antisymmetric stretching of hot CO_2 molecules with an extremely low false alarm rate, even in the presence of complex, fast-changing scenery backgrounds. Bispectral detectors are thus ideally suited for threat warning systems when used for the early detection of hot exhaust plumes of incoming guided missiles. Given the complexity of the quantum-effect based approach, however, the evolution from the first demonstration to a reproducible small-scale fabrication process with a high yield required major research and development effort. These bispectral detector arrays can meanwhile be produced with the required performance capability, with the outcome that, in cooperation with partners from the defence industry, this key technology is now in use in the MIRAS missile approach warning system of the Airbus A400M.

While conventional infrared photodiodes make use of the same band gap both in the space charge region and in the absorber (homojunction), antimony-based type-II superlattices are ideal for realising heterojunction photodiodes, with the space charge region being relocated to another part of the device that offers a higher band gap, thus reducing the dark current and detector noise by several orders of magnitude.

This leads to an electrooptical performance capability comparable to that of conventional homojunction diodes at a

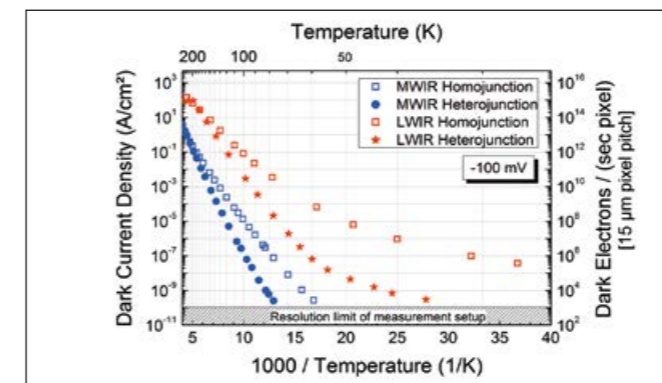


Fig. 3: Dark current density as a function of temperature for homo- and heterojunction photodiodes for MWIR and LWIR operated at a typical bias voltage of -100 mV

significantly higher operating temperature, which reduces the size, weight and power consumption of the cooled IR module, increases its life expectancy, and can significantly lower the life cycle costs. In cooperation with industrial partner AIM Infrarot-Module GmbH, high-performance LWIR superlattice cameras have been successfully demonstrated including, in detectors with heterojunctions, an imaging capability at operating temperatures up to at least 90 K. This capability is so far unique among European manufacturers.

Current work funded by the German Federal Ministry of Defence through Bundeswehr Technical Centre (WTD) 81 is focusing on developing the aforementioned approaches further towards dual-band infrared detector arrays with a high spatial resolution of 1280×720 pixels offering discrete channels for MWIR and LWIR. In degraded visual conditions such as smoke, dust and fog, search and targeting systems benefit in the LWIR from increased thermal emission as well as the improved visibility range, while the MWIR channel allows better object identification thanks to a smaller Airy disk



Fig. 4: Thermal image delivered by a 640×512 LWIR superlattice camera operated in this instance at a high temperature of 90 K. To date, the only European manufacturers in a position to demonstrate such a performance capability are cooperation partners Fraunhofer IAF and AIM Infrarot-Module GmbH

Dr. Lukas Deimling
Fraunhofer-Institut für Chemische Technologie ICT
Pfinztal

info@ict.fraunhofer.de

Gregor Billeb
Fraunhofer-Institut für Chemische Technologie ICT
Pfinztal

info@ict.fraunhofer.de

Test rig for pyrotechnical decoys

Pyrotechnical decoys afford an important contribution to protecting airborne platforms from infrared-guided missiles. Further development of such decoys is indispensable to maintain their effectiveness. Efficient development of new decoys calls for effectiveness analyses under near-real conditions. A new test rig closes this capability gap.

For the Bundeswehr Technical Centre for Protective and Special Technologies (WTD 52), the Fraunhofer Institute for Chemical Technology (Fraunhofer ICT) has designed a test rig which, based on pressurised-air components of the aerodynamic effects simulator installed there, allows stationary testing of pyrotechnical decoys under near-real conditions.

The new test rig has made it necessary to have flexible control over the air stream flowing out of the pressure tank. This has involved fitting each of the existing 37 pressure tank outlets with a fast, pneumatically operated ball valve. The required flexibility has been achieved by means of a computerised control unit that enables each of the 37 air channels to be opened and closed individually. This is essential to be able to realistically simulate the temporal flow field profiles that affect a pyrotechnical decoy when ejected from an aircraft. Air velocities of up to 300 m/s can be produced to take account of the different aircraft categories.

In order to assess the informative value of an effectiveness evaluation, it is also essential to use the original chain of decoy ignition elements. Fixing the flare body in a defined

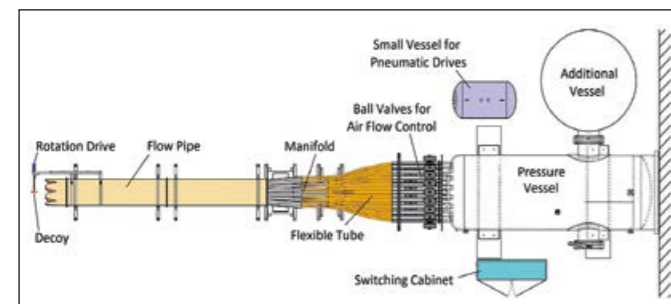


Fig. 1: Schematic set-up of the test rig



Fig. 2: Air flow pipe on the test rig (courtesy of WTD 52)

Achim Schreiber
Fraunhofer-Institut für Chemische Technologie ICT
Pfinztal

info@ict.fraunhofer.de

Jürgen Kaufmann
Wehrtechnische Dienststelle für Schutz- und Sondertechnik WTD 52
Oberjettenberg

WTD52Posteingang@bundeswehr.org

measuring position in the airstream will not enable the ejection procedure to take place in the same way as it does from an aircraft launcher. Instead, the process is inverted, with the shell being shed from the fixed flare body. To do this, the shell is provided with an axial slot, through which the mechanical fastener is attached for fixing the flare in place on the inside. Within the shell, all the ignition components of the original ignition chain remain as they are, without any modifications.

The rotation of the flare as it burns is a third important aspect in the characterisation of flare firings. It ensures homogeneous burnoff of the flare body surface and, particularly in the case of rod-shaped decoys, shows oscillations in the intensity of radiated emissions which also occur with real decoy firings.

The duration of the testing on the rig is limited in principle to 2 – 3 seconds, after which time the flare body has been consumed to the point that it breaks apart and leaves the measuring position due to the ambient flow field.

The investigations being conducted on this stationary test rig are focusing on the reliability and the temporal sequence of the ignition process, on the ignition transfer to the flare body, and on the intensity profile of the radiated emission in the relevant spectral bands (over two seconds).

Stationary firings of pyrotechnical decoys are very conducive to metrological investigations because the measuring systems can be adjusted and calibrated precisely. The defined radio-metric and atmospheric conditions facilitate the use of hyperspectral imagers, spectrometer systems and high-speed-cameras in the various spectral ranges and yield high-quality results.

The new test rig described here offers a cost-efficient method for examining novel pyrotechnical decoys for their efficacy and constitutes an important addition to already existing decoy test methods such as rocket sled trials or real flare firings from aircraft.



Fig. 3: Flare decoy ammunition on a fixed mount (courtesy of WTD 52)

Dr. Michael Holzapfel
Fraunhofer-Institut für Chemische Technologie ICT
Pfinztal

info@ict.fraunhofer.de

Dr. Michael Abert
Fraunhofer-Institut für Chemische Technologie ICT
Pfinztal

info@ict.fraunhofer.de

Safety testing of lithium-ion batteries (LIBs) for military applications

Lithium-ion batteries (LIBs) are becoming increasingly important for various applications in the Bundeswehr. They are characterised by their high energy density, yet have a certain hazard potential. Practical safety tests offer the possibility to evaluate their behaviour in the event of malfunctions as well as under live conditions and thus enable safe operation.

The Fraunhofer Institute for Chemical Technology (Fraunhofer ICT), together with Bundeswehr Technical Centre (WTD) 41, Department of Electrochemical Energy Storage (GF 230), is conducting safety assessments and tests on various types of lithium-ion cells and batteries (LIB) for military applications. LIBs have become indispensable for military use and will increasingly replace other rechargeable systems (lead-acid, Ni/Cd) in coming years. Their greatest advantage is their high energy density, which no other available battery system offers. LIBs can, however, pose a much higher risk both to people and machines.

Fraunhofer ICT has in recent years been working intensively together with WTD 41 to identify key hazards and countermeasures. In the case of LIBs, specific energy density and intrinsic safety are inversely proportional to one another. The Bundeswehr utilises only high-quality systems and, as a result, there have been no significant safety-related incidents during in-service use to date. Ballistic testing and trials involving abuse, however, have flagged up the hazard potential posed by this battery technology. In the event of a malfunction, the



Fig. 1: Cell-internal short-circuit

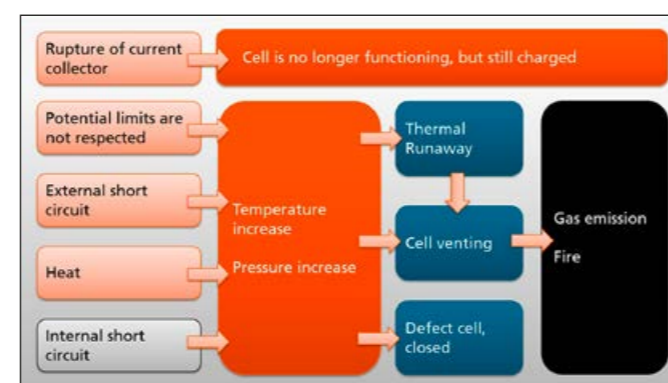


Fig. 2: Possible causes of failure of lithium ion cells

Prof. Karsten Pinkwart
Fraunhofer-Institut für Chemische Technologie ICT
Pfinztal

info@ict.fraunhofer.de

Dipl.-Ing (FH) Klaus Schmitt
Wehrtechnische Dienststelle für landgebundene Fahrzeugsysteme,
Pionier- und Truppentechnik WTD 41
Trier

WTD41posteingang@bundeswehr.org

energy stored in the cell may be released abruptly, causing a fire (thermal runaway, or 'TR'), which under certain circumstances can spread rapidly in a chain reaction (propagation) from one cell to all the cells of a battery.

The Institute is carrying out practice-relevant safety testing on all LIBs currently in use and, also, on those possibly to be used in future in the Bundeswehr. This includes, in particular, phenomena such as thermal ramps, overloading, overdischarge, external short-circuits, external mechanical influences, and much more, so as to also simulate the special live scenarios in military applications. It has been found that LIBs based on NCA (Ni-Co-Al oxide) and NMC (Ni-Mn-Co oxide) cathode materials are to be rated as the most critical in this regard. In the event of a malfunction, a TR soon comes about and propagation occurs. Cells with LiFePO₄ as cathode material (LFP) display significantly higher intrinsic safety. A TR can also happen with this type, but propagation is much less likely.

In the case of underwater applications, for example, this is of the utmost importance, as no escape is possible in the event of a malfunction. Yet also where land-based applications are concerned, caution must be exercised, as a shell splinter, for instance, can put an entire weapon system out of action, or even destroy it.

It is additionally important to examine the composition of possibly released substances, as toxic, corrosive and flammable components such as CO, HF, H₂ and hydrocarbons may also be present. Such findings are particularly important for applications involving limited installation space.

Production-related faults, or faults in electronic circuits, cannot be completely excluded, either, for which reason Fraunhofer ICT is also exploring design measures to largely mitigate the effects of a TR and prevent propagation. These include, among others:

- the development of so-called "intrinsically safe" cells which, by elaborate means, prevent a possible TR inside the cell,
- possibilities of isolating individual cells,
- use of heat-absorbing materials,
- measures for controlled dissipation of the reaction heat in the event of a TR.

A solution involving an intrinsically safe LIB would, especially, offer the advantage of not needing complex measures to ensure the safety of a battery module. Such technology is still in its infancy, but is being closely monitored and evaluated by the Institute.



Fig. 3: Electrolyte release and fire during thermal abuse testing of a lithium ion cell



Fig. 4: Propagation test by means of overcharging, involving two charged LFP cells. Left: before the test, right: after the test. The passive cell failed to catch fire itself during the thermal runaway of the neighbouring overcharged cell

Dr. Michael Arens
Fraunhofer-Institut für Optronik, Systemtechnik
und Bildauswertung IOSB
Ettlingen

info@iosb.fraunhofer.de

Peter Solbrig
Fraunhofer-Institut für Optronik, Systemtechnik
und Bildauswertung IOSB
Karlsruhe

info@iosb.fraunhofer.de

Joint Virtual Picture

On the way to “Army 4.0”, digitalisation will be key to achieving enhanced capabilities. The Fraunhofer Institute of Optronics, System Technologies and Image Exploitation (Fraunhofer IOSB) is helping to realise a digitised sensor-to-shooter cycle by developing a system for automatic target handoff. Based on the working principle of creating a common virtual view of an area of operation, its functional capability goes far beyond this, offering a “Joint Virtual Picture”.

The German Army, in its “Plan Heer” (Army Plan) strategy document, has committed itself to digitalisation and outlined in three position papers under what requirements “Army 4.0” will be expected to robustly operate: dispersed deployment of numerically inferior forces in volatile and complex environments posing multi-dimensional threats. These challenges are to be countered with, among other things, the capability for precise, scalable effects and operations conducted according to the combat-centric principle

To help realise these capabilities, Fraunhofer IOSB has developed a “Joint Virtual Picture” (JVP) technology demonstrator and its functional core, the “Target Handoff System” (THS[®]). The Institute’s self-defined goal has been to find a way of maximising precision and speed in the sensor-to-shooter cycle in a way which minimises soldiers’ cognitive workload, relies as little as possible on communication channels that are prone to jamming and limited in number, and makes best possible use of locally available imaging sensors and computing power. The basic function in THS[®] is the automatic, image processing-based, real-time registration of sensor images using a common

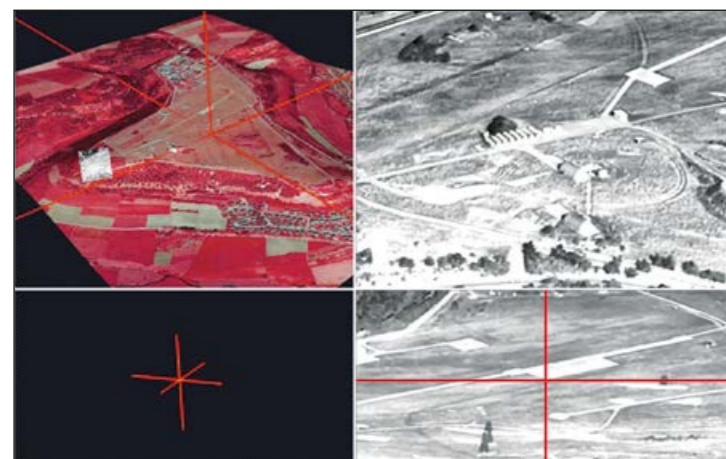


Fig. 1: THS used for highly precise target coordinate acquisition with airborne reconnaissance assets



Fig. 2: Experimental THS set-up for demonstrating target handoff between ground-based and airborne reconnaissance assets

reference model and, thus, immediate and lasting assignment of a unique space-time stamp for every observation made with the aid of a sensor system. A spin-off effect of this working principle is the capability to determine the position and orientation of a sensor completely without the aid of a GPS.

Together with partners from the defence industry, it has been possible to demonstrate the potential for precise reconnaissance and targeting. Target coordinate precision has been shown to be improved, taking the example of air reconnaissance assets of the German Army. It has equally been possible to demonstrate instant and highly precise target handoff between several ground-based and / or low-flying airborne sensors. And, last but not least, the developed methods can also be employed in connection with missile scenarios.

On a further level of abstraction, a benefit that goes far beyond those already mentioned becomes clearly manifest. Integrated into all elements of combined arms operations, such constant, spatially and temporally referenced information management will pave the way toward a role-oriented, real-time situation picture and thus to conducting operations according to the principle of “What one sees, all will know”. THS[®] creates a common virtual situational picture and becomes a JVP[®].

Where individual platforms are concerned, neither their own positions nor, therefore, obstructions (or movement) limit such a joint field of view. This offers the opportunity not only to have a needs-based, configurable overall situation picture available for forces and formations, but also to realise a formalised visual language which brings information superiority to bear through communication in real time.

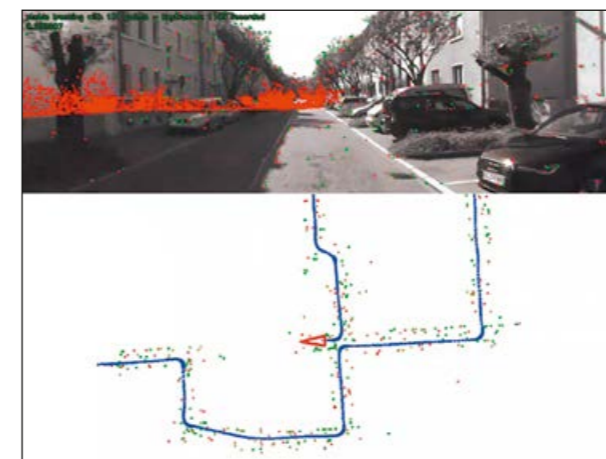


Fig. 3: THS permits image-based position estimation and navigation without recourse to GPS

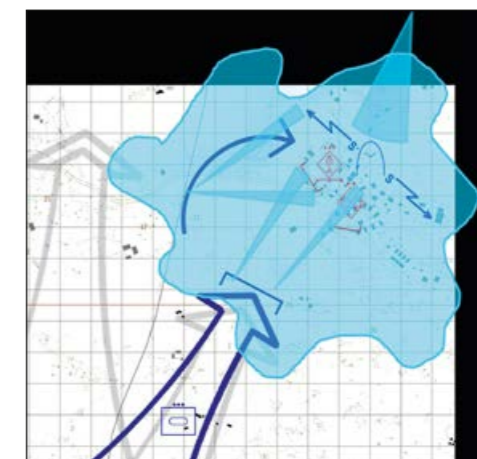


Fig. 4: THS leads to a Joint Virtual Picture: What one sees, all will know

Dipl.-Inform. Jutta Hild
Fraunhofer-Institut für Optronik, Systemtechnik
und Bildauswertung IOSB
Karlsruhe

info@iosb.fraunhofer.de

Dr. rer. nat. Wolfgang Krüger
Fraunhofer-Institut für Optronik, Systemtechnik
und Bildauswertung IOSB
Karlsruhe

info@iosb.fraunhofer.de

Improving human performance in video analysis through gaze interaction and automated algorithms

Video image exploitation and analysis is an essential capability for modern reconnaissance and surveillance systems. Gaze interaction allows optimised integration of automated algorithms for motion detection, object tracking and change detection into the interactive exploitation workflow. Results from user studies substantiate significantly improved performance and reduced workload.

Military imagery reconnaissance and surveillance is based on flying and ground-based platforms such as LUNA (“Luftgestützte Unbemannte Nahaufklärungs-Ausstattung”, or airborne unmanned short-range reconnaissance system), Heron, Tornado, or Fennek, which are equipped with optronic sensors. Various sensor types deliver imagery from regions of interest, from which mission-relevant information then has to be extracted. The progress made in the development of optronic sensors has meant that not only single images but, increasingly, full motion video data requiring live video stream analysis are available.

Video analysis demands continuously high concentration from human image and video interpreters and generates a much greater workload compared with single image analysis. There are advanced video exploitation systems available, one example being the ABUL (“Automatisierte Bildauswertung für Unbemannte Luftfahrzeuge”, or automated imagery exploitation for unmanned aerial vehicles) system developed by the Fraunhofer Institute of Optronics, System Technologies and Image Exploitation (Fraunhofer IOSB), which support the



Fig. 1: ABUL video exploitation system in the LUNA UAS ground control station, on the dual monitor to the left



Fig. 2: LUNA video frame with overlay highlighting the automatically detected moving objects



Fig. 3: LUNA video frame with visualisation of the automated object tracking process: box (magenta) around the tracked object, and image area analysed by the tracking technique (transparent cyan)

Dipl.-Math. Günter Saur
Fraunhofer-Institut für Optronik, Systemtechnik
und Bildauswertung IOSB
Karlsruhe

info@iosb.fraunhofer.de

analyst or sensor operator with specific functions for image optimisation, image stabilisation, and other automatic algorithms such as motion detection, object tracking or change detection. Motion detection highlights moving objects such as vehicles and persons through an overlay in the video stream. Object tracking makes it possible to track objects in a video stream continuously and automatically. Change detection highlights changes in image pairs taken from the same scene at different points in time.

The goal of the research work has been to optimise interaction with video exploitation algorithms so as to reduce the workload and increase the performance of human operators. It has been explored whether this is achievable by carrying out selection operations with gaze interaction instead of traditional mouse input. Gaze interaction is based on an eye-tracking device, which, through video sensors, identifies the area on the monitor screen that the user is looking at.

The gaze-based interaction technique developed at the Institute exploits the fact that the user visually fixates a target object or target area before selecting. Searching for and manually moving the mouse cursor are rendered unnecessary in this interaction, thus massively reducing the amount of manual intervention and significantly lowering the perceptive, cogni-

tive and manual workload. Prototype systems have been created for the research and implemented in user studies involving human operators to measure performance for the following tasks: marking of target objects, change detection, and interaction with a single-object tracker (initialisation, re-initialisation, visual feedback on tracking state).

The research findings have revealed substantial performance improvements as well as a workload reduction for all tasks when the user interface featured a combination of gaze interaction and automatic algorithms. Gaze interaction shows itself to be a measurably more effective and faster interaction technique than mouse input. When marking / selecting moving target objects (vehicles and persons), the test persons achieved up to 62 % more correct selections if the automated motion detection technique was available, and up to 37 % more when it came to the marking of changes. Object tracking was successfully initialised up to 15 % faster compared with mouse input.

Future work will address the challenges that emerge for systems such as the LUNA-NG, for example as a result of higher sensor resolution, parallel video streams or different spectral bands.

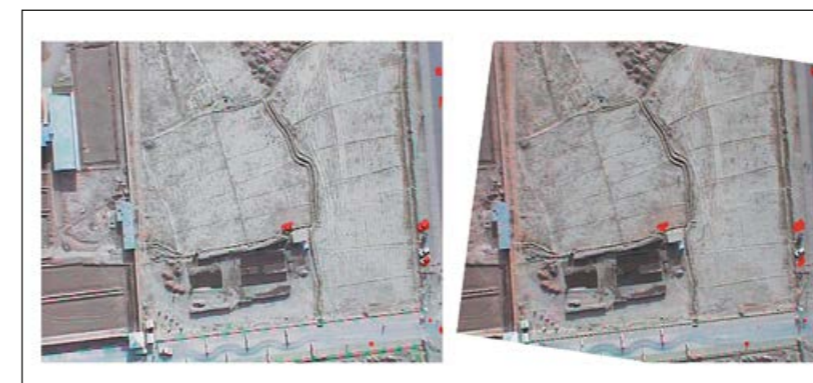


Fig. 4: Aligned pair of LUNA video frames highlighting the automatically detected changes. The experimental system presents the frames side by side, with the right-hand frame cropped to the scene area captured by both frames

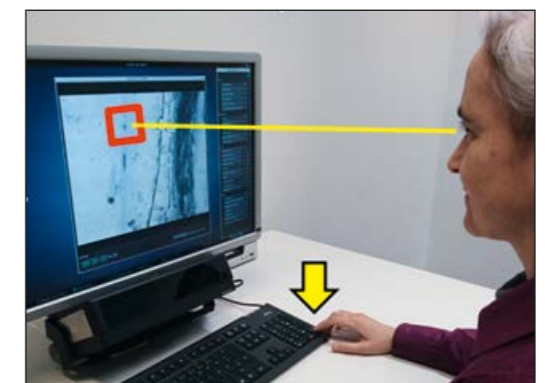


Fig. 5: Target object marking/selection in a LUNA video by means of gaze + key press interaction: the gaze position determines the selection position; the key press actuates the selection in the video

Johannes Wartmann
Deutsches Zentrum für Luft- und Raumfahrt,
Institut für Flugsystemtechnik
Braunschweig
info-pks@dlr.de

Martin Gestwa
Deutsches Zentrum für Luft- und Raumfahrt,
Einrichtung Flugexperimente
Braunschweig
info-pks@dlr.de

Avoiding obstacles during helicopter landing approaches: DVE mitigation flight trials

Helicopter operations in degraded visual environments (DVE) can offer a major tactical advantage, but require novel pilot assistance systems to ensure adequate visibility and situational awareness. The Institute of Flight Systems of the German Aerospace Center (DLR), together with HENSOLDT, have developed and tested such a system during NATO flight tests involving German, American and Swiss helicopter test pilots.

The approach-to-landing and hover phase of helicopters in unprepared and unknown terrain poses high operational risks. When visibility additionally deteriorates, it is referred to as a Degraded Visual Environment (DVE), with the pilot's workload and the probability of losing situational awareness both increasing significantly. The U.S. Army Research, Development and Engineering Command has initiated a DVE mitigation (DVE-M) programme with the aim of improving operational capabilities and survivability in DVE scenarios, which has led to technical information being shared with other NATO countries within NATO Industrial Advisory Group 193.

This has prompted the German Aerospace Center (DLR) and HENSOLDT Sensors GmbH to develop a novel pilot assistance system within the "Transition from forward flight to hover" (T2H) project funded by the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw). The T2H system comprises the HENSOLDT SferiSense 300 (HELLAS-W) LiDAR (Light Detection and Ranging)-based sensor suite for obstacle detection, an Elbit JedEye helmet-mounted display for 3D-conformal tunnel-in-the-sky



Fig. 1: DLR's ACT/FHS research helicopter approaching an obstructed landing site in Manching, Germany

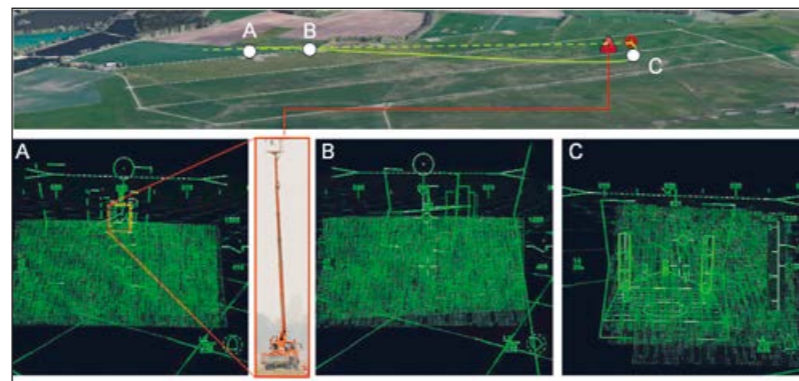


Fig. 2: Flight path planning and HMD visualisation of a helicopter final approach to an obstructed landing site (A: detection of hydraulic lift as an obstacle; B: re-planning of the flight path; C: symbology at hover point)

Michael Zimmermann
Deutsches Zentrum für Luft- und Raumfahrt,
Institut für Flugsystemtechnik
Braunschweig
info-pks@dlr.de

Stephanus Klasen
HENSOLDT Sensors GmbH
Immenstaad
hensoldt@hensoldt.net

Andreas Lederle
HENSOLDT Sensors GmbH
Immenstaad
hensoldt@hensoldt.net

visualisation, as well as path planning with monitoring and re-planning capability. The dynamic re-planning of flight paths is controlled by a monitoring module capable of detecting obstacles around a planned path. DLR developed the path planning and re-planning modules and provided the JedEye helmet as well as the EC135 ACT/FHS (Active Control Technology / Flying Helicopter Simulator) research helicopter with integrated SferiSense 300. HENSOLDT contributed the software for the sensor suite, the path monitoring module, and the symbology for the helmet-mounted display.

The T2H system was evaluated in flight in early 2017 using DLR's ACT/FHS research rotorcraft. There was also participation in NATO flight tests within the scope of the DVE-M programme together with the U.S. Army and Swiss Army. The flight tests were hosted by the Bundeswehr Technical Centre for Aircraft and Aeronautical Equipment (WTD 61) in Manching, Germany. Four trained test pilots took part in the evaluation flights involving the ACT/FHS; all of them had flown in the previous flight tests of the DVE-M programme and had flight experience with modern glass cockpits and helmet-mounted systems. They had accumulated between 1400 and 4400 flying hours on CH-47, AH 64, UH-72A and UH-60 as well as AS332/532 and EC635 helicopter models. Roughly one flying hour was allotted for each flight, which included two test scenarios. As most of the test pilots had

no flight experience with the ACT/FHS, obstacle-free approaches were made to start with, for the purposes of system familiarisation. Approaches to a landing site obstructed by a 20 m high hydraulic lift positioned in the approach path were then scheduled. A total of nine obstacle-free and 24 obstructed approaches were flown during the DVE-M flight tests.

DLR and HENSOLDT demonstrated deterministic avoidance and visualisation of unmapped obstacles in a challenging helicopter final approach scenario. The flight tests yielded valuable insights. For example, the obstacle was already detected at a distance of 950 m in the majority of approach flights, leaving enough time for path re-planning and pilot reaction. The obstacle was typically passed at a distance of more than 50 m, which the crews rated as "comfortable".

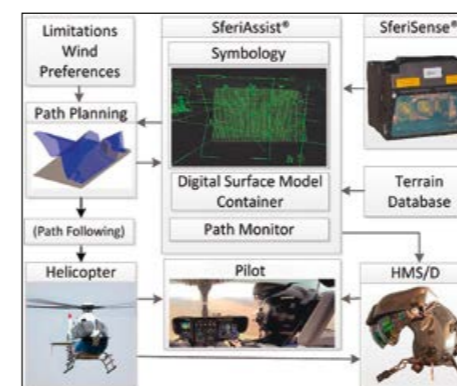


Fig. 3: General block diagram of the flight-tested pilot assistance system developed in the T2H project



Fig. 4: Flight test crew and DLR's ACT/FHS research helicopter

Dr.-Ing. Harald Anglberger
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Hochfrequenztechnik und Radarsysteme
Oberpfaffenhofen

PKS-WTF@dlr.de

Ralf Berger
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Optische Sensorsysteme
Berlin

PKS-WTF@dlr.de

Image fusion of radar and optical remote sensing data

Future satellite missions featuring optical or radar sensor payloads are set to take national capabilities in remote sensing – for example, for earth observation – to a higher level. Regardless of the applications for reconnaissance, combined processing of the data can significantly improve overall system performance capability. The Institute for Optical Sensor Systems and the Microwaves and Radar Institute of the German Aerospace Center (DLR) are exploring techniques for sensor fusion.

Remote sensing by means of space- or airborne platforms has become indispensable for situational awareness in crisis areas. The most familiar type in use is the optical sensor, of which a variety of systems are already operating in space orbit. Modern optical sensor systems offer high spatial resolution as well as very good analysability of the image data. However, being passive imaging systems that are strongly influenced by sunshine and cloud cover, striking gaps in the flow of information can come about. These gaps can be closed through the use of an active radar sensor that offers 24-hour availability and extensive capabilities, regardless of the weather conditions. Imaging synthetic aperture radar (SAR) systems, in particular, deliver high spatial resolution irrespective of target distance and, also, extensive spatial coverage. Together with the capability for robust change detection through time series exploitation, space-borne SAR is more than an ideal addition to the field of remote sensing.

Visual and automatic image analysis presents a challenge, however, as radar-specific imaging characteristics (such as noise or projection effects) make this more difficult.



Fig. 1: Optical MACS dataset of the Island of Heligoland with a ground/spatial resolution of 5 cm, transformed to the radar image plane. The optical slanted view was calculated using the radar's imaging geometry as well as elevation data derived from the optical stereo dataset itself



Fig. 2: Airborne F-SAR dataset for the Island of Heligoland with a ground/spatial resolution of 25 cm acquired in the X-band. The distinctive antenna mast at the image centre is absent in Fig. 1 because the wiry lattice structure of the mast did not lend itself to precise photogrammetric evaluation and induced an error in the elevation model

A combined image processing approach would therefore be useful as a means of bringing together the various advantages. But such data integration requires highly specialised methods that make optimum use of multi-sensor constellations. The DLR's Microwaves and Radar Institute, together with its sister Institute of Optical Sensor Systems, is addressing these challenges. As a demonstration of such image-based fusion, datasets relating to the Island of Heligoland have been acquired and processed with the aid of airborne experimental systems. The Modular Aerial Camera System MACS as an optical sensor mounted on a powered glider has acquired data with a ground resolution of 5 cm, which has been additionally used to generate a detailed digital surface model of the island. This elevation model offers the basis for highly accurate image registration with the radar image dataset previously acquired by the F-SAR system, mounted on a Do 228-212, with a ground resolution of 25 cm. This specific radar sensor is attractive because of its versatility, allowing fully polarimetric measurements in five frequency bands.

To be able to retrieve information from the respective datasets, it is necessary to align their respective image coordinate systems. This is no trivial task because the imaging principles differ entirely. An optical imager operates according to the principle of perspective projection, where the image plane is perpendicular to the line of sight of the sensor. A radar system, in contrast, measures primarily distances obliquely, thus defining an image plane that runs along the sensor's line of sight. For that reason, the conventional approach of ortho-rectification is disqualified, as this would cause strong local distortions in the radar image. Where data fusion is concerned, it is preferable to stay in the radar's range-based coordinate system and

transform the optical data instead. This is achievable with the aid of the 3D elevation data, making a special slanted (optical) view of the scene possible where the respective image planes will be congruent. This produces not only an accurate alignment for topographic formations (see Figs. 1 and 2) but also a pixel-exact alignment for detailed structures such as buildings, (see Fig. 3).

This type of processing is very helpful primarily for the visual analysis of radar data, with a view to a better understanding, interpretation and classification of signatures. Such preliminary processing could be used in future for a multitude of downstream processes, such as the combined automated identification of signatures.



Fig. 3: Details in the central urban region of the island. The pixel-exact alignment of the respective datasets is clearly visible both for topographic features such as the rock cliffs and for urban structures like the church, village buildings and large lattice mast

Dr.-Ing. Markus Peichl
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Hochfrequenztechnik und Radarsysteme
Oberpfaffenhofen

PKS-WTF@dlr.de

Simon Anger
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Hochfrequenztechnik und Radarsysteme
Oberpfaffenhofen

PKS-WTF@dlr.de

Advanced space situational awareness through modern radar imaging

The rapid increase in space objects calls for in-house as well as independent measurement capabilities to ensure up-to-date, reliable and comprehensive space situational awareness. This will essentially require trendsetting radar techniques that, in particular, are scalable and also adjustable to future requirements.

Near-Earth space is nowadays an indispensable economic area. Within it, besides space debris, there are currently almost 5000 larger space objects, mostly in the form of orbiting satellites, some 2000 of which are still active, and around 3000 are no longer in use but nevertheless still present. The number of satellite launches has increased considerably over the last decade, reaching more than 400 per year in 2017, with the basic tendency being clearly upward (Fig. 1). The NewSpace initiative of the past few years has established a trend that, for many applications, envisages the use of an enormous number of so-called micro- or nanosatellites a few cubic decimetres in size, instead of large conventional satellites measuring several cubic metres.

This development, as well as the further growth in new fields of application, is being fueled by the increasing parallel emergence of private enterprises pursuing the goal of offering lower-cost launcher systems (e.g. SpaceX). Also, the large majority of nations nowadays already have, at the very least, access to space technology of their own.

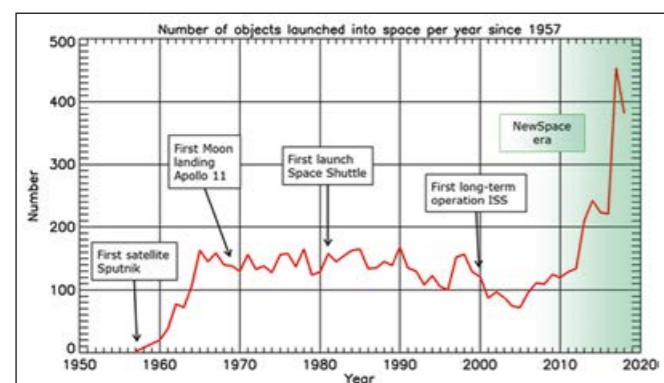


Fig. 1: Number of objects delivered into space each year since the start of unmanned spaceflight in 1957

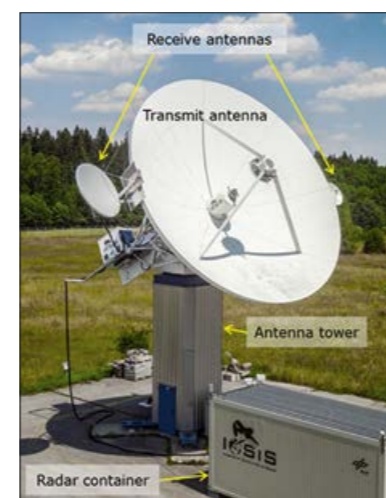


Fig. 2: IoSiS experimental radar system – transmit and receive antennas are intentionally mounted separately to facilitate research on new antenna concepts

Dr.-Ing. Matthias Jirousek
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Hochfrequenztechnik und Radarsysteme
Oberpfaffenhofen

PKS-WTF@dlr.de

Stephan Dill
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Hochfrequenztechnik und Radarsysteme
Oberpfaffenhofen

PKS-WTF@dlr.de

The dramatic growth in the utilisation of space is making constant observation and assessment of the situation in space indispensable. In Germany, this is the responsibility of the Centre for Space Situational Awareness (“Weltraumlagezentrum”), established in 2009. Reliable fulfillment of this challenging task means it is essential to have organic technological capabilities available. At the present time, where radar is concerned, Germany has only the TIRA (Tracking and Imaging Radar) system from the Fraunhofer Institute for High Frequency Physics and Radar Techniques (Fraunhofer FHR) available, which, based on large-dish antenna technology, is able to detect and also image objects. In 2019, the GESTRA (German Experimental Space Surveillance and Tracking Radar) system based on phased-array technology is to go into service exclusively to detect and track space objects for the Centre for Space Situational Awareness.

Given the previously described perspective on the evolution of space infrastructure, it quickly becomes evident that the future challenges in terms of reliable and independent assessment of the situation in space will require additional and, in particular, technologically forward-looking radar approaches.

The German Aerospace Center (DLR) has, for several years, been conducting research into novel concepts for high-precision and fine-detailed imaging of space objects and, accordingly, has

developed and set up IoSiS (Imaging of Satellites in Space), a radar system that will serve as a basic experimental platform (Fig. 2). Besides extensive theoretical analysis, IoSiS will especially provide the capability for measurement-based verification and validation of new concepts.

IoSiS has been constructed on the basis of DLR technology partly available in the X band and, by using the technique of inverse synthetic aperture radar, allows the possibility to generate two-dimensional images of the radar cross-section distribution of objects with a theoretical spatial resolution of up to 3.5 cm. In case of unknown objects, images of such quality or with an even higher spatial resolution would, for example, allow not only functional interpretation but also detection of the tiniest differences by time series analysis, with a view to being able to identify intended or also undesirable changes (Figs. 3 and 4).

In a study, DLR has explored concepts that envisage the use of very many small antennas in the millimetre-wave domain instead of large dish antennas. This would, feasibly, yield many benefits such as short measurement times for the synthetic aperture, multi-static observation, as well as truly three-dimensional imaging with the highest spatial resolution.

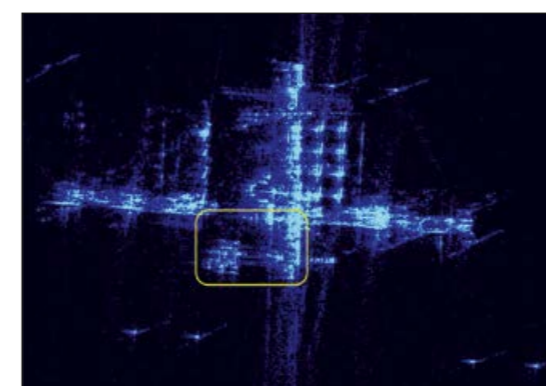


Fig. 3: IoSiS radar image of the International Space Station (ISS). The spatial resolution is 6 cm horizontally and 4 cm vertically. The horizontal length of the ISS is almost 110 m. The yellow-framed area is enhanced in Fig. 4

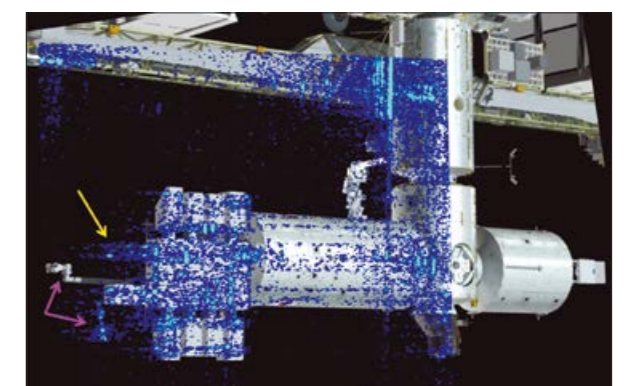


Fig. 4: Superposition of the radar signature of the yellow-framed area from Fig. 3 over a roughly congruent optical illustration of the ISS. The yellow arrow indicates an attached canister visible in the radar image but not present in the optical illustration. The violet arrows indicate a construction grapple, which has a different position in either image.

Dr. Ute Bierbrauer
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Technische Physik
Lampoldshausen

PKS-WTF@dlr.de

Dr. Christian Vorholt
Deutsches Zentrum für Luft- und Raumfahrt,
Institut für Technische Physik
Stuttgart

PKS-WTF@dlr.de

Modelling as a tool for assessing the scatter of high-energy laser radiation at the target

When utilising laser weapon systems, a part of the high-energy laser beam is scattered at the target. In order to assess the associated risks, the Institute of Technical Physics of the DLR is developing scatter models for the surfaces of typical target materials. These scatter models will afford an important contribution in future risk analyses for the use of laser weapon systems.

Risk analysis and assessment are essential for the use of laser weapon systems. One particular challenge is indirect exposure, in other words the effect of laser radiation scattered into the atmosphere or at the target. The first models suitable for calculating scatter in the atmosphere already exist, while a more in-depth means of assessing scatter at the target is yet to be found. For this reason, the Institute of Technical Physics of the German Aerospace Center (DLR) is developing models for assessing laser radiation scattered at the target with which it would be possible, in a first, simplified approach in future, to calculate the necessary safety distance to targets, for example.

The scattered light distribution needs to be known both for simple approaches and for complex models. It is essentially determined by the surface condition – in particular the roughness – of the target material. Theoretical scatter models exist for surfaces with a very low roughness. But in practice it has been found that empirical scatter models obtained by adjustments to experimental data generally deliver more useful results. The reason for this is that the surface of typical target materials often exhibits a higher roughness and complex

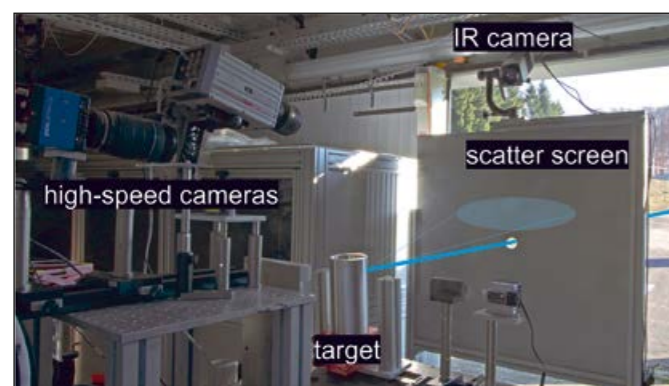


Fig. 1: Experimental set-up for measuring scattered light distribution on the laser test range

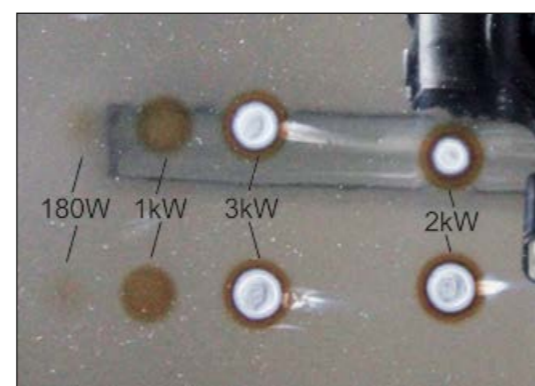


Fig. 2: Surface of a steel plate after irradiation with laser output power levels ranging from 180 W to 3 kW

Dipl.-Phys. Jochen Speiser
Deutsches Zentrum für Luft- und Raumfahrt,
Institut für Technische Physik
Stuttgart

PKS-WTF@dlr.de

structure which theoretical models fail to take sufficiently into account. Furthermore, the interaction with the laser beam leads to a change in the surface properties.

The scattered light distributions of typical materials have been measured so as to gain experimental data for empirical scatter models. These experiments were conducted both in a controlled environment in a laser processing chamber and under typical atmospheric conditions on the optical test range of the Institute of Technical Physics at the DLR site in Lampoldshausen.

On the optical test range, the laser beam scatter experiments involved plates and pipes made of steel and aluminium with diverse surface structures (different roughnesses, and also surface treatments such as powder coating or anodising), as well as generic mortar shells. In the laser processing chamber, aluminium and special steel plates were irradiated with intense laser beams. In all experiments, laser output powers of up to 5 kW were used, the typical spot sizes being about 20 mm.

The scattered light distribution measurements obtained from the irradiation tests are being input into scatter models, the objective being to represent the scattered light distribution through a small number of parameters. The development of

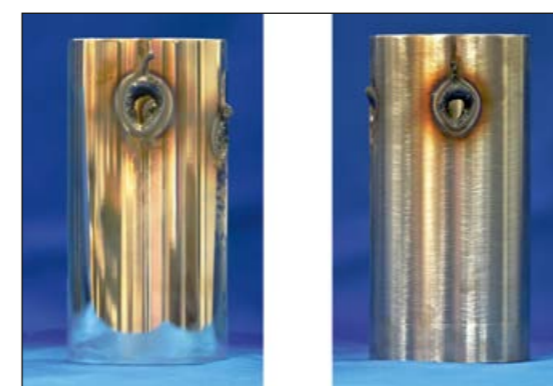


Fig. 3: Steel pipes with a low surface roughness (left) and high surface roughness (right) after 5 kW irradiation.

the models is a challenge, as the surface of the intensely irradiated target material alters very quickly. This change in the surface leads to the scattered light distribution typically being dependent on the irradiation duration and the laser beam intensity, which needs to be included in the models.

The models developed by the Institute of Technical Physics for assessing target-related scatter could become components in a future, more comprehensive model for analysing risks associated with the use of laser weapon systems. These scatter models, underpinned by the experimental research, will afford an important contribution to the safe utilisation of such weapon systems.

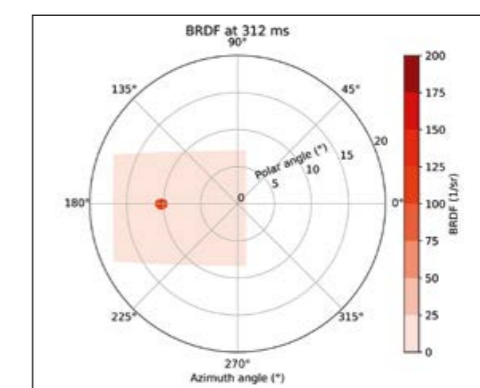


Fig. 4: Measured spatial distribution of laser radiation scattered on a polished aluminium plate

Dr.-Ing. Andreas Schütte
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Aerodynamik und Strömungstechnik
Braunschweig

PKS-WTF@dlr.de

Carsten Liersch
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Aerodynamik und Strömungstechnik
Braunschweig

PKS-WTF@dlr.de

Overall design of agile and low-signature military aircraft in the Mephisto project of DLR

The overall design approach in Mephisto, a DLR-internal research project, has been extended to include agile, low-signature military aircraft. The design and planning of highly swept flying wing configurations encompass an innovative control and structural concept as well as a highly integrated propulsion system, realised by using validated computational methods of various fidelity levels from previous military projects.

Next-generation military combat aircraft will likely no longer consist solely of piloted units. It is expected there will also be semi-autonomous, unmanned and, some cases, highly agile UAVs integrated into a so called FCAS (Future Combat Air System). Besides the challenges associated with unmanned systems in regard to autonomous and unmanned flight in combination with other, manned systems in controlled air space, the development of the platform itself presents very great challenges where a number of aeronautical disciplines are concerned. Unmanned aircraft offer far-reaching opportunities for system integration, which can be conducive regarding the requirement for a low radar, infrared and acoustics signature. On the other hand, the desired combination of low signature and high agility mostly leads to a platform with a high leading edge sweep angle dominated at medium to high angles of attack by a vortical flow topology. Managing such complex and non-linear vortical flow aerodynamics poses a major challenge for the aircraft's control system.

Within the scope of military defence projects, the German Aerospace Center (DLR) is seeking to contribute to the design,

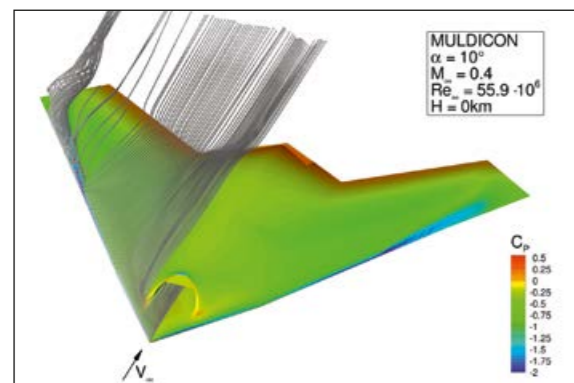


Fig. 1: MULDISON design with highly integrated engine intake, showing surface pressure distribution and flow field streamlines

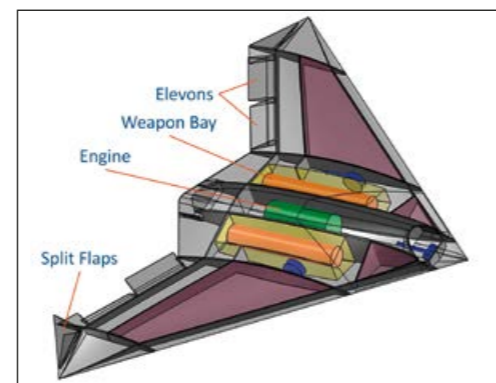


Fig. 2: Sketch of the overall MULDISON design, showing basic structural layout and systems

Dr.-Ing. Markus Rütten
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Aerodynamik und Strömungstechnik
Göttingen

PKS-WTF@dlr.de

analysis and assessment of highly agile UAVs. In its Mephisto project, one focus has been on developing a design environment which covers a multitude of disciplines. In addition to aerodynamic design, these include structural layout, structural dynamic behaviour, mission-specific engine layout, flight mechanics assessment, control system development, and assessment of radar, infrared and acoustics signature.

The design and performance assessment capability for an agile, low-signature flying wing military aircraft configuration has been successfully demonstrated in DLR's Mephisto project by means of MULDISON (Multi-Disciplinary Configuration), a flying wing UAV demonstrator, which has shown that a required military mission can be flown with the aid of the designed control concept, and that the basic propulsion concept, consisting of highly integrated inlet, engine and nozzle, largely fulfills the specified requirements.

Particularly the aerodynamic wing design and the development of a control concept without a vertical stabiliser have presented sizeable challenges. It has been shown that yaw control/stability can be achieved by means of wing tip spoilers within an adequate angle-of-attack range without affecting pitch and roll, and also that additional systems, such as thrust vector concepts, are needed for higher angles of attack.

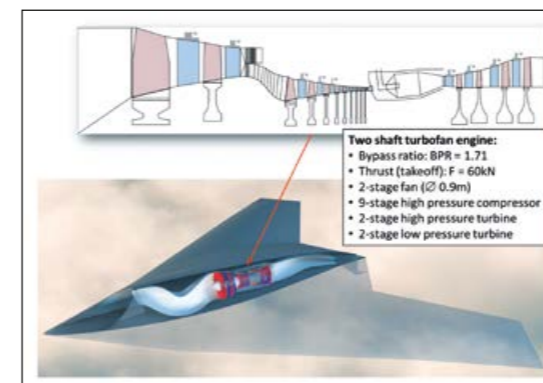


Fig. 3: Engine inlet duct, engine, and nozzle design of the highly integrated propulsion concept

Sebastian Zenkner
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Antriebstechnik
Köln

PKS-WTF@dlr.de

A highly integrated engine concept comprising a low-signature intake and nozzle has been realised, including – among other things – the design of a complex S-duct inlet, with the aim of avoiding any direct view of the fan as well as possibly ensuring an undisturbed flow field as far as the compressor inlet plane. Various design concepts for flat engine nozzles have also been explored.

It has proven possible in the Mephisto project to improve overall design capability through suitable process integration of the various disciplines and through a high degree of confidence in the methods used, as well as to deliver valid performance predictions for components and for overall aircraft design.

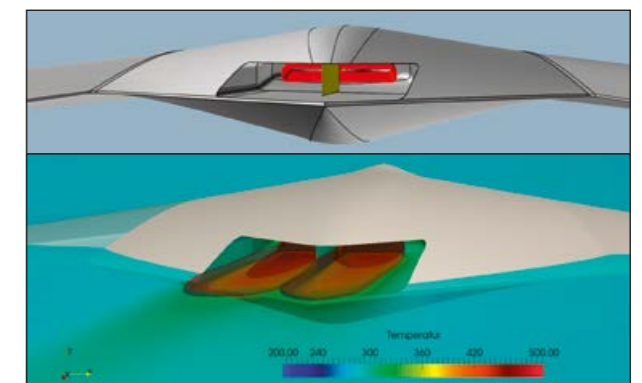


Fig. 4: Above: Variable fan nozzle and thrust vector vane. Below: Exhaust plume simulation to verify the performance of the thrust vector system and to provide exhaust plume data for infrared signature assessment

Max Friedrich
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Flugführung
Braunschweig

PKS-WTF@dlr.de

Dr. Dagi Geister
Deutsches Zentrum für Luft- und Raumfahrt
Institut für Flugführung
Braunschweig

PKS-WTF@dlr.de

Design of a human-machine interface for the supervision and guidance of multiple highly automated UAS in controlled airspace

One objective of the “Future UAS Guidance Functions” research project is to design and develop a system that permits simultaneous supervision and guidance of multiple UAS. Empirically validated human factors methods have been applied aiming to design a human-machine interface (HMI) that optimally supports UAS-pilots in their work.

Within the scope of the “Future UAS Guidance Functions” research project, an HMI is currently undergoing development with the aim of supervising and guiding multiple highly automated unmanned aircraft systems (UAS). A major focus of the work is on the intuitive and operator-friendly design of the HMI.

Unmanned aviation has experienced higher accident rates than conventional manned aviation. The accidents are often-times attributable to shortcomings in the design of the HMI. Non-intuitive automation, unsuitable colour design concepts and warning philosophies, as well as poorly thought-through information management lead to situations in which important information and warnings are not accurately recognised or understood and/or where the response is inadequate. Many of the shortcomings in HMI design are a consequence of insufficient consideration of human factors engineering principles in the systems’ early development phase.

A major focus of the “Future UAS Guidance Functions” research project is on applying established and empirically validated human factors methods to design an HMI that adequately sup-



Fig. 1: HMI for the supervision and guidance of multiple UAS in controlled airspace

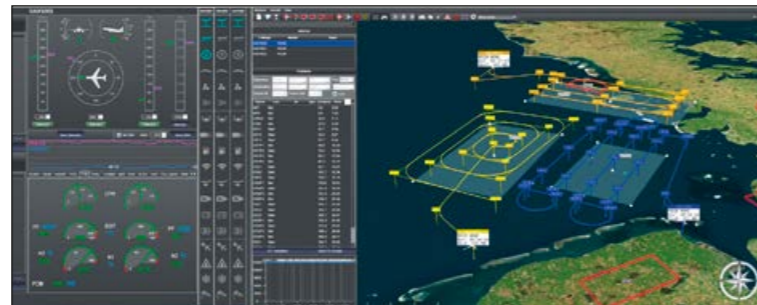


Fig. 2: HMI for the supervision and guidance of three UAS during a reconnaissance mission (screenshot)

ports UAS pilots in their tasks. With the aid of cognitive work analysis methods and findings from scientific literature on guidance of visual attention and HMI design approaches, a novel HMI has been designed for the supervision of safety-critical functions as well as the guidance of multiple highly automated UAS.

Cognitive work analysis has served as a means for deriving information requirements for the HMI. The further development of interface design methods has led to an information management concept aimed at presenting all relevant information to UAS operators on a continual basis while keeping the on-screen flood of information at lowest possible levels. So-called display clutter is avoided through the dynamic and structured concealment of non-relevant information from the primary view of the UAS pilot. Systematic variation of the degree of abstraction of the information presented also enables UAS pilots to quickly and efficiently monitor the states of safety-relevant system functions of all the UAS under their control.

The concept for the colour design of the interface and the presentation of critical states of safety-relevant system functions has been derived from psychological models for visual perception and attention guidance. The concept facilitates quick perception of critical system states irrespective of the number of UAS requiring supervision.

The graphic design concept has been empirically validated in an experimental study, and the usability of the designed HMI evaluated in the course of two simulation studies. During the simulation studies, UAS pilots were required to manage and

supervise multiple UAS in controlled airspace simultaneously. Various critical situations (such as engine failure) were initiated in several scenarios and, by doing so, the situation awareness of the UAS pilots as well as the suitability of the concept for the guidance of visual attention were evaluated. Initial results are promising, but further studies are necessary to be able to arrive at empirically reliable judgements about the suitability of the HMI in different critical situations.

The results obtained in the course of these studies will yield information on important factors regarding the design of concepts for interacting with autonomous systems. The applicability of the validated concept to other areas such as Manned-Unmanned Teaming and the Future Combat Air System (FCAS), in particular the supervision of multiple UAS from a conventional manned aircraft, appears promising and is to be explored further in future.

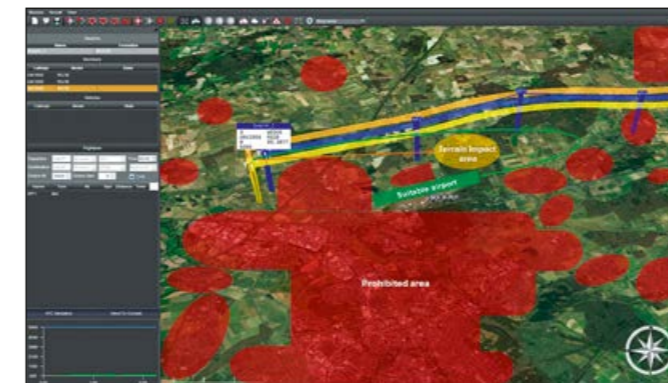


Fig. 3: Example of the implementation of information requirements for an engine failure of a UAS, necessitating an emergency landing or premature flight termination



Fig. 4: Aggregated fixations (heatmap) during an engine failure situation in the first simulation study

Alina Mielke, M.Sc.
Deutsch-Französisches Forschungsinstitut Saint-Louis (ISL)
Saint-Louis, Frankreich

isl@isl.eu

Dr.-Ing. Daniel Klatt
Deutsch-Französisches Forschungsinstitut Saint-Louis (ISL)
Saint-Louis, Frankreich

isl@isl.eu

Magnus effect on spinning finned projectiles in supersonic flow

Research work being undertaken at the French-German Research Institute of Saint Louis (ISL) is focusing on a hitherto little explored topic, namely the complex flow around highly agile spinning projectiles fitted with different kinds of fins. The flow phenomena occurring in this connection lead to lateral forces and yaw moments that can significantly affect flight behaviour.

Projectiles as well as other missiles can be stabilised along their flight path through rotational motion around their longitudinal axis. The fluid mechanics phenomena that occur through exposure to lateral flow lead to lateral forces and moments referred to as the Magnus effect. To satisfy increasing requirements in regard to range, agility or manoeuvrability, spinning projectiles can be additionally fitted with different kinds of fins or lifting surfaces.

Although the Magnus effect on simple rotationally symmetrical projectiles is already largely understood, the fin-induced fluid mechanics interactions occurring with more complex projectiles have been explored only little to date. Knowledge and understanding of these phenomena are, however, essential for predicting or controlling the flight behaviour of new configurations. The ensuing dynamic loads vary according to the Mach number and angle of attack, roll angle, and spin rate of the projectile, among other things. Depending on the configuration, the fins can increase, reduce or even reverse the occurring lateral forces and yaw moments.



Fig. 1: Model in canard configuration



Fig. 2: Model in tail fin configuration

Univ.-Prof. Dr.-Ing. Christian Mundt
Universität der Bundeswehr München
Neubiberg

info@unibw.de

A spinning finned body, when flying under an angle of attack, is exposed to two opposing effects: the classic Magnus effect, induced through viscous interaction of the rotating projectile body surface with the external crossflow, and a so-called pseudo-Magnus effect, which is caused by air flow against and around the individual fins.

Within the framework of this study at ISL, two generic projectile configurations are being explored under supersonic flow conditions at Mach 2 by means of both wind tunnel experiments and numerical flow simulations. One is a canard configuration (Fig. 1), and the other is a projectile with tail fins (Fig. 2). The fins are canted in either case to induce a spin rate typical of spin-stabilised projectiles.

The forces and moments resulting for the individual configurations are dictated by the interaction of various physical phenomena (see Figs. 3 and 4). Due to the crossflow, asymmetrical loads act on the opposing fins because of their different effective angles of attack. In addition, shocks develop at the leading and trailing edges, becoming superimposed and interacting, or possibly reflected at other fins to form a complex shock pattern. This influences the surface pressure distribution on the projectile significantly.

It leads to a displacement or distortion of the boundary layer on the spinning body surface and, for higher angles of attack, to an asymmetrical vortex separation which, in turn, reduces the pressure on the leeward tail fins. The forces generated directly or indirectly by the fins act in each case in opposition to the spin-induced body forces.

The research conducted at ISL allows a detailed insight into the generation of lateral forces and moments as well as into the underlying physical effects which can have an important influence on the stability and precision of complex spinning projectiles and, for that reason, are essential, especially for designing future projectile configurations.

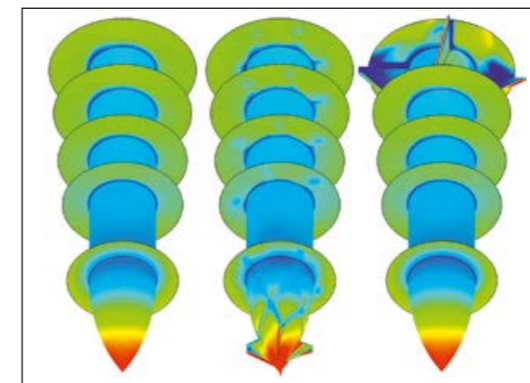


Fig. 3: Comparison of flow fields (Mach 2) around a non-finned, rotationally symmetrical body (canard configuration and tail-finned configuration spinning at 1000 Hz), visualising the pressure distribution on the model surface as well as the flow field density, in slices, for an angle of attack of 5°

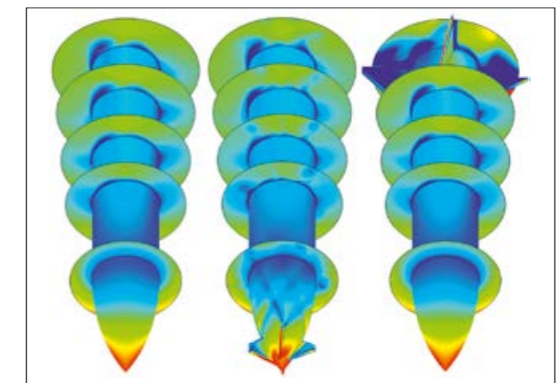


Fig. 4: Comparison of flow fields (Mach 2) around a non-finned rotationally symmetrical body (canard configuration and tail-finned configuration spinning at 1000 Hz), visualising the pressure distribution on the model surface as well as the flow field density, in slices, for an angle of attack of 10°

Assoc.Prof. Dr. Bernd Michael Fischer
Deutsch-Französisches Forschungsinstitut Saint-Louis (ISL)
Saint-Louis, Frankreich

isl@isl.eu

Dr. Sebastian Engelbrecht
Deutsch-Französisches Forschungsinstitut Saint-Louis (ISL)
Saint-Louis, Frankreich

isl@isl.eu

Effects of material ageing in protective systems on their performance capability

There is increasing use of polymers and composite materials in modern protective systems, in particular with a view to reducing overall weight. In many cases, however, their long-term behaviour has not yet been fully explored, and the question therefore presents itself to what extent material ageing influences systems' protective performance. This is being studied in a detailed multi-disciplinary approach at the French-German Research Institute of Saint-Louis (ISL).

In recent years, new types of materials have increasingly been put to use in protective systems in order to offer the most comprehensive protection possible against ever more complex threat scenarios. In some instances, specific new functionalities have been exploited, such as those of auxetic materials, which, when stretched, become thicker perpendicular to the direction of applied force. In the main, however, the aim is to reduce overall weight. Where some of these materials are concerned, in particular polymers and epoxy resins, ageing effects are already known and often have been extensively tested for their civilian applications. In some cases, morphological changes in a material's microstructure can especially lead to not inconsiderable changes in the material parameters.

In other cases, though, such changes are more subtle, only becoming really apparent within a composite structure consisting of different materials and possibly leading to a weakening of the structure or to delamination or softening of what previously were firmly bonded-together material components.

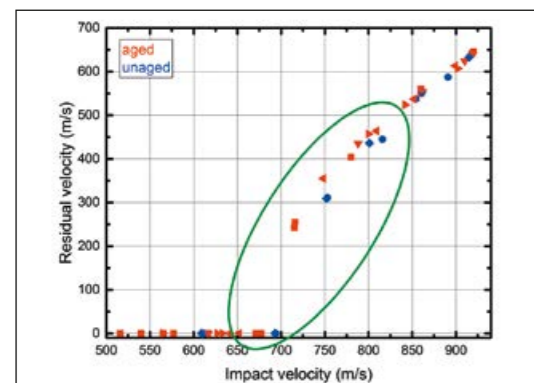


Fig. 1: Ballistic tests show that aged plates (red) are penetrated at lower impact velocities than unaged aramid plates (blue). Especially in their edge regions, the aged plates exhibit penetration at lower impact velocities, as well as a higher residual velocity for the same impact velocity

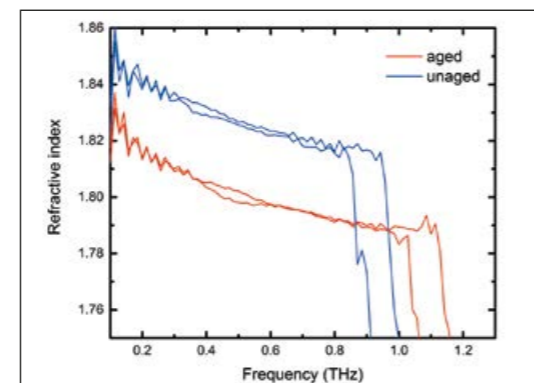


Fig. 2: Spectroscopic results allow a clear distinction between aged (red) and unaged (blue) aramid plates

Yet not every ageing-induced change in the material parameters will inevitably lead to a change in the protective performance of these structures. Current material tests which identify ageing effects are, in consequence, not generally suited to estimate whether the protective performance has been affected or not. To be able to make predictions more reliably in this regard, it is essential to have a better understanding of the correlation between ageing and its effect on the performance capability of protective systems, so as to both monitor the current status of systems in use and to better plan the design and development of new, future systems.

The consciously selected multi-disciplinary approach to the research at the ISL is particularly well-suited for work on such a topic, which calls for close cooperation between materials development, material science, and terminal ballistics teams.

Using special-purpose ovens and climate chambers, materials are artificially aged so as to then compare the changes in the material parameters with the results of the terminal ballistic tests and identify potential correlations. The findings thus obtained are then compared with data from experiments conducted on naturally aged systems containing the same materials, with the aim of possibly attributing any loss in protection performance to corresponding, previously identified ageing-induced changes in the material. The materials development team may then possibly design new alternative materials that are less susceptible to those specific ageing effects. The suitability of different non-destructive test methods for identifying and monitoring ageing effects relevant for changes in protective performance is also being explored.

Three systems are currently being tested as examples in a first approach: helmets, transparent armour, and high-performance textiles (fabric) for protective vests.

The topic of protective system ageing is of relevance for many nations, for which reason the work at ISL is being conducted in close coordination with, and under the joint guidance of, the French and German authorities. The complexity of the topic also exceeds the capabilities of any one institute, which is why further institutes and academic partners are closely involved through existing partnerships. The second international workshop on this topic, organised by and held at ISL in 2018, was, as a result, actively supported not only by the German and French authorities but also by Australian and British official bodies. Yet further nations have announced their active participation for the third workshop, scheduled for October 2019.



Fig. 3: Artificially aged polymer samples. A strong change in colour is evident

Prof. Dr.-Ing. Jochen Schein
Universität der Bundeswehr München
Neubiberg

dekanat.eit@unibw.de

Michal Szulc, M.Sc.
Universität der Bundeswehr München
Neubiberg

dekanat.eit@unibw.de

Dr.-Ing. Stephan Zimmermann
Universität der Bundeswehr München
Neubiberg

dekanat.eit@unibw.de

Plasmatechnologies for material surfaces, PlasmaTec

The functions of materials are determined to a large extent by their surfaces. For defence applications the range of the first atomic layers up to a few micrometers is of particular importance. In the project, plasma treatments are being explored and deliberately used with the aim of optimising materials for military applications.

Plasma treatments allow precise structuring and chemical functionalisation of material surfaces. With this in mind, the 'PlasmaTec' project is exploring the potential of various plasma sources for military applications, specifically the joining of fibre reinforced plastics, the functionalisation of textiles, and material protection. Increasing use of structural adhesive joints is being considered as a means of exploiting further lightweight construction potential offered by CFRP (carbon fibre reinforced plastic) structures and composite constructions for the defence industry. The Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB) is conducting research into a combination of peel-ply and atmospheric pressure plasma (ADP) treatment in order to develop a safe and reliable process chain for the pretreatment of structural bonds between CFRP structures. Where the research into the aforementioned processes is concerned, there is a lack of knowledge about the relevant plasma parameters (e.g. emission wavelengths, temperature distribution), their dependence on associated operating parameters and their influence on the material.

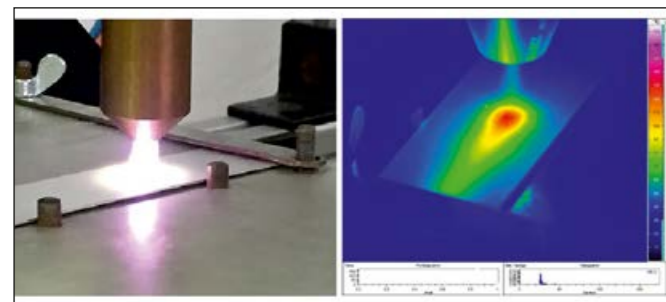


Fig. 1: Surface modification

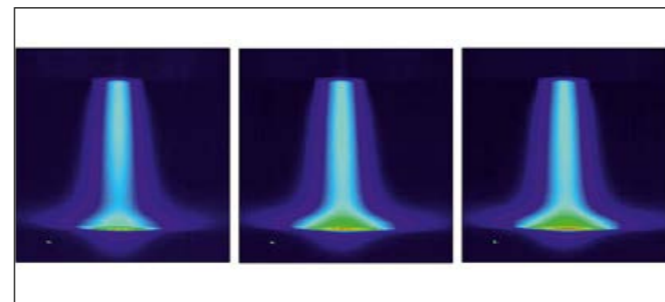


Fig. 2: Interaction between plasma and surface when varying the operating parameters (here: variation of the process voltage, from left to right: 260 V, 290 V, 300 V)

Dr. Timo Hofmann
Wehrwissenschaftliches Institut für Werk- und Betriebsstoffe WIWeB
Erding

wiweb@bundeswehr.org

Jörg Rehbein, M.Sc.
Wehrwissenschaftliches Institut für Werk- und Betriebsstoffe WIWeB
Erding

wiweb@bundeswehr.org

WIWeB and the Lab for Plasma Technologies (LPT, EIT1) at the Bundeswehr University, Munich, are working closely together in a joint study entitled "Plasmatechnologies for material surfaces, PlasmaTec", which is to run for a period of three years, and, to do so, have pooled their expertise on material-related issues as well as in plasma generation and diagnostics.

Being explored is the use of so-called cold plasma, which is a gaseous, low-energy mixture of ionised molecules and electrons, and in this case is to serve the purpose of treating defence material surfaces (Fig. 1). The work is focusing on plasma systems that can be automated and are suitable both for surface activation and for depositing thin layers on material surfaces. Other aims include being able to realise coatings by adding further materials to the plasma gas, and determining the local composition of the plasma (e.g. temperatures, wavelengths and intensities) from the plasma radiation with the aid of optical methods. Figure 2 shows first results obtained when varying the plasma parameters. In further steps it will be ascertained diagnostically what influences (plasma instabilities, electrical operating parameters etc.) exert with regard to the surface pretreatment of CFRP structures, especially for bonding with different working distances, nozzle geometries and different process gases.

The use of different process gases for plasma tuning (i.e. for controlled adjustment of the plasma) serves as a preliminary test for the precise activation and deactivation of chemical reactions and, thus, for defining optimised plasma parameters, which differ in their emission wavelength distributions. One goal is to emit as little short-wave radiation as possible, and another to produce, if possible, long-wave radiation above a predefined cut-off wavelength of 375 nm. What is important in this respect is that photoinduced dissociation (i.e. splitting) of individual carbon or hydrocarbon bonds can be controlled and deliberately initiated or impeded (see Figure 3). Materials for defence applications (lightweight design potential for structures constructed from carbon fibre reinforced plastics (CFRP) and polymeric composites) can thus be created, and the necessary fundamentals established for bonding to take place as a cohesive joining process.

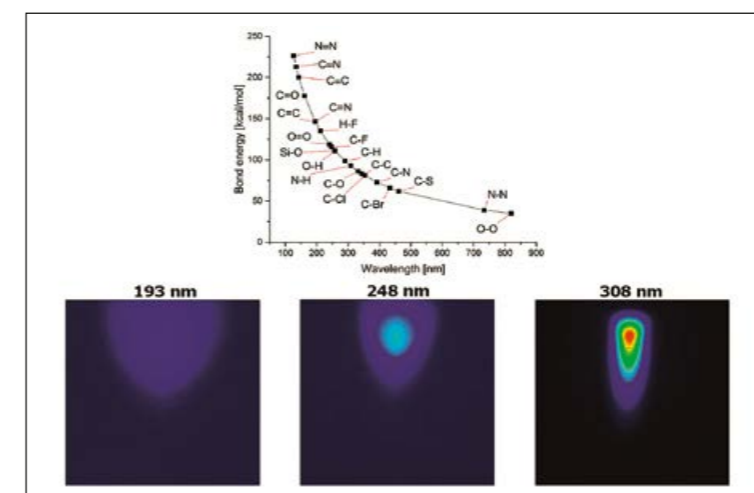


Fig. 3: Photodissociation wavelengths of chemical compounds, wavelength-dependent photoemission of a plasma parameter

Yannick Brand, M.Sc.
HAT.tec GmbH
Neubiberg

info@hattec.de

Dipl.-Ing. Fabian Schmitt
HAT.tec GmbH
Neubiberg

info@hattec.de

Adaptive associate systems for manned-unmanned teaming missions

Guiding multiple unmanned aircraft from the cockpit of an aircraft can increase mission performance while reducing potential risks to the crew. In order to offset the high additional task load, the Institute of Flight Systems is developing and evaluating adaptive associate systems that support the crew with the aid of cognitive ergonomics and artificial intelligence methods.

Future military missions will benefit from multiple unmanned aerial vehicles (UAVs) being deployed and directly controlled by crews of manned aircraft (manned-unmanned teaming – MUM-T). The additional task load that this will create for pilots will particularly include cognitive tasks such as planning, monitoring and decision-making. Tasks of this kind are characterised by high demands on mental processing resources. If such demands exceed available mental capacity, as, for example, in time-critical multitasking situations, this can lead to diminished human performance, overload and errors.

Research activities at the Institute of Flight Systems (IFS) of the Bundeswehr University, Munich, are focusing on adaptive associate systems to counter these problems. Such “digital copilots”, represented by cognitive agents, support human pilots in performing cognitive tasks for the purpose of enhancing mission performance as well as correcting and, in particular, proactively preventing human errors. The support is adapted to the task situation and the mental state of the pilot. Nevertheless, when decisions are made in the cockpit, the pilot remains the ultimate authority.



Fig. 1: Manned-unmanned teaming: Guiding multiple unmanned aircraft from the cockpit of a manned aircraft requires a high level of automation. An effective team comprising automation and humans is the key to successful missions



Fig. 2: The FCAS/NGWS MUM-T simulator of the Institute of Flight Systems is used for testing novel assistance, planning and mission functions. Two single-seater or, alternatively, one twin-seater cockpit can be used to simulate different cockpit configurations

Felix Heilemann, M.Sc.
Universität der Bundeswehr München
Neubiberg

fmff.lrt@unibw.de

Univ.-Prof. Dr.-Ing. Axel Schulte
Universität der Bundeswehr München
Neubiberg

fmff.lrt@unibw.de

A human copilot has cognitive abilities where flying and tactical decision-making are concerned, and a digital agent is similar in its capabilities. Like human teams, the agent, to function effectively, also needs data on the pilot's mental state. The basis for this is expert knowledge from the application domain, which is extracted in close cooperation with military pilots and made available to the associate system as a digital task model. The agent uses this model to determine on which tasks the crew are currently working and how great their mental workload is. The combination of this model knowledge with the mission plan additionally makes it possible to project future tasks and hence predict critical stress situations in the future, which the associate system proactively counters by adapting the assistance provided to the crew.

Building upon the findings from various research studies funded by the German FMoD in connection with MUM-T missions, the Institute of Flight Systems is developing laboratory prototypes for combat aircraft and helicopters.

In 2017 and 2018, a detailed evaluation of an assistance system took place, involving military pilots on helicopter missions. The team, consisting of pilots and digital agent, completed several MUM-T missions in highly dynamic scenarios, characterised by unexpected changes in the tactical situation and

mission objective. Despite the massive workload, the crews were able to complete their missions in full with the support of the cognitive agent.

The achieved research results have already been successfully put to use in a specially developed laboratory prototype of a “6th Generation Fighter Cockpit”, with a view to the Bundeswehr procuring a new fighter aircraft (Future Combat Air System (FCAS) / Next Generation Weapon System (NGWS)). An experimental campaign involving Bundeswehr fighter pilots is in the preparation stage.

HAT.tec GmbH, an enterprise spun-off from the IFS, is looking to industrialise the conceptual knowledge that has been gained and to implement the innovative concepts in product-related solutions.



Fig. 3: Conducting an MUM-T experimental campaign in a helicopter mission simulator to evaluate the adaptive associate system



Fig. 4: With the aid of eye tracking and other sensors, the crew's activities are recorded contact-free and non-intrusively and combined with model knowledge to provide task-specific support

Jakob P. Haug, M.Sc
Universität der Bundeswehr München
Neubiberg

isa@unibw.de

Univ.-Prof. Dr.-Ing. Reinhard Niehuis
Universität der Bundeswehr München
Neubiberg

isa@unibw.de

Challenges for the next generation of fighter jets – exploring specific flow phenomena inside a modern intake system with the aid of numerical simulations

Use of fully integrated propulsion systems serves to reduce the radar signature of modern military flying systems. For civil aviation, they are used within new aircraft designs aiming at reduced emissions. The complex flow field in such intake systems shows strong interactions with the compressor, which can have a considerable influence on jet engine operating behaviour. This is being explored by means of experiments offering high spatial and temporal resolution, as well as with the aid of precise numerical simulation methods.

Reduced detectability is an important requirement for future flying weapon systems. This can be met through the installation of compact, highly curved intake systems, thereby avoiding a direct line of sight onto the highly reflective rotating parts of the jet engine. The curvature of the flow path, however, induces unwanted flow distortions, which can have a negative influence on jet engine operating behaviour in terms of performance and safety. The compressor can also influence the flow in the intake duct through its flow field, though. This strong interaction between the intake and compressor flow regimes has to be kept under control and taken into consideration in the design process of the individual sub-systems.

The Bundeswehr Technical Centre for Aircraft and Aeronautical Equipment (WTD 61), in collaboration with the Institute of Jet Propulsion at the Bundeswehr University Munich, has successfully completed numerous analyses of flow phenomena in compact, highly contoured intake ducts within the scope of several research projects and initiated further research activities. Within these projects, a research intake duct (MEIRD, or Military Engine Intake Research Duct, Fig. 1) has been developed

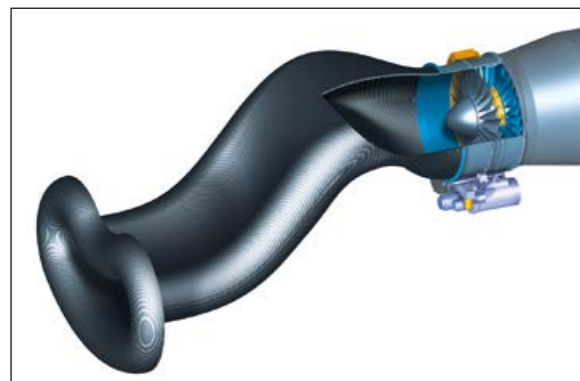


Fig. 1: CAD model of the MEIRD intake system with coupled Larzac 04 low-pressure compressor



Fig. 2: Experimental set-up with installed MEIRD intake system and Larzac 04 engine in the engine test facility at the Institute of Jet Propulsion

TRDir Dipl.-Ing. (univ.) Michael Krummenauer
Wehrtechnische Dienststelle für Luftfahrzeuge und Luftfahrtgerät
der Bundeswehr (WTD61)
Manching

WTD61AntriebFuT@bundeswehr.org

and manufactured. It induces a strong combined swirl and pressure distortion typical of military intake systems. Time-resolved numerical Methods (URANS with Reynolds Stress Model) are being used for the precise prediction of the complex flow situation in the MEIRD.

Coupled intake-compressor simulations have been conducted to study the interaction of intake and compressor flow in detail. As the intake-induced flow distortion is not axisymmetric, it is necessary, when conducting time-resolved simulations, to consider the full annulus of the low-pressure compressor (LPC), as a reduction to one single blade passage is no longer meaningful.

This leads to a large numerical set-up comprising more than 120 million computational cells. With an adequate time resolution for one rotor rotation and the necessary high number of rotor rotations, the amount of computing time required is hence very high, which is why even on a high-performance cluster the simulation of one operating point takes about 15 weeks. To ensure the numerical simulations deliver a precise prediction of the flow, they are being accompanied by experimental investigations (Fig. 2), for which 143 pressure taps are placed on the MEIRD and also high-frequency pressure data (up to 500 kHz) is recorded at four positions. The flow field in the AIP (aerodynamic interface plane) between the MEIRD

and compressor has been additionally measured by means of a traversable measurement rake.

In order to provoke a strong interaction between intake and compressor flow, the MEIRD is positioned directly upstream of the compressor (Fig. 2). The vortex systems induced in the intake system extend downstream into the fan of the LPC. Together with the strong pressure distortion they influence the flow and the loading of the compressor (Fig. 3). Due to the high intensity of the flow distortion in the intake, it still interacts with the flow in the second compressor stage. These data are compared against simulations of an isolated duct and undisturbed compressor in order to evaluate the influence of the individual components.

The numerical simulation data show a good consistency with the experimental data. A detailed analysis of the flow simulation visualises the strong interaction of the intake flow with the compressor flow. A precise assessment of the intake system's influence on the jet engine in regard to performance and safety is still pending.

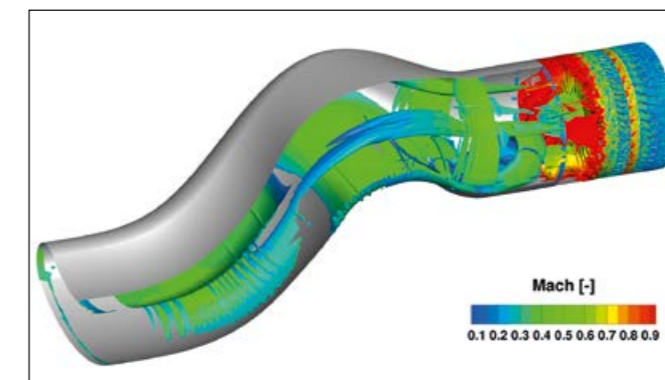


Fig. 3: Flow phenomena within the MEIRD and the coupled Larzac 04 low-pressure compressor, based on numerical simulation data

Jun.-Prof. Dr.-Ing. Christian Hofmann
 Universität der Bundeswehr München
 Neubiberg

Univ.-Prof. Dr.-Ing. Andreas Knopp, MBA
 Universität der Bundeswehr München
 Neubiberg

office.sp@unibw.de

office.sp@unibw.de

Miniaturised transceivers for global connectivity via satellite

In a study commissioned by the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw), the Institute of Information Technology at the Bundeswehr University Munich, has been looking into new types of satellite communication technology. This has led to the development of an innovative technological approach that allows miniaturised transmitters to communicate via existing geostationary satellites operated by the Bundeswehr.

Field forces of the Bundeswehr are equipped with a variety of telecommunications equipment enabling them, where necessary, to establish links for situation reporting and for issuing orders. Special operations forces, isolated units or individual unattached elements are often dependent on satellite communications (SATCOM) if the range of terrestrial links is inadequate and cellular networks are unavailable or not secure to use.

For higher frequency ranges (> 1 GHz), satellite terminals require a dish reflector antenna and are also non-portable, which is why armed forces use portable systems (Fig. 1) in the VHF/UHF range (around 300 MHz) to establish a voice connection via geostationary satellites (GEO) worldwide, when needed.

Even the lattermentioned systems, though, require a relatively large antenna and, due to the limited resources in the frequency band in use, do not permit communication with many subscribers via the GEO satellites, which are more than 36,000 km distant.



Fig. 1: Man-pack UHF satellite radio for links via geostationary satellites, as currently used in the Bundeswehr (Source: nara.getarchive.net)

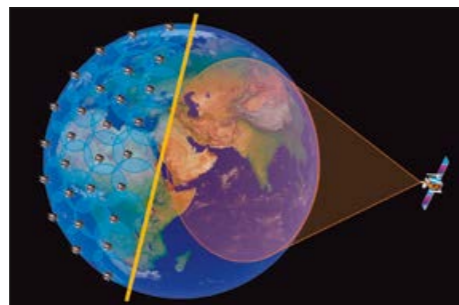


Fig. 2: Geostationary satellites already in orbit ensure constant coverage over wide areas (right), while a low-earth-orbit (LEO) satellite system requires a very large number of satellites for continuous connectivity (left)



Fig. 3: The Bundeswehr's geostationary communication satellites (COMSATBw) cover its area of interest completely and, with the newly developed technology, could make communication possible for a very large number of miniaturised transmitters

Reduction of the size and weight of the terminals and an increase in the number of global satellite communications users make it necessary to have a system of low-earth-orbit (LEO) satellites operating in orbits of less than 1000 km from Earth. Constant user connectivity, however, calls for a very large number of satellites (> 60) that re-route information among one another. Such a constellation of LEO satellites necessitates considerable financial and regulatory resources and is not realistic as a near-term military project.

By contrast, three GEO satellites already make global coverage possible, with the exception of the polar regions, and the Bundeswehr's two existing GEO satellites completely cover its main area of interest. So far, though, there are no systems that transmit data to GEO satellites using compact integratable antennas, as regulatory provisions aimed at protecting other systems greatly limit the maximum allowable transmitter power output, and the long distance, together with a low transmitter power, makes data transmission nearly impossible.

In searching for innovative SATCOM technologies for BAAINBw, the Institute of Information Technology within the Faculty of Electrical Engineering at the Bundeswehr University, Munich, has developed a new type of transmission technology capable of mastering this major challenge. The approach is based on repeatedly transmitted, so-called correlation sequences. These can be detected in noise, which is up to 10,000 times stronger than the signals, only after suitable further processing at the receiver.

Existing methods fail in this regard due to the limited accuracy of available oscillators. The newly developed method relies on

unipolar coding, which defines the distance between the correlation sequences and also allows separation of the different users.

The design of the transmitted signals makes it possible for many miniaturised transmitters to transmit simultaneously and uncoordinatedly at any time when needed, without having to coordinate the transmission times among users.

The constraints in regard to permitted transmission power, distance and sensitivity of the GEO satellites allow data transmission rates with theoretical upper limits of only a few bits per second. These are certainly too low for the transmission of speech or lengthy texts, but sufficient for applications such as blue force tracking, the transmission of short standardised messages, or emergency paging.

The developed technology will in future allow the use of very compact transmitters with extremely small antennas and ensure accessibility in all operational areas via the GEO satellites already operated by the Bundeswehr.

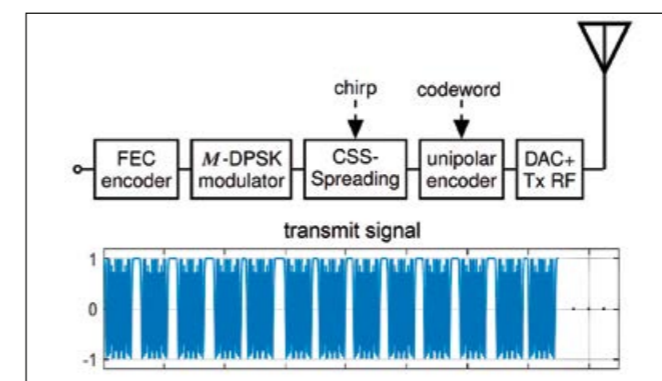


Fig. 4: Block diagram of the proposed transmitter for the new transmission method and real part of the transmitted signal

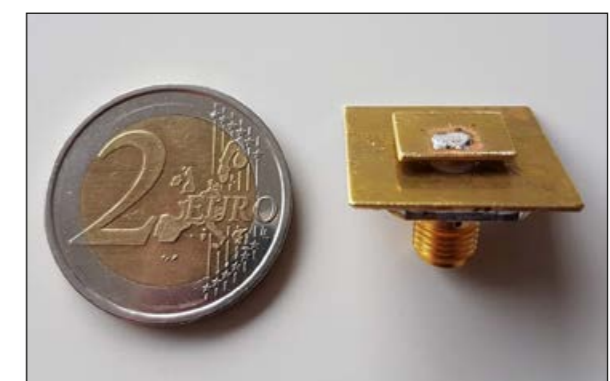


Fig. 5: Communication at very low data rates via geostationary satellites can take place in higher frequency bands using very compact antenna structures

Prof. Dr. Carlo Masala
 Universität der Bundeswehr München
 Neubiberg

info@unibw.de

Tim Tepel
 Universität der Bundeswehr München
 Neubiberg

info@unibw.de

Scientific advice for study on IT-supported crisis early warning

In an R&T study, the Federal Office of Bundeswehr Equipment, Information Technology and Inservice Support (BAAINBw) and enterprise IBM are exploring a software-based crisis early warning solution for Germany's Federal Ministry of Defence. The Center for Intelligence and Security Studies (CISS) is supporting the study with scientific advice, under the direction of Prof. Carlo Masala, with a view to validating the conceptual and methodical approaches employed in the study.

The aim of crisis early warning is advance identification of political, economic and social developments that can potentially lead to the violent escalation of conflicts within countries or regions. Crisis early warning systems provide early indications of critical developments through automated assessment of information. A reduction in information collection efforts can generate efficiency gains with respect to the actual analysis and processing of information, thereby facilitating better decision-making support.

In scientific research on crisis early warning, data sources are used which can roughly be grouped into two categories. Dynamic political and societal developments can be derived from event data that, for instance, describes interactions between key actors in a country. Event data is often obtained from news reports. Also, political, economic, demographic, social, geographical and ecological indicators are considered in the analysis of political risks. These are often subsumed under the generic term 'structural data'. The underlying data sources are provided by international organisations, national statistics offices or research institutes. Frequently, structural indicators

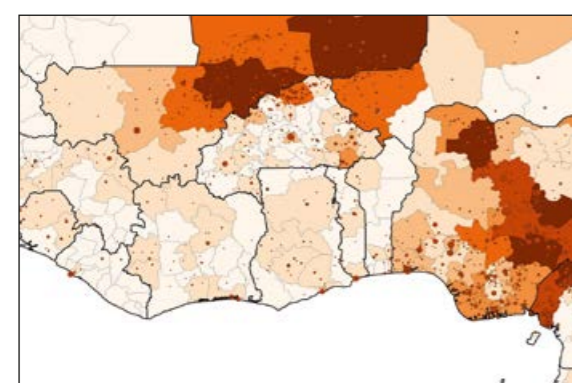


Fig. 1: Conflict events in 2018 (Armed Conflict and Event Location Data, Raleigh C, et al. (2010) Introducing ACLED-Armed Conflict Location and Event Data. Journal of Peace Research 47(5), 651-660)

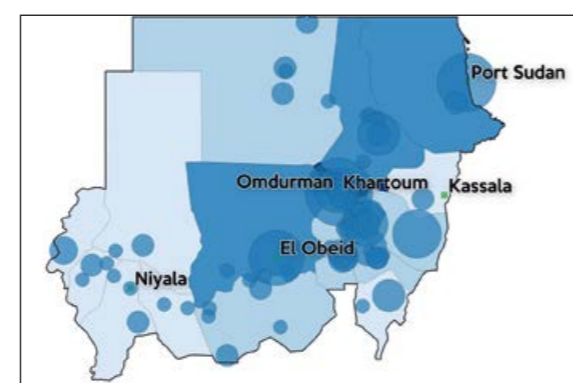


Fig. 2: Protest events in Sudan in 2018 (Armed Conflict and Event Location Data, Raleigh C, et al. (2010) Introducing ACLED-Armed Conflict Location and Event Data. Journal of Peace Research 47(5), 651-660)

are also derived from geospatial GIS (geoinformation system) data. Indicator data is less dynamic than event data obtained from up-to-the-minute news data, yet reflects the structural baseline risk for crisis developments in countries or regions.

Input data suitable for risk modelling is pre-processed and fed into statistical or machine learning models for evaluation. Variables for predicting political crises are selected by reference to theories of political conflict. The models are trained on the basis of historical data. Taking conflict datasets such as those provided by the Armed Conflict & Event Location Project or the Uppsala Conflict Data Program as a basis, it is coded when, in the past, crises have occurred. The aim of the modelling process is to use suitable variables to predict the "future" occurrence of such crises. To do so, the data is split into training, validation and test sets. Models are initially trained on the basis of the training sets, and evaluated and optimised with the aid of the validation sets. A final evaluation of the model's performance is then conducted using a previously withheld test set.

Crisis early warning models not only deliver a risk estimate, but can also offer insights into relevant influencing factors and, thus, better decision-making support. This necessitates the identification of variables that exhibit especially high predictivity. The identification of interaction effects between two or more variables which only in combination will impact on the risk of a crisis occurring, is also often of particular interest for validating underlying theoretical assumptions and for improving the models.

Crisis early warning research poses domain-specific challenges in regard to implementing risk models successfully. These

pertain, for example, to the definition of crisis types relevant from the end users' perspective, to the selection of input data suitable for their prediction, or to the consideration of spatial and temporal dependencies in the modelling. The scientific advice for the study on IT-supported crisis early warning is intended to ensure that the employed conceptual and methodical approaches are fit to meet end user requirements.

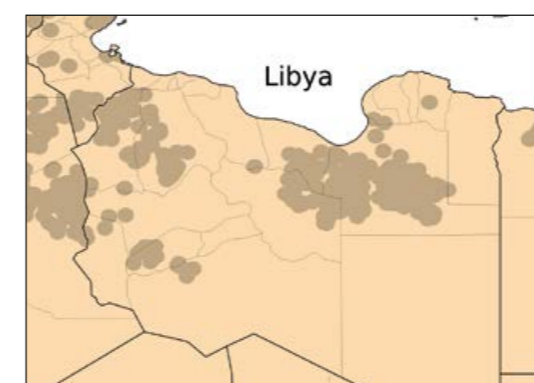


Fig. 3: Example of GIS data: Petroleum Deposits (PRIO Petroleum Dataset, Lujala P, Rød JK, Thieme N (2007) Fighting over Oil: Introducing A New Dataset. Conflict Management and Peace Science 24(3), 239-256)

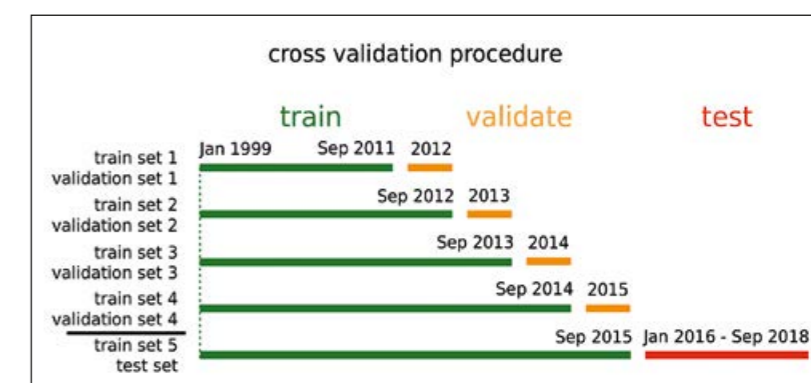


Fig. 4: Cross-validation procedure (example)

Prof. Dr. Carlo Masala
 Universität der Bundeswehr München
 Neubiberg

Dr. Konstantinos Tsetos
 Universität der Bundeswehr München
 Neubiberg

info@unibw.de

info@unibw.de

M&S support for crisis and disaster management processes and climate change implications

The Chair for International Politics at the Bundeswehr University Munich, is contributing academic expertise to working group MSG-147 in the context of crisis management support, with the focus on modelling and simulation (M&S) for the study “Supporting the German Technical Contribution to the NATO Modelling & Simulation Group (NMSG) 147”. Previous contributions to the concept of working group MSG-147 are being broadened and the original contributions used to complete the concept.

In the context of the study “Supporting the German Technical Contribution to the NATO Modelling & Simulation Group (NMSG) 147” (M&S Support for Crisis and Disaster Management Processes and Climate Change Implications (Ustg DEU-Tech-NMSG-147)), the German delegation has been affording substantial contributions to the progress being made by the multilateral group. Since 2017, Germany has provided important input, both conceptually and technically, as additional support for the Crisis Management and Disaster Response Center of Excellence (CMDR COE), which is undergoing development.

In close cooperation with the Bundeswehr Office of Defence Planning, Division IV (Scientific Support and Interoperability) – which has taken on the management of the associated experiments – and with enterprise IABG GmbH – who have provided the technical director and are responsible for the technical implementation – the Bundeswehr University Munich, has, as ConceptLead, devised the Concept Development & Experimentation (CD&E) concept for the working group. The university has also conducted the scientific and conceptual validation of the project and provided substantial support to the Experiment-

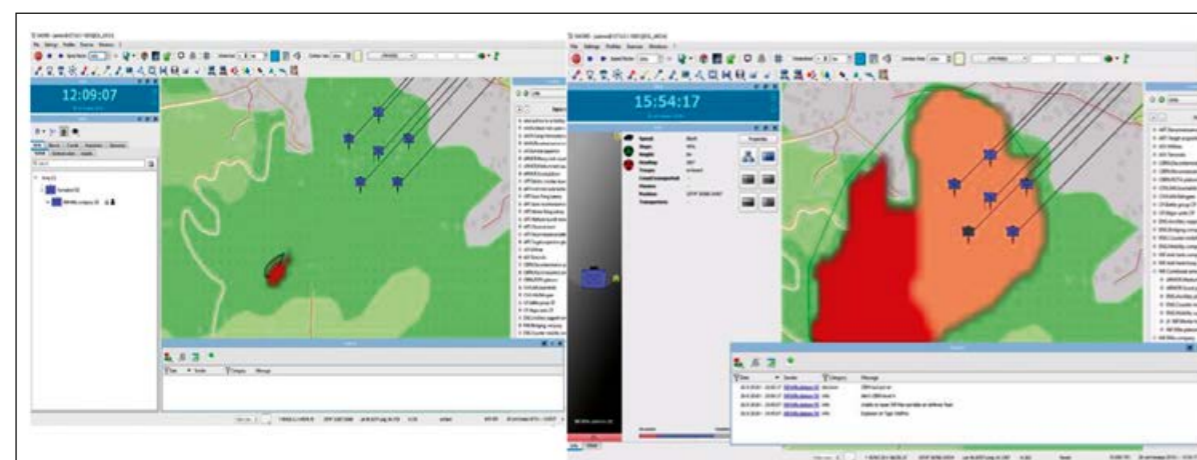


Fig. 1: Fire propagation in the SWORD simulation programme

Lead. For this purpose, numerous simulation and command & control systems have been examined, experimented and evaluated for their usability in forecasting and assessing operations in the wake of natural disasters. A disaster module developed by the CMDR COE has been assessed and validated as an interface between simulation systems and as middleware between simulation and command & control systems. Recommended improvements have been communicated to the participating enterprises in close collaboration with the NATO Joint Forces Training Center (JFTC) with the aim of improving the analysis capabilities, training applications and decision-making support capabilities for dealing with natural disasters. It has also been possible to derive insights into standard operating procedures, as one of the goals of the project is to increase the resilience of the armed forces in the event of any disaster.

In previous experiments within the framework of MSG-147, the need to develop a disaster FOM (FOM = Federation Object Model) module has also been identified. This includes conceptual further development (in the areas of operation and planning, analysis, as well as training and practice), technical developments, and complex experimental reviews of the solution approaches. Within the project, Germany has also taken on responsibility for developing SOPs (SOP = Standard Operating Procedure) that are to be implemented in a crisis situation. By deriving generic SOPs to improve the crisis management, the aim is to also develop approaches to training, education and practice, which are to be established alongside decision-making support as a further core product of the planning group. IABG and the Bundeswehr University Munich, are developing suitable models and approaches in this connection designed to have a substantial impact on the crisis response capability of armed

forces in disaster scenarios, improve training and practice, and ultimately help to strengthen resilience in crisis situations. By doing so, Germany is contributing significantly to the further development of the multinational M&S tools and instruments that will be available. This achievement would be equatable to a prestigious technological leap which, while generating significant added value, would have implications for international crisis management, analysis, preparation, operational command, and training. This will have a positive impact on crisis management education and training both at the national level (with KORA as the legacy simulation system; KORA: Armed Forces Synthetic War Game and Crisis Response System) and internationally (NATO JFTC / CMDR-CoE and M&S-CoE).

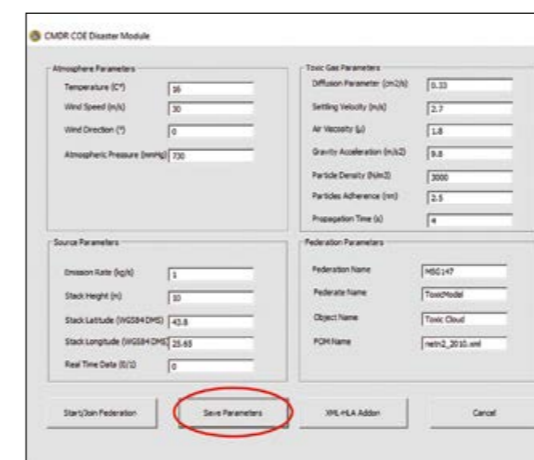


Fig. 2: CMDR COE Disaster Module: Setting of parameters

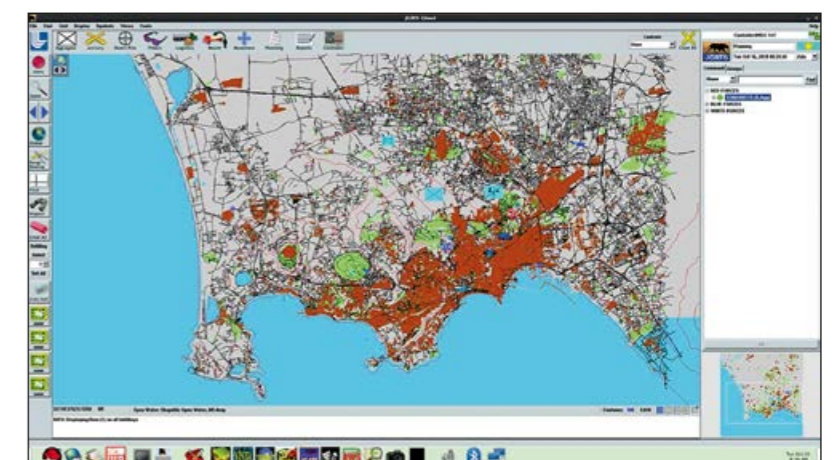


Fig. 3: Visualisation: KORA – JCATS federation (JCATS = Joint Conflict and Tactical Simulation)

Classifying state stability

The Bundeswehr is actively involved in operations in multiple regions around the world as part of various alliances. The reason for these operations is, often, a grave crisis situation in a particular country. To be able to identify crises at an early stage, it is important to assess the stability of states in which crises might occur.

Regardless of whether political or economic, crises are an undesirable state of affairs. Early identification or prediction of crises is always an issue, therefore, so that they do not even arise, or can be addressed in a timely manner. To identify a potential flashpoint, it is crucial to consider a state's stability. Fragile states are more likely to succumb to a crisis than stable states.

A team at the Bundeswehr University, Munich, in cooperation with the Bundeswehr Operational Communication Centre, has addressed this problem and developed a software (Global Analysis of Stability Indicators, or GASI) for the purpose of analysing how vulnerable states are to crises.

Early crisis identification is often based on media analysis aimed at providing indications of short-term shocks. GASI pursues a different approach. It examines the social environments in states in which shocks could occur. How stable is that state, to the extent that the likelihood of shocks there, or their impact, is lower? When considering state crises, it is important to distinguish between short-term shocks occurring in a state and the state's long-term stability.

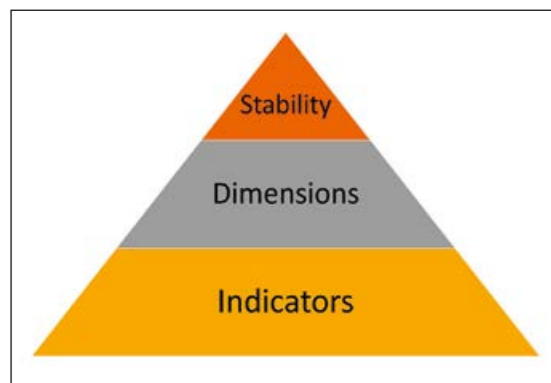


Fig. 1: Structure of the GASI model

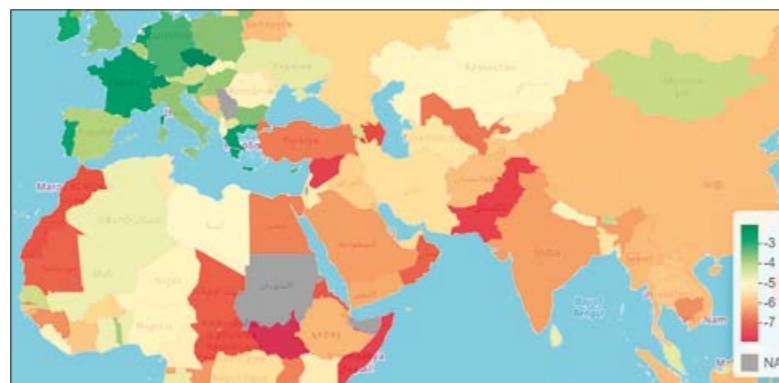


Fig. 2: Representation on a world map

One constraint when analysing state stability is that it is not directly measurable. It can only be assessed indirectly, by drawing upon a variety of indicators. But how can the values of the individual indicators be aggregated into a single value for stability, especially if they are contradictory? Simple average values would imply that all the indicators are of equal importance. For which reason, use is made of a weighted average, which requires weighting factors.

GASI has two distinct features. The first is that an intermediate level is included between the indicators and stability, encompassing the dimensions upon which the stability of a state is based, namely authority, legitimacy, capacity, and social cohesion. With the aid of indicators, the state's strengths (and weaknesses) in these four dimensions are then assessed, and the state's stability judged according to those dimension values (see Figure 1).

The second distinct feature is to be found in the indicator values and the process of their aggregation. If indicators are used as a basis for classifying a state, they must be comparable across the board for the states included in the analysis. The structural data used in GASI is hence from international sources such as the World Bank. This data is first scaled and then aggregated. The weighting factors for the aggregation are not determined subjectively, however, but statistically through correlation with the extent of a crisis.

In the assessment the stability, dimension or indicator values are displayed on a world map. It is possible to analyse the evolution of a particular dimension or indicator over a period of time and compare it with that of another state. The strengths

and weaknesses of a state in the dimensions can also be displayed in the form of a network diagram (see Figures 2 to 4). Similar to other software-based crisis identification tools, the quality of any analysis carried out with the aid of GASI depends significantly on the quality and selection of the underlying data. The GASI approach, with its focus on stability criteria, offers an advantage over other crisis indicator-based models.

Crisis forecasting is often confronted with a variety of contradictory signals. There are states in which multiple circumstances could lead to crises. In such cases GASI can provide helpful clues for a closer analysis. It identifies which states are unstable and thus more susceptible to crises, and which areas should be analysed more precisely, as weaknesses are revealed in a particular dimension.

An analysis conducted with GASI can be used as support in the early identification of crises and serve as a basis for a more in-depth examination and media evaluation.

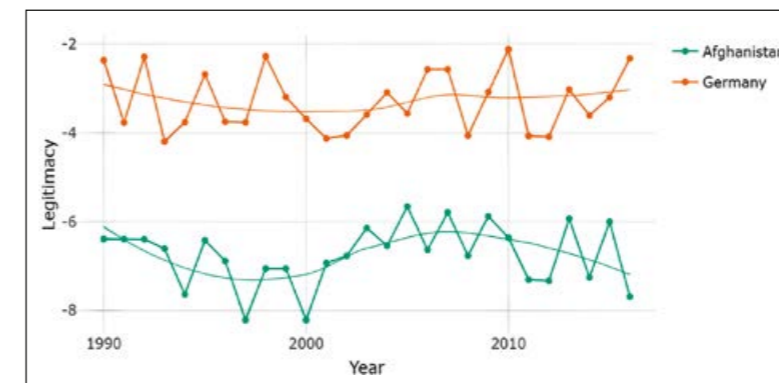


Fig. 3: Development of an indicator

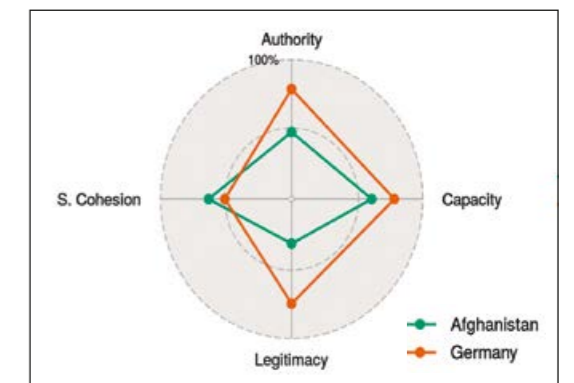


Fig. 4: Radar chart of the four dimensions

Hptm Marcus Knüpfer, M.Sc.
 Forschungsinstitut CODE
 Universität der Bundeswehr München
 Neubiberg
 code@unibw.de

Prof. Dr. Gabi Dreö Rodosek
 Forschungsinstitut CODE
 Universität der Bundeswehr München
 Neubiberg
 code@unibw.de

A training ground for cyberspace – recent research activities on the subject of cyber ranges

The number and quality of cyberattacks are increasing constantly, presenting a challenge in terms of efficient detection and countermeasures. The Cyber Defence and Smart Data Research Institute (RI CODE) of the Bundeswehr University Munich, is exploring possible applications of so-called cyber ranges – virtual training environments that allow realistic education and training of IT professionals in the field of cybersecurity and effective response to the emerging challenges.

The defence of communication networks against cyberattacks is based on the constant use and monitoring of a variety of cybersecurity tools. Knowing about any operational vulnerabilities in one's own network is a key element when it comes to establishing a comprehensive cyber defence strategy. The increasing interconnection of devices, the growing complexity of systems, and the diversity of the tools available to potential attackers means that administrators face an ever greater task to defend their own IT infrastructures. Added to this, there is a glaring need for well-trained IT personnel.

Cyber ranges offer possibilities for IT professionals to train how to handle cybersecurity tools, and for teams to practice predefined playbooks and courses of action when cyberattacks arise. Cyber ranges transport the concept of training areas and flight simulators to cyberspace by providing isolated environments in which, on the basis of realistic scenarios, it is possible to acquire and practice skills and abilities.

Research activities at RI CODE include the analysis and further development of cyber range concepts and technologies, focus-

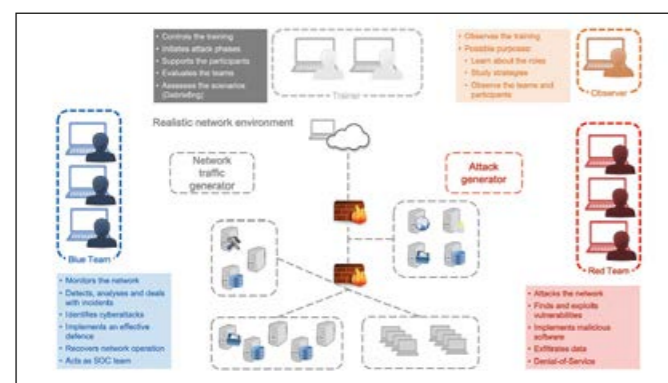


Fig. 1: Example of the structure of a cyber range environment and possible roles

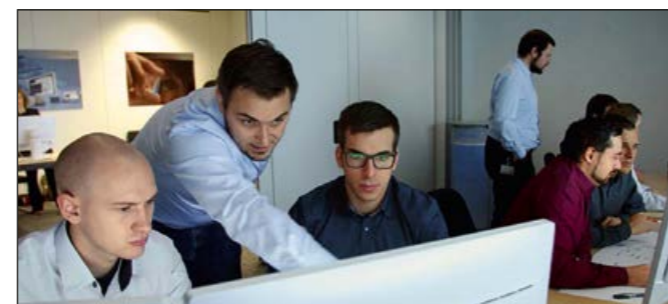


Fig. 2: Students of the Bundeswehr University, Munich, during an exercise in a cyber range

ing especially on the advancement and implementation of new scenarios.

By using automation technologies, where possible, processes are being developed to encompass military and other high-security networks and systems and map them in a cyber range. Ways are also being explored, together with project partners, to generate realistic network traffic synthetically with the aid of machine learning approaches. This is to create a possibility for training military and civilian IT professionals efficiently and under realistic conditions on specific systems. An environment is also being created whereby technology and system developments can be tested without negatively impacting productive networks.

Market research has initially been conducted to review and evaluate the diverse approaches regarding cyber range environments. Defining the criteria necessary for the evaluation has formed an essential part of this process, with the flexibility and extensibility of cyber ranges being identified as very important requirements. New elements, including physical components and systems and operational technology in particular, should be simple to integrate. Simple implementation of new scenarios and test cases is also essential for practical use. A cyber range solution has ultimately been identified that best meets the requirements and is to be set up at RI CODE in the first quarter of 2019.

It is, furthermore, being examined in the cyber range context how to integrate the new technological possibilities into the academic syllabus for specific target groups. Bachelor and master students from the fields of computer science (CS), busi-

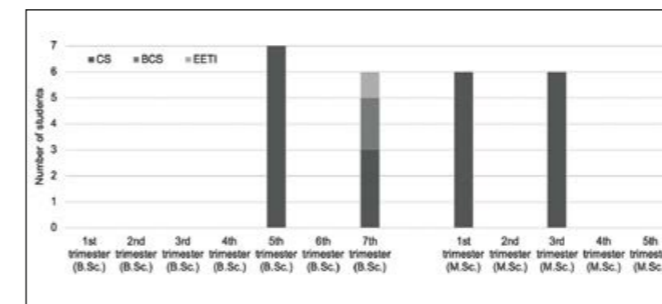


Fig. 3: Breakdown of test exercise participants by study course and trimester

ness computer science (BCS), and electrical engineering and information technology (EETI) at the Bundeswehr University, Munich, have completed test exercises in a first empirical study (Fig. 3). After the exercises the participants evaluated the subjective degree of difficulty and usefulness of a cyber range for their studies. While all the students rated the exercises as useful, a varied picture emerged where the subjectively perceived degree of difficulty was concerned (Fig. 4).

The research in this field will be expanded significantly once the set-up of the cyber range at RI CODE has finally been completed. It will also be included in the curriculum for the new masters course in cybersecurity at the Bundeswehr University, Munich. Ultimately, the knowledge gained from the research activities will form a valuable basis for the future use of cyber ranges in the armed forces as well as the civilian economy.

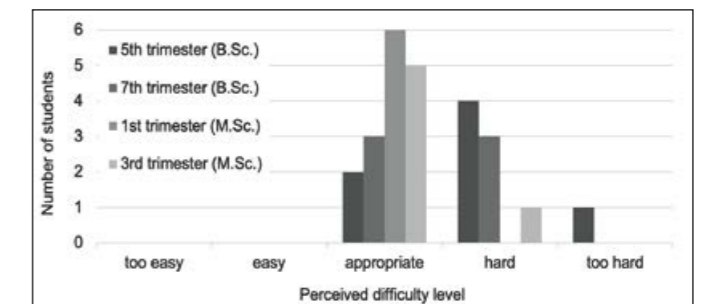


Fig. 4: Difficulty of the conducted test exercises as subjectively perceived by the participating students

Klement Streit, M.Sc.
Forschungsinstitut CODE
Universität der Bundeswehr München
Neubiberg

code@unibw.de

Prof. Dr. Gabi Dreo Rodosek
Forschungsinstitut CODE
Universität der Bundeswehr München
Neubiberg

code@unibw.de

Security analysis of Software Defined Radios with IP-capable waveforms at Research Institute CODE

Software Defined Radio (SDR) technology and IP-supported transmission enable soldiers in the field to exchange different types of data via a Mobile Ad-Hoc Network (MANET). Such data include Voice over IP (VoIP), imagery, video streams and situational information. In the context of such data types, the current research project is examining suitable encryption and transmission techniques in MANETs with the aim of complying with data type-specific Quality of Service (QoS) requirements.

Radio communication architecture in the military sphere is on the threshold of a new era. So-called SDR technology, which is being fielded as the future means of radio communication, has various functionalities, such as IP-based transmission by means of high data delivery rates, and the formation of ad-hoc networks, or MANETs. It will consequently be possible to connect previously and, in most cases, non-interoperable legacy radio technology to the new system and provide communication extending beyond a particular armed service (Fig. 1).

The future higher-bandwidth waveforms available with SDR offer a high tactical potential and great flexibility, enabling mixed-mode transmission of voice and data simultaneously in the MANETs as well as other transportable, quasi-static networks. This involves new requirements with regard to transmission, routing, and security. Given the dynamically changing network topology and extensive theatres of operation, there are many different threat scenarios against which these networks need to be secured. Far-reaching research issues have, therefore, to be investigated in this connection.



Fig. 1: The BOXER transport vehicle and the PUMA armoured personnel carrier are being equipped for now with "SVFuA" (multiservice networkable radio equipment)

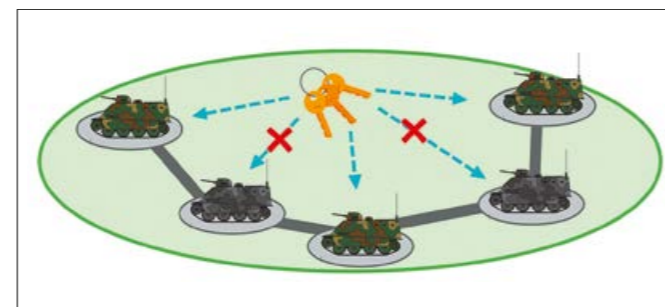


Fig. 2: Efficient exchange of secret keys with selected participants

In view of cyber security, the research is focusing on the following areas: efficient and secure key exchange techniques, data type-specific encryption, and anomaly detection with the aid of Intrusion Detection Systems (IDS). Key exchange techniques serve to ensure secure communication of the secret keys with the intended participants. Using existing techniques as a basis, a Group Key Management (GKM) concept customised for the Bundeswehr has been developed which ensures that only group members have access to the transmitted data (Fig. 2).

Where encryption is concerned, commonly used methods and their suitability are being tested and evaluated for different communication techniques (streaming, file transfer) and their data types (video, VoIP, situation pictures etc.) in MANET environments.

The research concerning anomaly detection in MANETs is focusing on various attack vectors and security measures aided by self-learning methods.

Besides the safety-critical aspects, it is important that the data transmission methodologies comply with the QoS requirements. As a result, existing routine algorithms and signal transmission techniques are being tested and upgraded to guarantee the required quality. One possible solution is to distribute the transmission of the data types according to the participants in the MANET (Fig. 3). A further project goal is to analyse and evaluate known protocols, such as the border gateway protocol (BGP), transport control protocol (TCP) and domain name system (DNS), for their possible use in a MANET environment.

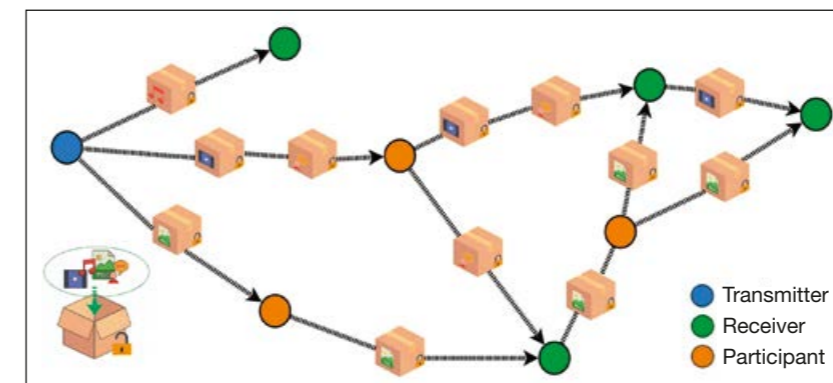


Fig. 3: Transfer of different data types in a MANET

This project is being conducted in cooperation with the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw), the Fraunhofer Institute for Communication, Information Processing and Ergonomics (FKIE), the Fraunhofer Institute for Integrated Circuits (IIS), and Bundeswehr Technical Centre (WTD) 81. The research findings are also being presented at scientific conferences as well as input directly into product development.

Prof. Dr. Gabi Dreo Rodosek
 Forschungsinstitut CODE
 Universität der Bundeswehr München
 Neubiberg

Hptm Marcus Knüpfer, M.Sc.
 Forschungsinstitut CODE
 Universität der Bundeswehr München
 Neubiberg

code@unibw.de

code@unibw.de

Moving Target Defence – a new paradigm in cybersecurity

Traditional IT systems and networks are normally based on static configurations. This is no longer adequate in times of targeted and persistent attacks (so-called Advanced Persistent Threats). Moving Target Defence offers greater cybersecurity by dynamically reconfiguring the attacked surface and thus reducing static vulnerabilities.

The battle ongoing between attackers and defenders in cyberspace has reached an unprecedented level of maturity and complexity. While defenders are looking to new detection and response tools, attackers are developing diverse techniques and methods to bypass these mechanisms. In a worst-case scenario it is sufficient for an attack to exploit a single vulnerability to be successful, whereas successful defence involves securing the entire system. This asymmetry clearly demonstrates the need for a new paradigm to improve cybersecurity.

Usually, deception technologies are among the methods preferred by an attacker. Surprise and uncertainty offer the attacker an inherent advantage over the defender, who is unable to predict the attacker's next move. Moving Target Defence (MTD) techniques do away with the static security mechanisms and constitute a new paradigm by creating uncertainty on the part of the attacker. Controlled changes at different IT levels (network, platform, application) create a dynamically adapted attack surface, thus significantly increasing the difficulty and, consequently, the work effort and cost involved in conducting a successful attack.

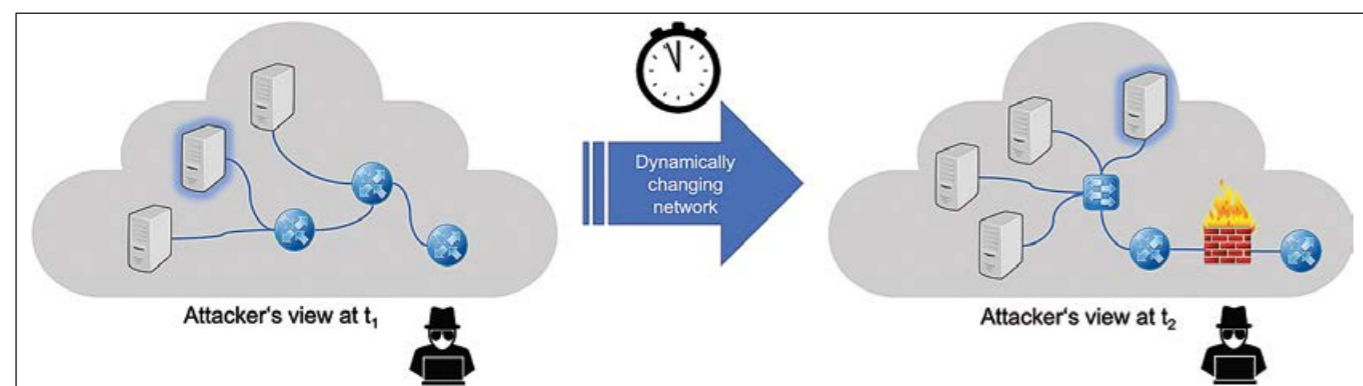


Fig. 1: Example illustrating the MTD paradigm applied at network level

Dr. Daniela Pöhn
 Forschungsinstitut CODE
 Universität der Bundeswehr München
 Neubiberg

code@unibw.de

Dipl.-Inf. Volker Eiseler
 Forschungsinstitut CODE
 Universität der Bundeswehr München
 Neubiberg

code@unibw.de

Software-Defined Networking (SDN) technologies, furthermore, offer the possibility to make rigid, monolithic network architectures more flexible by virtualising essential network services and separating them from the hardware. SDN hence provides excellent possibilities for implementing the MTD paradigm at network level.

An analysis of the research landscape shows that, at network level, there is increasing development of MTD concepts that implement SDN as a key technology. It is also found that the evaluation of new concepts is mostly limited to special application scenarios, while comparative studies and efficiency analyses are hard to find. The activities at Research Institute CODE are looking to address this.

The state of the art regarding MTD has been identified and evaluated in an initial step. Key aspects of the research include the identification, evaluation, selection and further development of MTD technologies, with the focus being on their use in military and high-security networked systems. With a view to developing a vector enabling the comparison and selection of MTD techniques, evaluation criteria have been extracted that permit a comparative examination, namely of reliability, integrity, diversification, randomisation, scalability, overhead, and system-specific practicability. On this basis it is possible

to compare existing and future MTD technologies, expressly including efficiency in a specific system. Work is currently focusing on the design and set-up of a test environment to compare SDN-based MTD technologies.

Although the MTD approaches appear to be very promising, the research in this field is still in its initial stages. Defining an attack surface and possible transformations, functional equivalency, and integration into existing environments, are examples of issues that are unresolved. Also, the focus is shifting to SDN-based MTD technologies in particular, with the aim of developing a reliable, trustworthy and resilient network infrastructure, which is essential both for military and for civilian use.

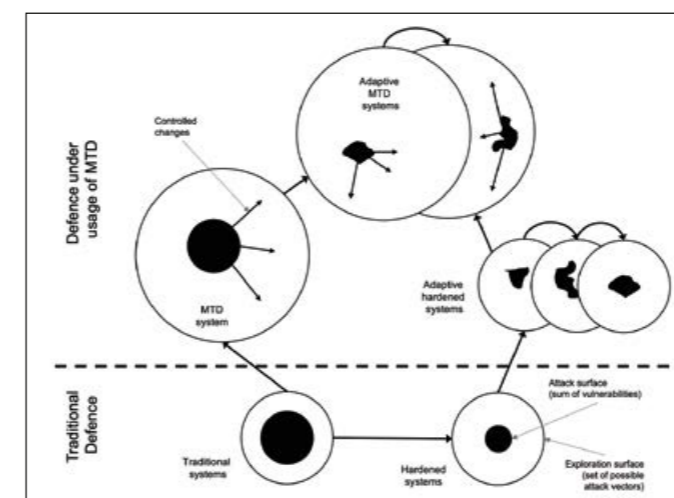


Fig. 2: Schematic diagram illustrating the ideas and principles of MTD

RDir Dr. rer. nat. Stefan Köhne
Wehrwissenschaftliches Institut für Schutztechnologie –
ABC-Schutz (WIS)
Munster

wis220bdetektion@bundeswehr.org

ORR Dr. rer. nat. Sylvia Schirmer
Wehrwissenschaftliches Institut für Schutztechnologie –
ABC-Schutz (WIS)
Munster

wis220bdetektion@bundeswehr.org

Lateral flow assay for biological agent simili

Detecting biological warfare agents is an important capability for the CBRN defence forces of the Bundeswehr, so as to identify potential dangers and initiate appropriate follow-up measures as early as possible. A lateral flow assay for biological agent simili has been developed for training in the field under realistic conditions.

Beyond the classic, purely military threats, manifold and, in some cases, completely new challenges have emerged for the Bundeswehr when on operations. Because of the internet there is a burgeoning pool of information available concerning methods and procedures for producing so-called “handmade/homemade” CBRNE warfare agents in “garage laboratories”. As a result, the potential risk posed to the forces in the field is constantly increasing. Classed as biological warfare agents are pathogens or toxins which can cause infectious diseases or poisoning in humans, animals or plants. Wide-ranging possibilities to rapidly detect and identify such agents are required in order to protect our military forces. A defined workflow comprising sampling as the first step and adhering to the “Chain of Custody” would create the conditions needed for later laboratory-based, legally valid verification.

As part of the sampling equipment, the Bundeswehr is provided with commercially available lateral flow assays (LFA) for the detection of biological warfare agents. These rapid tests are purely qualitative in terms of their detection capability and combine thin-layer chromatography with immunostaining.



Fig. 1: Sampling exercise



Fig. 2: Handling of the lateral flow assay

Dipl.-Ing. (FH) Corinna Schache
Wehrwissenschaftliches Institut für Schutztechnologie –
ABC-Schutz (WIS)
Munster

wis220bdetektion@bundeswehr.org

A warfare agent (antigen), which is in a liquid phase, is bound specifically to a target structure (antibody) on a membrane. Antibodies labelled with gold colloids bind themselves to the antigen, resulting in coloured test line visible to the naked eye. An additional control line indicates the validity of the rapid test. Because of its small size (approx. 110 mm x 30 mm), easy handling and fast display of results (within 20 minutes), the LFA technology is widely used in human and veterinary medicine as well as food safety.

The use of LFA for education and exercises in the field under simulated realistic conditions would sharpen the senses of the Bundeswehr’s CBRN defence personnel with regard to structured workflows, their own confidence in and knowledge of the effectiveness of the applied methods/procedures, the identification of possible risks, and strict compliance with protective measures. As German legal regulations (e.g. Ordinance on Biological Agents, Infection Protection Act) prohibit any handling of biological warfare agents outside of special laboratories, a lateral flow assay for the protein ovalbumin has been developed within the context of a technical and scientific study initiated by the Bundeswehr Research Institute for Protective Technologies and CBRN Protection (WIS), in collaboration with Göttingen-based enterprise miprolab, as a simulant for toxins. Following two years of intensive research activities, the first production

batches have been undergoing testing and evaluation at WIS since early January 2018. Having yielded promising preliminary results thus far regarding sensitivity, specificity and storage stability, further analyses concerning matrix effects and environmental samples are planned for 2019.

To secure the intellectual property for the Bundeswehr, a utility patent titled “Lateral Flow Assay for B agent simili” was applied for, and the invention was accepted on 17th January 2018, in accordance with §§ 6 para. 1 and 7 “Act on Employees’ Inventions”, for the Federal Republic of Germany. The purpose-driven R&T activities and the development of a lateral flow assay for biological agent simili have led to an important module being generated for the support and qualification of Bundeswehr CBRN defence personnel.



Fig. 3: LFA: Testing of sensitivity with ovalbumin solution (100 ng/ml), and testing of specificity (cross-reactivity) with fetal calf serum (FCS)

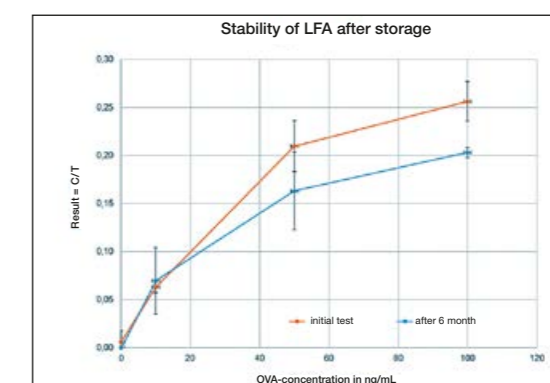


Fig. 4: Storage stability of LFA after six months.

Dipl.-Ing. Bodo Gudehus
Wehrwissenschaftliches Institut für Schutztechnologien –
ABC-Schutz (WIS)
Munster

Dipl.-Phys. Berthold Römer
Wehrwissenschaftliches Institut für Schutztechnologien –
ABC-Schutz (WIS)
Munster

WISPosteingang@bundeswehr.org

WISPosteingang@bundeswehr.org

Neutron radiation hardening of autonomous systems

This study addresses a procedure for hardening complex electronic circuits by means of radiation, the objective being to protect military materiel from nuclear weapon effects. The study findings are also of importance for aerospace applications and for autonomous vehicles operating in a heavily radiation-exposed environment.

The study is being conducted by the Bundeswehr Research Institute for Protective Technologies and CBRN Protection (WIS) in Munster in collaboration with the Institute for Automation Technology at the Helmut Schmidt University / Bundeswehr University Hamburg.

Autonomously operating vehicles, i. e. those without a human operator, make it possible in principle to avoid environments or situations that are potentially dangerous for humans. This also applies particularly to areas heavily contaminated with ionising radiation. Yet, if the intensity of the radiation is very high, it can not only cause long-term consequential damage but also have acute immediate effects. As autonomous systems are designed to operate independently, they have to reach decisions on the basis of sensor data and target settings (for example, on the route to take). Their autonomy also means, however, there are higher expectations regarding the reliability of the technical system.

Previous research has looked at the sensitivity of individual components needed for complex electronic systems and shown

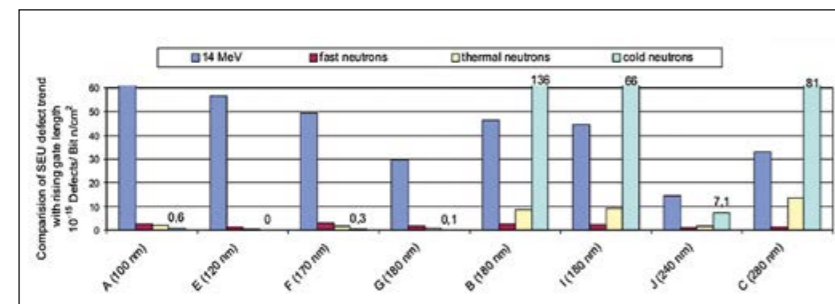


Fig. 1: Varying sensitivities of different memory components (A-G) for three different neutron energy spectra and for 14 MeV, as a function of CMOS technology (gate length), normalised to memory size, neutron flux and exposure time

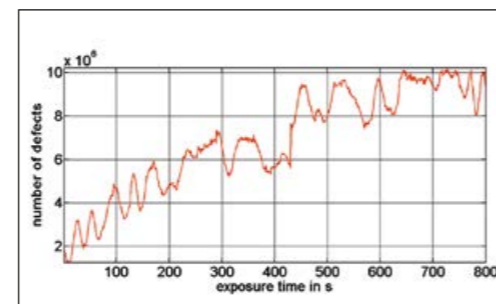


Fig. 2: Development of colour errors of a CCD camera during neutron irradiation. The flux density here is around 1.2×10^8 n/s cm² for fast neutrons and 0.6×10^8 n/s cm² for thermal neutrons

Dr.-Ing. Jürgen Zabel
Helmut-Schmidt-Universität / Universität der Bundeswehr Hamburg
Hamburg

forschung@hsu-hh.de

that, especially in the case of neutron radiation occurring during nuclear fission, the difficulties caused by Single Event Upsets (SEU) increasingly arise. SEUs are corrupted data which, although they do not permanently damage components or devices (soft error), they can however cause serious disturbances in electronic circuitry during operation and are therefore highly relevant in regard to system reliability.

One product of this research is a comparative diagram of the sensitivities of individual SRAM devices as a function of different neutron energies and technology (Fig. 1).

Another focal point has been the analysis of camera sensors (CCD and CMOS technology). This has involved recording different images before, during and after exposure to neutron radiation and evaluating them with regard to the change in the colour values of the individual pixels. Each pixel comprises three values for the colour information (RGB standard), with each value varying between 0 and 255. The total error count results from the sum of the colour discrepancies (Fig. 2).

The influence of different materials for casings and for shielding against radiation is also being explored. However, at least where suitable casing material thicknesses of up to 2 mm are concerned, there have been no significant reductions in error

rates at exposure levels equivalent to a fission spectrum with an energy distribution of around 1.6 MeV.

The findings have been used to develop an autonomous model system (Fig. 3) for exploring and evaluating radiation hardening measures. Serving as a basis are components which are not explicitly marked as radiation-tolerant but, through the research, have been identified as such, so as to thus utilise commercially available, lower-cost, parts. The radiation tolerance has been verified within the framework of testing conducted at the FRM 2 research reactor in Garching using a suitable test set-up (Fig. 4).

The testing at FRM 2 showed that a sensor necessary for vehicle navigation failed, preventing the model system from moving any further. The two microcontrollers that monitor each other continued to work without failure, such that the operating system also remained active in the event of a controller failure. With the exception of one electronic device, all the components selected for the model system withstood the neutron exposure in FRM 2. The resistance to radiation has to be improved, however, something which can be verified by using two physically independent sensors, for example.



Fig. 3: Autonomous model. Vehicle with infrared navigation and LCD display for status indication, light detection, and sensor for measuring the radioactivity

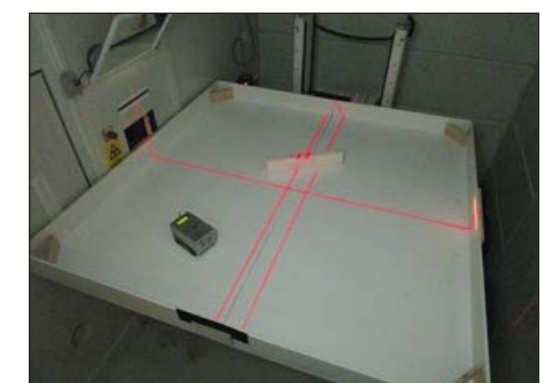


Fig. 4: Test course at the FRM 2 research reactor in Garching/Munich. The reactor is operated by the Technical University of Munich

Timo Watzelt, M.Sc.
Wehrwissenschaftliches Institut für Schutztechnologien –
ABC-Schutz (WIS)
Munster

WISposteingang@bundeswehr.org

ORR Dr.-Ing. Jeldrik Moritz
Wehrwissenschaftliches Institut für Schutztechnologien –
ABC-Schutz (WIS)
Munster

WISposteingang@bundeswehr.org

Development of a nature-identical inorganic particle test water

To prove the suitability of mobile water treatment plants, the Bundeswehr requires test waters that reflect nature-identical loads of surface waters.

In military operations, the Bundeswehr must be able to secure its drinking water supply from surface waters (see Fig. 3). In a field camp, the treated drinking water is not used only for direct consumption, but also for sanitary facilities, food preparation, medical services, laundries, decontamination systems, and also for the construction of drinking water wells.

The Bundeswehr has fielded state-of-the-art mobile water treatment plants for the production of drinking water from surface waters. The plants are based on reverse osmosis as the main filtration stage. This technology can remove practically all substances dissolved in water if the input water is almost particle-free. However, to produce almost particle-free input water in a first treatment step is technically a very demanding task, because every surface water is different in its composition. In general, reverse osmosis based plants must be protected from undissolved substances such as algae, humic substances, polysaccharides and inorganic particles. Prefiltration technology has to be suitable in such a way that drinking water production is also possible from waters containing these pollutants.

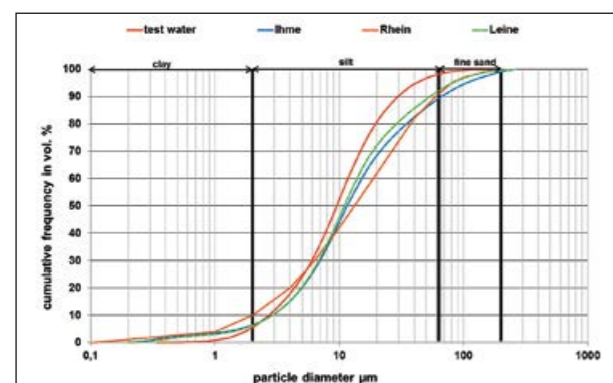


Fig. 1: Particle size distribution of the test water and of natural waters



Fig. 2: Particle test water

The extent to which water may be polluted so that it can be considered worthy for treatment is described in DIN 2001-3 based on sum parameters of water quality.

So far, there has been no suitable test method available for conducting a reproducible and nature-identical simulation of these water quality parameters, which is why the Bundeswehr Institute for Protective Technologies and CBRN Protection (WIS) has developed an inorganic test water to close precisely the testing gap for mobile water treatment plants.

A starting point for the development was the important recognition that, firstly, inorganic particles are often responsible for turbidity, especially during floods, and, secondly, that these particles often consist of the minerals kaolinite, quartz and iron oxide.

Kaolinite has covering properties due to its molecular platelet structure, while quartz has abrasive properties on account of its sharp-edged crystal structure, and iron oxide has colouring and abrasive properties. The aforementioned insoluble minerals were selected for the solid content of the test water so as to preserve the natural combination of properties.

In addition to the material properties, the particle size distribution is of major importance for the selection of suitable filter materials, with the consequence that the test water must have a particle size distribution that is reproducible and on the same time close to nature-identical.

A further finding of particular importance for the development of the natural particle size distribution was that the particle



Fig. 3: Fayzabad raw water source (Source: Häser, BAAINBw U.3.1)

size distributions in natural surface waters do not differ from one another very much.

Given this fact, an average and natural particle size distribution in suspension was achieved by mixing a specified ratio of two different test dusts. (see Figs. 1, 2 and 4).

The particle size distribution is, however, influenced by the pH value and by the ion composition of the water. The salt concentration and composition were chosen so as to be comparable to those of river water.

Using the developed particle test water, WIS can reproduce inorganic particle loads of typical surface waters, thus enabling nature-identical testing of water treatment technologies. For the first time ever, the test water enables reproducible and concurrently nature-identical qualification conditions for the testing of mobile drinking water treatment plants according to the requirements of DIN 2001-3.

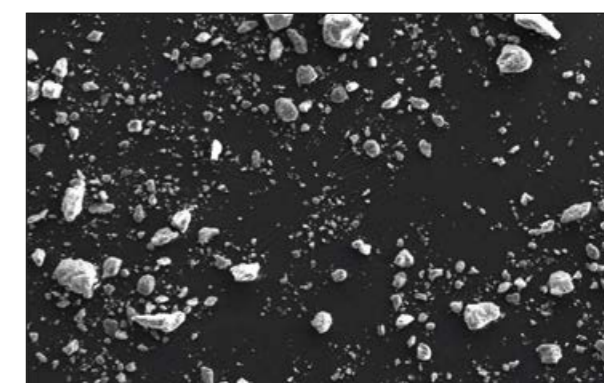


Fig. 4: Electron micrograph of the test water; 200 x magnification

Dipl.-Ing. Elisa Arian
Wehrwissenschaftliches Institut für Werk- und Betriebsstoffe (WIWeB)
Erding

wiweb@bundeswehr.org

Dr.-Ing. Jens Holtmannspötter
Bundesamt für Ausrüstung, Informationstechnik und Nutzung
der Bundeswehr (BAAINBw)
Koblenz

BAAINBwposteingang@bundeswehr.org

Structural adhesive bonding of high-performance thermoplastics

High-performance thermoplastics are finding increasing use for structural applications in aviation. They are proving to be of particular interest as matrix systems for fibre reinforced plastics. Also, new surface pretreatment processes developed at the Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB) offer the possibility to adhesively bond these materials robustly and reliably so as to realise new high-strength and high-performance lightweight aerospace structures.

Carbon fibre reinforced plastics (CFRP) with a thermoplastic matrix are growing in importance within the aerospace industry. High-performance thermoplastics such as polyetheretherketone (PEEK) offer high strength combined with high ductility over a wide temperature range. Their formability as well as improved recyclability compared with epoxy resins, speak for the use of these materials.

Where the joining of lightweight CFRP structures in manufacturing and repair is concerned, adhesive bonding is proving to be of great interest. It allows weight-efficient joints which, in contrast to other methods such as riveting or welding, do not involve any fibre damage or thermal input.

The poor adhesive properties of PEEK used to be a major disadvantage due to an absence of suitable surface pretreatment methods for a reliable build-up of adhesion. New pretreatment approaches have therefore been explored with the aim of realising high-strength adhesive bonds for CFRP with PEEK matrix systems.

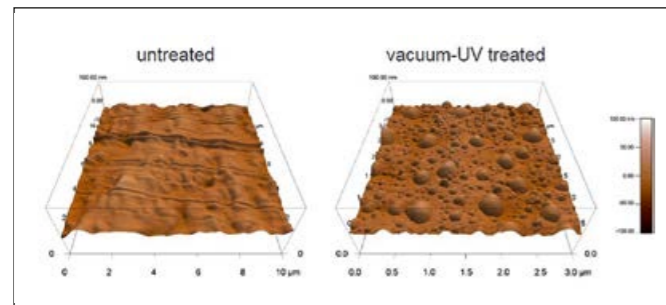


Fig. 1: Atomic force microscopy images of an untreated and vacuum-UV treated PEEK sample. (3x3µm scan area)

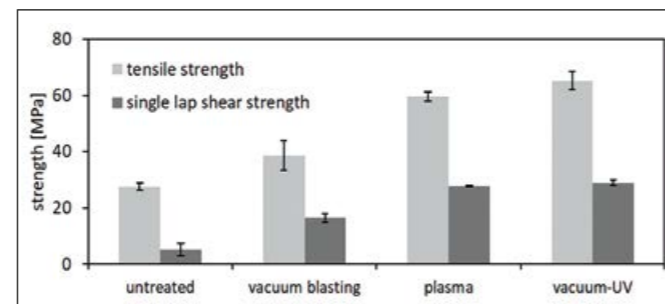


Fig. 2: Tensile strengths (butt joint) and shear strengths (single lap) of different surface pretreatment methods compared to untreated PEEK specimens

Various mechanical (grinding, blasting) and physical (plasmas, UV radiation) pretreatment methods have been assessed and optimised with regard to their effect.

Purely mechanical pretreatments such as grinding or vacuum blasting have led only to moderate bond strength increases compared with untreated PEEK specimens. Physical pretreatment methods such as low-pressure and atmospheric pressure plasmas as well as the use of vacuum UV radiation have, after intensive optimisation, led to significant strength increases. In addition to the adhesive bonding tests, the chemical and topographical changes modified by the treated surfaces have been thoroughly investigated with the aid of various surface analysis methods, such as photoelectron spectroscopy, atomic force microscopy, and contact angle measurements (Fig. 1). By doing so it has been possible to observe the effect of the pretreatment on the surface as a function of the method used and intensity.

Outstanding results have been achieved for PEEK through the use of novel vacuum UV sources, with high-strength adhesive-bondable surfaces being created after a short treatment time of just a few seconds (Fig. 2). During destructive testing of the bonded joints, the test pieces no longer fail along the bondline. Nor do the bonds show any kind of ageing effects in humid environments. The bonding process itself is also very robust. Pretreated surfaces can also be adhesively bonded to high strength even weeks later.

The new pretreatment strategies have already been successfully applied to other high-performance thermoplastics, such as polyethersulfone (PES) and polyetherimide (PEI).

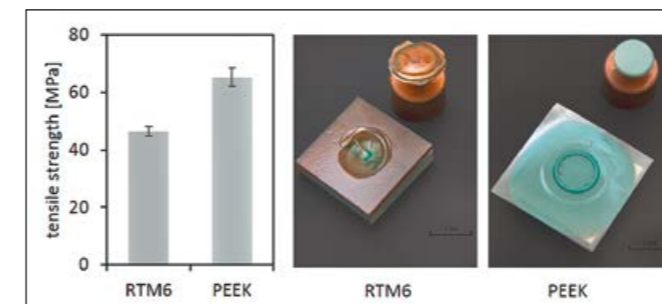


Fig. 3: Comparison of the maximum achievable strength of vacuum-UV treated butt joint specimens. The epoxy resin RTM6 shows a brittle failure, characterised by much torn-out material; the thermoplastic PEEK, by comparison, displays a ductile substrate failure very close to the surface

As Figure 3 shows, it is now possible in some cases to achieve significantly higher strength levels in bonded structures with thermoplastics compared with the so far used thermoset matrix materials (epoxy resins; in the present case RTM6). Because of their increased ductility, thermoplastics are able to reduce stress peaks better through local strain.

The knowledge that has been gained will lead to improved structural designs. It will be possible, for example, to combine the advantages offered by the global, high stiffness of duroplastic CFRP with the damage-tolerant material behaviour of thermoplastics. Figure 4 shows examples of single-lap shear joints in which thermoplastic films have been inserted in areas where strain is high. Static testing has shown a significant increase in the strength of the specimens containing thermoplastic films compared with "pure" thermoset CFRP specimens. Dynamic fatigue testing has also demonstrated significantly longer lifetimes of the bonded joints.

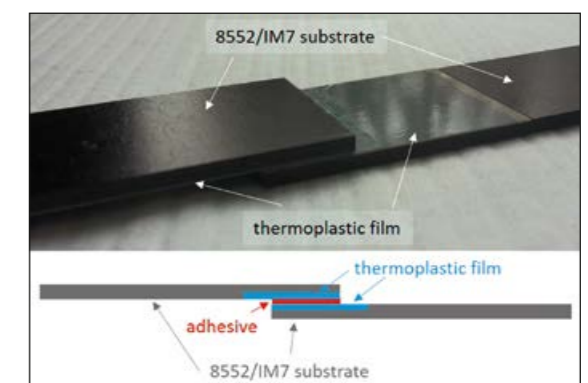


Fig. 4: Photo and schematic diagram of a CFRP (8552 / IM7) single-lap shear specimen modified with PEEK film

ORR Dr. rer. nat. Markus Spallek
Wehrwissenschaftliches Institut für Werk- und Betriebsstoffe
Erding

wiweb@bundeswehr.org

Temporary camouflage coatings for Bundeswehr equipment - A new approach to a well-known concept

Temporary camouflage coatings offer the possibility to swiftly match military equipment to its environment. External R&D projects and studies at the Bundeswehr Research Institute for Materials, Fuels and Lubricants have led to the development of environmentally friendly means for removing temporary camouflage coatings as well as to novel coating formulations based on sustainable raw materials.

Crises and military conflicts worldwide are on the rise. The number of deployments abroad and thus the presence of the Bundeswehr in various climate and vegetation zones is also increasing. As a consequence, standard camouflage coatings and so-called disruptive patterns in the visible and IR spectrum continue generally to be of very high importance for major defence equipment. Whether abroad or during training, it is appropriate to adjust the camouflage pattern of the equipment to the environment at the time.

A highly flexible camouflage concept is therefore needed which allows military equipment to blend into the environment at short notice and can be adjusted to particular weather conditions, such as snow. Removable paints can be used for temporary coatings, the aim being to repaint the military equipment in the requisite disruptive pattern tones for maximum camouflage effect and thus reduce detectability for enemy forces.

The camouflage concept should encompass camouflage application, suitable weathering resistance during service use, and full removal of the temporary coating after a mission or



Fig. 1: Landscapes typical of Bundeswehr missions and training exercises (from left to right / top to bottom: Afghanistan, Norway, Germany, Mali) serving as a basis for disruptive pattern planning



Fig. 2: Field-testing the stripping of removable paint from a Fuchs armoured carrier (APC)

redeployment, thus restoring the prior state (base coating) of the equipment. The focus of the R&T activities has been on developing a coherent and practical camouflage concept and on its thorough testing in the laboratory as well as in the field.

The Bundeswehr Research Institute for Materials, Fuels and Lubricants undertook initial studies in 2016, and these revealed inadequate removability of existing temporary coating systems, which was also substantiated under field conditions. Various means and methods for removing camouflage coatings were therefore tested as an emergency measure and, on that basis, a new approach subsequently derived. In close cooperation with industry partners, and by using novel, state-of-the-art technologies, the removal of temporary coatings has been made significantly more practical. At the same time, the ageing and weathering of the coatings have been analysed in extensive series of tests, leading to a new accelerated artificial weathering test. In late 2017, the composition of the camouflage coating itself was comprehensively analysed, and a new one developed in 2018. In this way it has been possible not only to give consideration to environmental aspects beside the camouflage concept itself, but also to incorporate already sustainable materials for use as a basis.

The outcome has been the development of a new, eco-friendly camouflage paint remover with improved properties, which is still undergoing trials at the Bundeswehr Research Institute for Materials, Fuels and Lubricants with a view to testing new sustainable and environmentally friendly removable paint compositions in 2019. It has also been possible to simulate the ageing of coatings by means of an optimised accelerated laboratory test. Several major items of equipment are currently undergo-

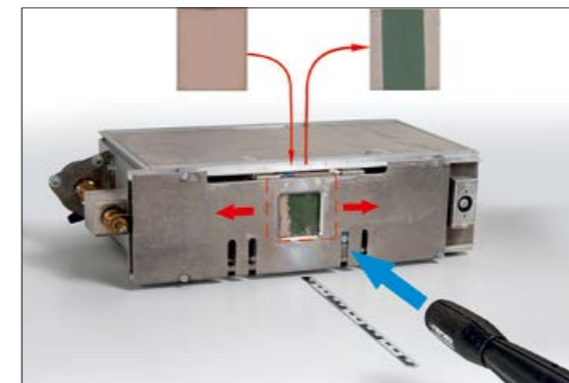


Fig. 3: Sled and high-pressure spray lance (bottom, right) for reproducible, lab-scale stripping of removable paints from small test pieces

ing field testing. The research activities are expected to lead to a completely new temporary camouflage coating concept that complies with the highest environmental standards through the use of state-of-the-art technologies. The primary goal is to make a means of temporary camouflage coating available to the Bundeswehr for its missions which is highly flexible, robust, transportable, as well as storable, and can be applied to a broad range of military equipment.



Fig. 4: Outdoor exposure test rig for weathering and stripping removable paints at the Bundeswehr Research Institute for Materials, Fuels and Lubricants

TORR Dipl.-Ing. (FH) Christian Mengel, M.Eng.
Bundesamt für Ausrüstung, Informationstechnik und Nutzung
der Bundeswehr (BAAINBw)
Koblenz

BAAINBwPosteingang@bundeswehr.org

OLt Sebastian Schmitz, M.Sc
Universität der Bundeswehr München
Neubiberg

info@unibw.de

WEASEL CSL: Light tracked armoured vehicle with lightweight hull designed as a CFRP sandwich structure

In cooperation with the Institute for Lightweight Structures at the Bundeswehr University Munich, a hull for light tracked armoured vehicles has been designed as a carbon fibre reinforced polymer (CFRP) sandwich structure and its various load application points subjected to life testing. Separation of the hull's protective and loadbearing functions makes it possible to reduce its mass significantly by 70 %.

A characteristic feature of conventionally designed tank hulls is that the protection level required in accordance with STANAG is the determining factor for dimensioning the outer hull's wall thickness. For lightly armoured tracked vehicles this can lead to a trade-off between parameters characterising vehicle body stiffness, such as torsional stiffness. If the vehicle body is too soft, this will then be impractical should, during vehicle operation, drive train or running gear vibrations stimulate the natural frequencies of the vehicle structure. Light tank hulls whose superstructures consist of a thin-walled metal weldment will thus, inevitably, have areas characterised either by excess or insufficient material. The latter is then the case, for instance, if the wall's metal thickness meets the requirements with regard to protection, but needs to be greater to ensure structural stiffness. Conventionally designed tank hulls, given their homogenous metal thickness throughout, are unsuitable for any topology-optimised, and hence weight-optimised, use of materials.

Separation of the protective function from the load-bearing function makes it possible to circumvent this with a hull opti-

mised in terms of both stiffness and lightweight design forming the basic structure, which is additionally hardened by means of externally bolted-on, adaptable, lightweight protective plates. An additional benefit of this separation is that the protection can be upgraded to the state of the art simply by exchanging modules. Even a mission-specific protection configuration is conceivable, thus affording the user additional leeway where the payload is concerned.

It is with this in mind that, in cooperation with the Institute for Lightweight Structures at the Bundeswehr University, Munich, a lightweight tank hull has been designed whose outer hull consists of a CFRP sandwich structure. Besides analysing the contours characteristic of various commercially available tracked vehicles and determining the torsional stiffness of the Wiesel 2 hull by bench testing when designing the vehicle layout, consideration was given to current, innovative research projects being conducted in the fields of propulsion, running gear, armament and ergonomics.

Taken into account as boundary conditions for the subsequent FEM calculation were not only the force effects introduced via the running gear into the structure, but also the driving forces, and the weight force of the modular lightweight protection elements and weapon system, including the recoil forces. The orientation and number of layers, and the cell size and thickness of the honeycomb core were varied and simulated until the lightest layer assembly was found, while giving suitable consideration to the required torsional stiffness. To validate the calculations, a side panel segment of the CFRP hull was fabricated which includes the connection location for a hydro-pneumatic spring damper element as a load introduction point.

Similar to the hull-side upper screw connection for the hydro-pneumatic spring damper element on the WEASEL HYDROP vehicle demonstrator, this segment was also subjected to life testing on a servo-hydraulic vibration test rig.

The successful testing confirmed the simulation results, which reveal an impressive reduction in mass of approximately 70 %. This, in turn, offers the possibility to attach lightweight protection elements. In situations where the protection aspect of a mission is not the primary goal, the full potential of such a weight reduction can be utilised by removing the protective modules, thus yielding significant improvements with regard to the handling dynamics.



Fig. 1: Wiesel 2 hull torsion measurement on a 4-actuator running gear test bench (WTD 41-GF 220)



Fig. 2: Life testing on a servo-hydraulic vibration test bench (WTD 41-GF220)

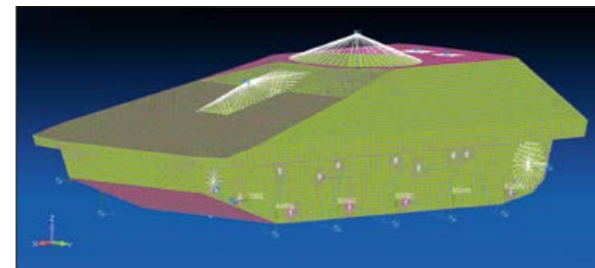


Fig. 3: WEASEL CSL: Visualisation of the force application points and the constraints for the FEM calculation (FEM = Finite Element Method)

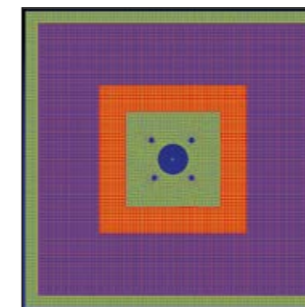


Fig. 4: FEM illustration of the layer assembly in the area of load introduction

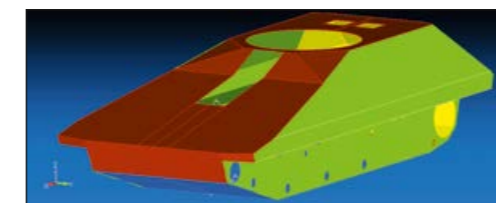


Fig. 5: CAD model of a future lightweight tracked vehicle with a CFRP hull (WEASEL CSL)

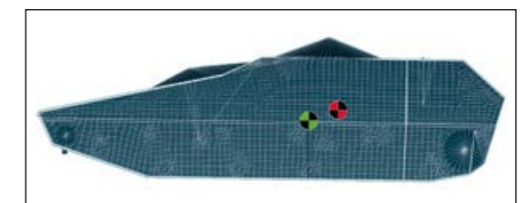


Fig. 6: CAD model: side view of a future lightweight tracked vehicle in CFRP design (WEASEL CSL)

TORR Dipl.-Ing. (FH) Christian Mengel M.Eng.
 Bundesamt für Ausrüstung, Informationstechnik und Nutzung
 der Bundeswehr (BAAINBw)
 Koblenz

BAAINBwPosteingang@bundeswehr.org

WEASEL S38: Downsizing of a two-stage supercharged lightweight engine

In cooperation with Trier University of Applied Sciences, a downsized, two-stage supercharged three-cylinder diesel engine has been developed with the aim of enhancing performance with regard to torque, engine mass and specific fuel consumption and of using it as a drive system for future light tracked and wheeled vehicles, either as a pure internal combustion engine or as a hybrid solution.

As part of an R&T project entitled “Future Drive Concepts”, and in cooperation with the Institute for Automotive Engineering of Trier University of Applied Sciences, a downsized, two-stage supercharged three-cylinder diesel engine has been developed which can serve as a retrofit solution for existing light wheeled and tracked vehicles. It could, as an integral part of hybrid drive train structures, also represent the main form of drive for future lightly armoured vehicles.

In the course of making a rough pre-selection of suitable basic engines, existing drive trains of the Wiesel 1 and Wiesel 2 weapon carrier systems have initially been analysed with regard to torque pattern, specific fuel consumption and mass of the internal combustion engine, and the findings compared with the present generation of highly supercharged combustion engines / current state of development. The analysis has also involved defining and subsequently measuring the most realistic driving profiles possible, which in turn has resulted in different performance requirements, depending on the driver, terrain topology, and the vehicle’s laden state. In correlation with individual values measured on a test rig, such as drag force,



Fig. 1: WEASEL S38 engine with two-stage Borg Warner Turbo Systems R2S charging assembly on the engine test bench (Trier University of Applied Sciences)

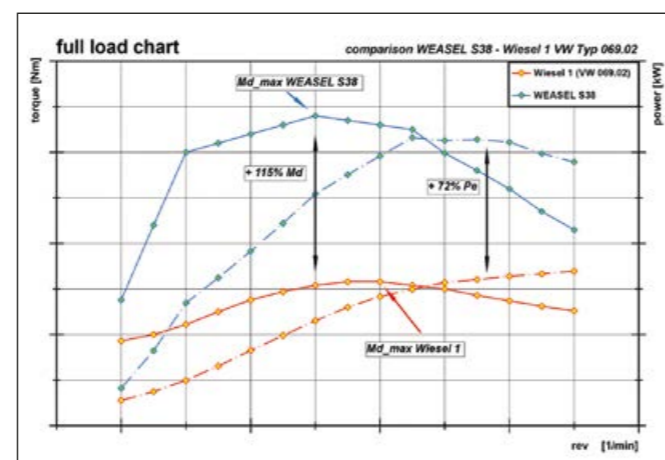


Fig. 2: Comparison of the torque and performance characteristic curve between WEASEL S38 and series-manufactured Wiesel 1 engine

it has been possible, in light of the current state of the art concerning feasible litre capacities, to identify an appropriate basic engine in combination with the requisite charging assembly.

Selected as a basic unit for this purpose has been a 1.5 litre three-cylinder common rail diesel engine produced by BMW whose cylinder capacity of 0.5 litres can be considered thermodynamically ideal and, because of its modular design, requires only relatively simple reinforcement of the crankshaft drive to cope with higher loads resulting from the exchange of individual high-performance derivative components.

In the further course of the research, the charging assembly has been re-designed with regard to torque pattern and maximum performance with the aid of simulations and analytical calculations, in order to reach the target values. The focus when designing the two-stage charging assembly, which includes a low-pressure and a high-pressure compressor, has been particularly on achieving a high torque just beyond idle speed (low-end torque) without compromising maximum performance.

It has consequently been possible to increase the maximum torque by 25 % compared with the basic unit to, in the meantime, 340 Nm, which corresponds to a peak value with regard to the effective intermediate pressure ($p_{me} = 28.5 \text{ bar}$). In comparison with the five-cylinder Wiesel 1 diesel engine that is in service, the values are even more impressive. By significantly increasing the maximum torque by 115 %, there has at the same time been the possibility to lower the specific fuel consumption by 25 % at the optimum operating point and reduce the engine mass by 50 %.

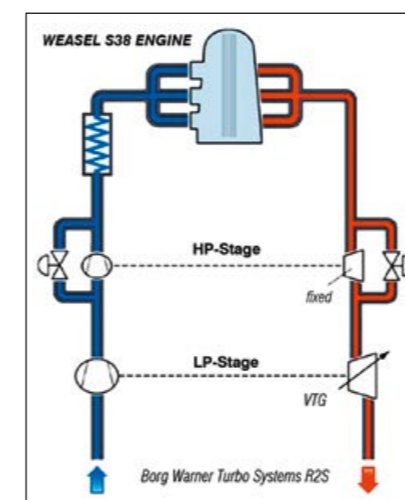


Fig. 3: Schematic diagram of the two-stage charging of the WEASEL S38 engine

The latter-mentioned aspect, in particular, coupled with the reduction of the space required for the drive system, now allows hybrid components such as a flywheel generator including associated power electronics and energy storage device to be accommodated in the drive train with almost no weight impact. Intelligent control of this parallel hybrid structure could further enhance both the overall performance potential, thanks to a possible boost function, and the efficiency of the drive train.

As the project progresses, the intention, in addition to coordinating the dynamic control unit parameters during the driving tests, is to realise or integrate further lightweight features, such as a CFRP intake module, an air-water charge-air cooler manufactured by 3D metal printing and incorporated into the air pathway, as well as a lightweight dry-sump lubrication system.

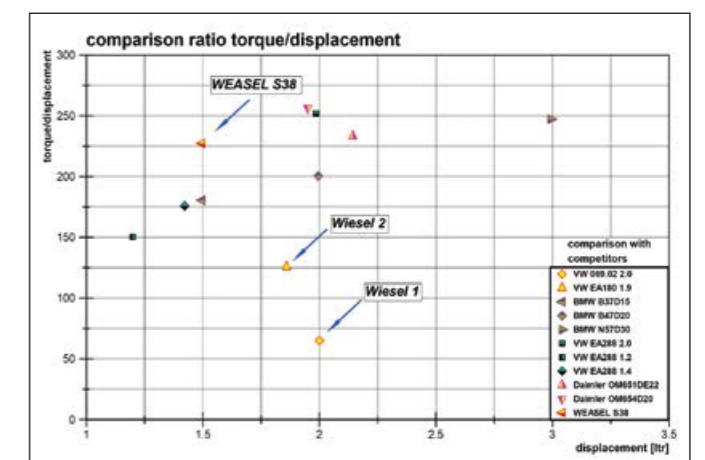


Fig. 4: The WEASEL S38 engine has the highest torque/displacement ratio in its displacement class

TORR Dipl.-Ing. (FH) Christian Mengel M.Eng.
 Bundesamt für Ausrüstung, Informationstechnik und Nutzung
 der Bundeswehr (BAAINBw)
 Koblenz

BAAINBwPosteingang@bundeswehr.org

TRamtm Martin Ludes
 Wehrtechnische Dienststelle für landgebundene Fahrzeugsysteme,
 Pionier- und Truppentechnik (WTD 41)
 Trier

WTD41AF120@bundeswehr.org

WEASEL HYDROP: Lightweight tracked vehicle with hydro-pneumatic suspension system

Bundeswehr Technical Centre (WTD) 41 has, with the WEASEL HYDROP, developed and manufactured a further chassis demonstrator, which has a completely redesigned running gear with a hydro-pneumatic suspension system. The flexibility thus gained with regard to the chassis set-up, coupled with an increase of both spring travel and road clearance, significantly improves the vehicle dynamics.

Options for optimising the running gear of light tracked vehicles have already been identified in the past through research into various intelligent suspension systems conducted on the WEASEL eDK2 (electric damper control). Compared with the Wiesel 1 series configuration, it has been possible, by means of an electrically interlocked frequency-selective damper (KONI FSD eLockout), to improve hit accuracy during firing operation by 80%, as well as driving safety to a significant degree.

The WEASEL HYDROP with its hydro-pneumatic running gear is the logical further development of previous chassis demonstrators, providing the opportunity to test and evaluate a variety of chassis on a tracked vehicle with the aim of identifying the ideal chassis based on future tracked vehicle requirements. Besides the improvement of mine protection through the elimination of chassis components in the crew compartment, the installation of Hydrop on the outside of the vehicle offers the flexibility which is needed for the design of variable chassis geometries, and is indispensable for the realisation of height-adjustable running gear. A further benefit of the weight-neutral



Fig. 1: WEASEL HYDROP: The track rollers and return rollers are made of CFRP (Capricorn Composite GmbH)



Fig. 2: WEASEL HYDROP: Bonnets and covers are made of aluminium foam sandwich AFS (pohltec metalfoam GmbH)



Fig. 3: WEASEL HYDROP: With a ground clearance of 400mm, it has 100mm greater spring travel than the Wiesel 1

replacement of torsion bar springs and shock absorbers by a hydro-pneumatic suspension system (Hydrop) is variability of the spring characteristic line, which is defined by the filling pressure of the gas. In combination with an intelligent control arrangement, it is possible to achieve the functionality of a semi-active chassis and thus find the ideal compromise between driving safety and driving comfort at all times, depending on the driving situation.

Hydrop has been designed and developed as a lightweight system in cooperation with enterprise Hemscheidt. Its integration into the existing Wiesel 1 basic vehicle has however required major changes, both to the hull and to the elements for attaching the running gear. For example, the changed load case has meant a complete redesign of the axle arm. It has also been necessary to integrate additional support rollers, relocate the track tensioner including optimised characteristic line into the interior of the vehicle, and have hull-side load introduction points to accommodate Hydrop along with the accompanying vehicle body stiffening elements.

Driving tests conducted both in rough terrain and on synthetic test tracks (swiss track and sine track) formed the basis for the final set-up involving multiple adjustments of the characteristic line, with considerably lower vehicle superstructure pitch angles coming about at comparable acceleration values at the driver's position. These were, on average, 20 % below the values for the series configuration. The resulting improvement in the driving safety of the Hydrop running gear consequently allowed significantly higher obstacle crossing speeds. As a final measure, a comparative test drive was conducted in rough terrain with the WEASEL eDK2, which was equipped with FSD dampers.

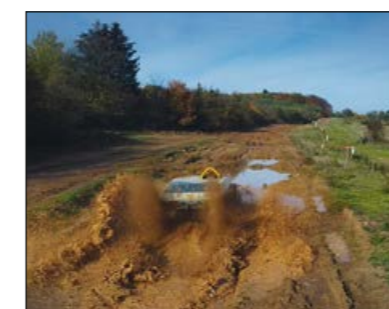


Fig. 4: WEASEL HYDROP: Impressions of the comparative test drives in heavy terrain at WTD 41

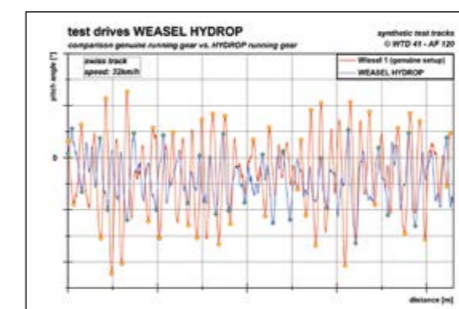


Fig. 5: Comparison of pitch angle deflection between WEASEL HYDROP and Wiesel 1 on swiss track

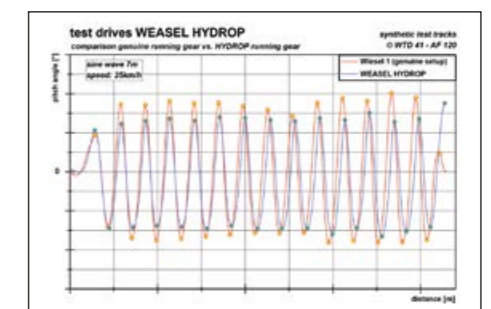


Fig. 6: Comparison of pitch angle deflection between WEASEL HYDROP and Wiesel 1 on 7m sine track

Because of its longer spring travel, its 100mm greater road clearance and its, tendentially, more softly calibrated superstructure spring, the WEASEL HYDROP showed its superiority particularly when it came to crossing obstacles and deep water holes, enabling it to rapidly complete the required obstacle course.

The driving tests performed by the WEASEL HYDROP have impressively shown that Hydrop is suitable for use on light tracked vehicles and, moreover, that it can significantly improve driving comfort and driving safety. Crucial advantages in comparison with conventional running gear systems lie in the flexibility for realising height-adjustable running gear and in the comparatively simple inclusion of semi-active functionalities. The integration of frequency-selective damper valves is conceivable, as is an interlocking function.

Harald Wehner
Fraunhofer-Institut für Chemische Technologie ICT
Pfinztal

info@ict.fraunhofer.de

Christian Teicht
Fraunhofer-Institut für Chemische Technologie ICT
Pfinztal

info@ict.fraunhofer.de

Phase Change Materials (PCM) and their possible applications in infrared signature management

An important aspect of efforts by units, facilities and assets of the Bundeswehr to protect themselves is the camouflaging of infrared (IR) signatures. Conspicuousities in the IR spectral range are usually the result of temperature differences between parts of an object or between the object itself and its background. The use of Phase Change Materials can help to reduce such conspicuities.

Classic IR camouflage systems are based on materials with a low emissivity or a high thermal convection coefficient. Combining such systems with PCM offers new possibilities for IR camouflaging. The thermal enthalpy of PCM enables it to store or release heat. This means that the material is able to absorb heat from an external source and store it in the phase change. Figure 1 demonstrates the basic principle of PCM camouflaging an electric power supply. The temperature of the PCM remains relatively constant for as long as the material stores heat over a particular period of time.

The aforementioned principle serves as the basis for using PCM to camouflage objects. One example in this regard is the heat generated by the brakes of a vehicle as the vehicle slows down. A PCM device can partly absorb the generated heat and thus reduce the radiation pattern. The image sequence in Figure 3 shows this application of PCM in a first experiment. This principle allows effective protection of hotspots from IR sensors for a certain duration.

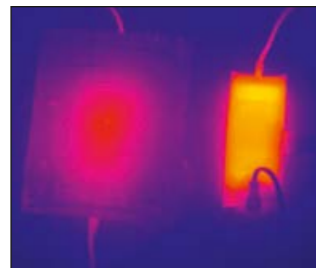


Fig. 1: IR camouflaging of a power supply unit (on the left, with PCM; on the right, without)

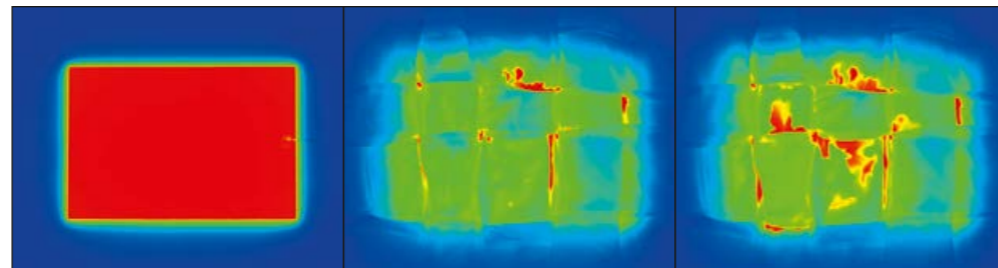


Fig. 2: Left: heating mat used to simulate a IR hotspot (not camouflaged); centre: heating mat covered by PCM IR camouflaging (30 minutes after being covered); right: heating mat covered by PCM IR camouflaging (120 minutes after being covered)

TRAmtn Dirk Theiß
Wehrtechnische Dienststelle für Schutz- und Sondertechnik (WTD 52)
Oberjettenberg

WTD52posteingang@bundeswehr.org

Current IR camouflage systems are normally based on thermal insulation of the object in need of camouflaging. If no measures to remove excess heat have been taken or are impossible to carry out, there may under certain conditions be a build-up of heat, leading to overheating of the system. The use of PCM would avoid this by absorbing the heat and thus preventing any heating-up of visible camouflage device surfaces for a certain period of time. This method offers the possibility to introduce passive temperature control systems for a wide variety of applications and to protect objects and devices from exceeding defined temperature thresholds. The advantage in this connection is that this is done completely passively and that no electronic components (or electric power) is needed. It could support air conditioning units and reduce power consumption, for example. A further positive side effect would be a reduced acoustic signature as a result of reduced motor and power generation unit running times. Drawbacks of PCM camouflage systems include their larger volume and higher weight compared with classic camouflage systems, which has to be taken into account for whatever application is being considered.

PCM could also be used to disrupt signatures by combining different PCM with one another, thereby generating a special IR camouflage pattern. Figure 2 shows a possible IR camouflage

pattern application in which parts provided with different PCM have differing emissive properties and so generate a particular pattern.

Such described properties open up a very varied spectrum of civil and military applications for PCM. These materials are already available on the market in various configurations and are obtainable at a relatively low price. They are also easy to process. Studies conducted so far in regard to the use of PCM in camouflage technology have identified a major potential, which has been confirmed through first positive laboratory test and field trial results.

In view of the good experience gained thus far regarding the possible applications of PCM, Bundeswehr Technical Centre (WTD) 52 and Fraunhofer ICT are planning to conduct further research work in this field.

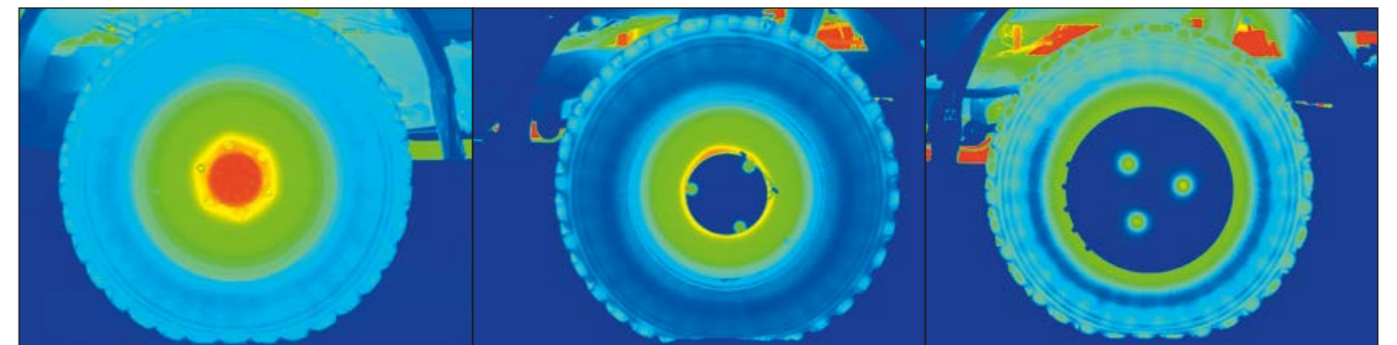


Fig. 3: Left: hotspot on the wheel hub of a vehicle; centre: IR camouflaging of the hotspot, covering only the wheel hub with PCM; right: IR camouflaging of the hotspot by using PCM over the wheel rim

Dr. Jan Abshagen
Wehrtechnische Dienststelle für Schiffe und Marinewaffen,
Maritime Technologie und Forschung (WTD 71)
Kiel

WTD71posteingang@bundeswehr.org

Dr. Volkmar Nejedl
Wehrtechnische Dienststelle für Schiffe und Marinewaffen,
Maritime Technologie und Forschung (WTD 71)
Kiel

WTD71posteingang@bundeswehr.org

Flow acoustics experiments for future low-frequency sonar systems

Flow-induced self-noise restricts the performance capability of low-frequency sonar systems and is, therefore, detrimental to its possible uses in modern submarine sonars. Flow acoustic towing experiments at sea allow both fundamental exploration of sonar-related issues under maritime conditions and the improvement of components for future sonar systems.

The performance capability of passive low-frequency sonar systems as operated on board of modern submarines depends to a high degree on the so-called self-noise produced by the sonar. This includes all interfering noises which originate either from the sonar platform or from the sonar antenna itself, but excludes hydroacoustic noise, such as ocean ambient noise generated in the farfield of the sonar. Sonar self-noise is composed precisely of those interfering noises that depend on the design of the antenna and platform and whose origins consequently need to be considered during a sonar system's design process.

Noise induced by the turbulent boundary layer on the hull of a towed or platform-mounted sonar antenna can contribute significantly to a sonar's self-noise level. In the low-frequency range this interfering noise can already dominate the spectral level at speeds relevant for sonar operations, thus limiting the operational options of submarine sonars for passive detection. Despite the tremendous progress made with flow acoustics simulations over the last few years, the generation of flow-induced noise within a sonar antenna is still not amenable to



Fig. 1: RV Elisabeth Mann Borgese launching the FLAME towed body in Sognefjord (Norway)

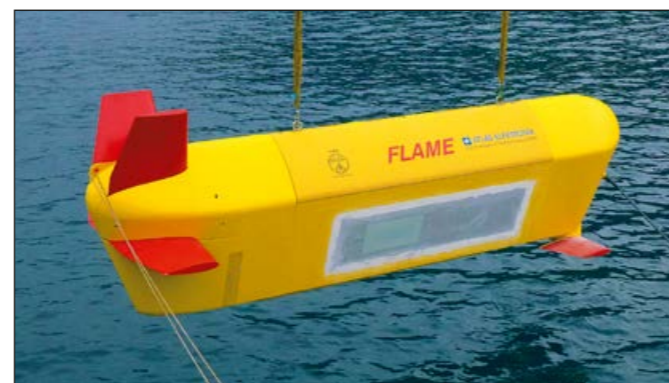


Fig. 2: FLAME towed body with an FRP plate configuration

numerical calculations of realistic boundary conditions, this being due to the high Reynolds numbers involved and the disparity between turbulent and acoustic scales.

To explore the flow-induced self-noise of hydroacoustic receivers under realistic maritime conditions, enterprise Atlas Elektronik had developed a towed-body measurement system, or FLAME (Flow Noise Analysis and Measurement Equipment) for and in cooperation with a public contracting authority, which it operated for the first time in 2004. Since 2011 this system has undergone continuous further development at Bundeswehr Technical Centre WTD 71 to become a flexible measurement system for carrying out fundamental research on sonar-relevant issues. Figure 1 shows the FLAME towed body during a research cruise undertaken by RV Elisabeth Mann Borgese in Sognefjord, Norway, in 2014. This system is suitable for conducting flow acoustic experiments at speeds up to 12 knots and depths as great as 200m.

In the course of five research cruises since 2013, two of which as part of EDA project CAPEM (Conformal Array Performance Estimation Modelling), there has been extensive research into the generation and reduction of flow-induced noise on flow-excited plate structures, conducted with the aid of the FLAME towed body. Considered in this regard have been, among other things, different materials (Fig. 2), hydrophobic and superhydrophobic coatings, as well as new types of sensors based on piezoelectric thin-film technology.

Apart from the scientific knowledge that has been gained, the research has led to a substantial improvement in experimental methods and measurement techniques.

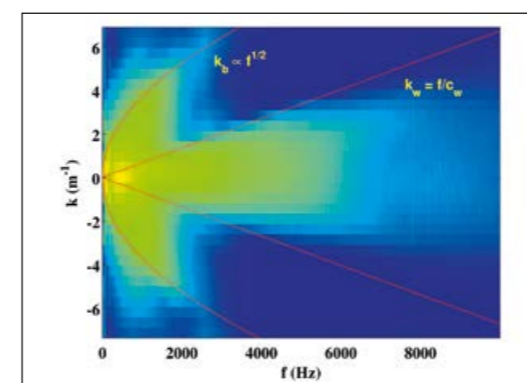


Fig. 3: Wavenumber-frequency spectrum measured by the FLAME towed body at a speed of 8 knots. Dispersion relations of underwater sound and a bending wave are included

Measurements of flow-induced noise at sea present challenges because the ambient noise level is frequently higher than the measured level of flow-induced noise. But by using a linear antenna, it is possible to (partially) separate and identify the noise sources by means of a wavenumber-frequency analysis and, regardless of the ambient noise level, thus estimate the flow-induced self-noise level (Fig. 3).

In 2005 the FLAME towed body measurement system was used to explore functional models for components of a planar flank array for the U212 A (2nd batch), based on wavenumber frequency analysis (Fig. 4). The results of this analysis have had a significant impact on the subsequent design of the extended flank arrays currently operated by this boat class. In just the same way, flow acoustics experiments with a towed body may again also provide an important contribution to the development of future low-frequency sonar systems.

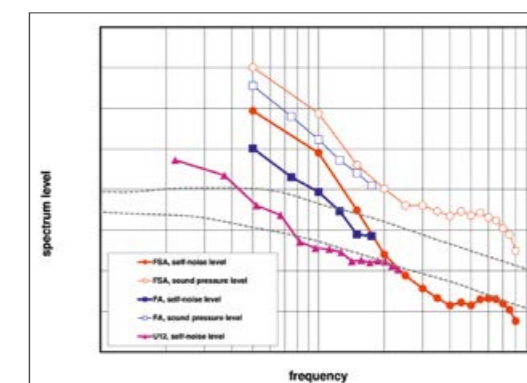


Fig. 4: Power spectral density of the total/self-noise level of components of a flank array (FA) and of a functional model of a planar flank array (FSA), as well as the self-noise level of a platform-mounted sonar (U12)

Dipl. Math. Dr. Ivor Nissen
Wehrtechnische Dienststelle für Schiffe und Marinewaffen,
Maritime Technologie und Forschung (WTD 71)
Kiel

WTD71posteingang@bundeswehr.org

Dipl. Inf. Michael Goetz
Fraunhofer-Institut für für Kommunikation,
Informationsverarbeitung und Ergonomie FKIE
Wachtberg

info@fkie.fraunhofer.de

Tactics for unmanned sensor platforms operating underwater with decentralised data fusion

Strategy and tactics are determined by there being multiple alternative courses of action available. Strategy is hence the concatenation of individual operations, the sequential execution of coordinated tactics, which may also include sacrifices, in other words local non-optimality. But what are good tactics for cooperative autonomous systems underwater?

Cooperation requires communication. In the water column, communication links between manned and unmanned subjects (divers, floats, gliders, bottom nodes, ASV, AUV, gateway buoys and submarines) are usually not robust, while, in shallow waters, it can happen that only about two-thirds of messages reach the intended receiver correctly, or even fewer under poor sonar weather conditions. This shows that the sound propagation channel, where changes occur in the millisecond range, is one of the most challenging, highly variable channels for communication. Transmission also consumes a lot of energy and occupies the same frequency band that acoustic sensors need so much for their detection functions. Good tactics will minimise the length and spectrum of packet transmissions while maximising correct delivery and accomplishing the mission within a given timeframe under military constraints. But, how can such a complex problem be resolved for a mobile ad-hoc underwater network?

The Bundeswehr Technical Centre for Ships and Naval Weapons, Maritime Technology and Research (WTD 71) in Kiel and the Fraunhofer Institute for Communication, Information Process-

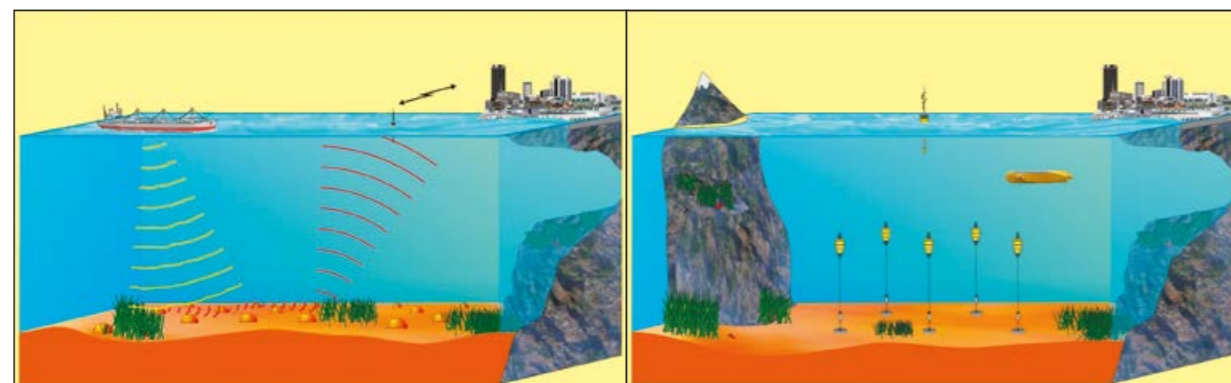


Fig. 1: Stationary sensor networks on the seafloor, also implemented as permanently installed infrastructure, afford a useful contribution to MSA; detection and communication share the same medium of underwater sound

ing and Ergonomics (FKIE) in Wachtberg have been working on this question since 2009. A suitable communication approach has been identified for underwater acoustic sensor networks [1,2]. During a European comparison of different protocols in EDA project RACUN (Robust Acoustic Communication in Underwater Networks) in 2014, this technology approach dominated in the final demonstration at sea, involving 14 autonomous subjects, as well as in accompanying simulations involving 230 subjects. This infrastructure itself, however, does not yet map the tactics at application level, i. e. the subjects' courses of action for cooperating with one another.

Unlike in project NGAS (Next Generation Autonomous Systems), featuring classic central data fusion, the COST (COoperative Strategies and Tactics Sea Trial) 2018 sea experiment held in autumn 2018 explored two tactics [3]. Using the newly developed "publish-subscribe" capability of the GUWMANET network protocol as a basis, the subjects were able to access the knowledge of neighbouring sensors autonomously. In contrast to the centralised approach in which the data is collected and distributed by means of a central entity, considerably fewer packet transfers are required. The decentralised approach saves channel capacity, energy and time.

This was demonstrated in an experiment in Tromper Wiek bay in the Baltic Sea. Automated naming in the ad-hoc network with limited namespace as well as autonomous cooperation of the bottom sensor nodes were tested with the aim of developing a "Common Role-Oriented Underwater Situation Picture". Ships on the sea surface were also tracked acoustically. The latter task falls within the topic area of MSA (Maritime Situational Awareness), see Figure 1. The experimental set-up comprised



Fig. 2: Contact reports of ships detected within one hour of operation

three bottom sensor nodes (red, green, blue), see Figure 2, which the research vessel Elisabeth Mann Borgese (EMB) deployed. Each node is able to locate a contact by means of beamforming via a tetrahedron arrangement of the four hydrophones and additionally detect it magnetically. A single sensor node is only able to determine the direction, not the distance, however. Cooperation with neighbouring sensor nodes afforded the possibility to fuse these individual bearings locally and to calculate the position of the contact with the aid of cross-bearing. Figure 3 shows the contacts determined within one hour. The three location markings indicate the positions of the bottom nodes. Each point represents the detection of a contact, e. g. a ship on the surface. The inside of a circle indicates the colour of the neighbouring sensor with the initial bearing, and the outer edge the colour of the sensor node that calculated the cross-bearing.

In the past few years of joint work, therefore, not only the communication stack from bit transmission to the network protocol has been explored in greater detail, but now also the step toward autonomous cooperation and coordination including corresponding quality measurement has been taken.



Fig. 3: Deployment of the blue bottom node by RV EMB

Frank Jaspers
Wehrtechnische Dienststelle für Waffen und Munition (WTD 91)
Meppen

WTD91posteingang@bundeswehr.org

Augmented reality and mixed reality technologies

Augmented reality (AR), virtual reality (VR) and mixed reality (MR) are technologies which offer enormous potential, especially for military applications. The “AR & VR Technologies” study addresses their use to fill military capability gaps. A focal point of the study is their implementation for Joint Fire Support Teams.

The “AR & VR Technologies” study explores the potential of augmented reality and mixed reality. Its aim is to examine the use of relatively new technologies to generate new military applications that would not otherwise be feasible or could only be implemented at great financial expense.

In collaboration with their potential user, implementation for Joint Fire Support Teams (JFST) has been defined, which is to be successively pursued on the basis of milestones. A prototype, VECTOR AR, has been developed according to military specifications. It is a replica of the Leica Vector binoculars, but additionally offers the possibility to place virtual objects and effects in real terrain. Technically, it is a video-see-through device with a VR interface.

To display virtual objects and effects in a real environment, the video images from the built-in video cameras are captured and then further enriched with contents from a virtual mission.

The enriched picture is then shown on the VECTOR AR display. Such enriched pictures are referred to as “augmented reality”



Fig. 1: VECTOR AR in use for JFST



Fig. 2: VECTOR AR - prototype 01

or “mixed reality”, as the source for the enrichment of the live images stems from a virtual environment.

As in the original device, a laser rangefinder has additionally been integrated, which receives the distance calculation from the virtual environment. The digital direction angle display from the original device has also been incorporated.

A multisensor gives the spatial location of the VECTOR AR and also allows a positionally accurate determination of the location of objects and effects in real terrain. As this sensor data is insufficient on its own, it is complemented by image tracking.

The Vector AR offers a new way of presenting training content previously unavailable in this form. To date, instructors have had to rely on the powers of imagination of their trainees when issuing the instruction “Imagine an enemy T-80 tank standing at the corner of the house”; now that enemy T-80 tank can be displayed as a digital 3D object in real terrain.

The system can also be used to map complete military missions. The editing of the missions is done on a separate computer with the aid of the “Virtual Battlespace (VBS)” software widely used in the Bundeswehr. This is a military simulation software from the domain of Serious Gaming.

While VBS is used for mission control, Unity, a widely utilised game engine, is employed to display the virtual content in real sight, as it allows full access to the graphics pipeline and in contrast to VBS is free from restrictions. The 3D objects from the military mission are then transferred from the virtual environment via a simulation interface to the real world.



Fig. 3: Chief of the German Army trying out the VECTOR AR

To be able to map a mission, it is furthermore necessary to create high-resolution 3D terrain databases, for which purpose real terrains in the regions of Meppen and Idar-Oberstein have been overflown by a drone. From the recorded (raw) data, the engine-specific terrain databases can then be created in several successive steps, thus ensuring that the 3D objects are also later placed in their correct position.

The system has been networked with a VR flight simulator and presented to a broad specialist audience as part of the annual symposium “AR, VR and MR in the Bundeswehr”.



Fig. 4: Inside View of the VECTOR AR

2

Military Medical and Military Psychology Research

Military medical research is absolutely essential for the Medical Service so that it can maintain and consolidate its capabilities for protecting and restoring the health of Bundeswehr soldiers. This section presents a selection of military medical research projects.

Attacks involving “dirty bombs” are among the most frequently discussed threat scenarios in radiological and nuclear medical defence. The Bundeswehr Institute of Radiobiology describes the background of these threats as well as diagnostic and therapeutic countermeasures.

Anthrax is a widespread zoonotic disease in many regions of the world. Spores of the pathogen *Bacillus anthracis* can be misused as a biological weapon. The Bundeswehr Institute of Microbiology has investigated the relationships between isolated anthrax strains of an endemic region. Such information may help us differentiate between natural and man-made incidents in unusual cases of illness.

Reducing animal experiments as much as possible and replacing them with alternative approaches is a challenge for military medical research. The Bundeswehr Institute of Pharmacology and Toxicology presents the Cultex cell culture model, which enables scientists to examine the toxic effects of airborne substances.

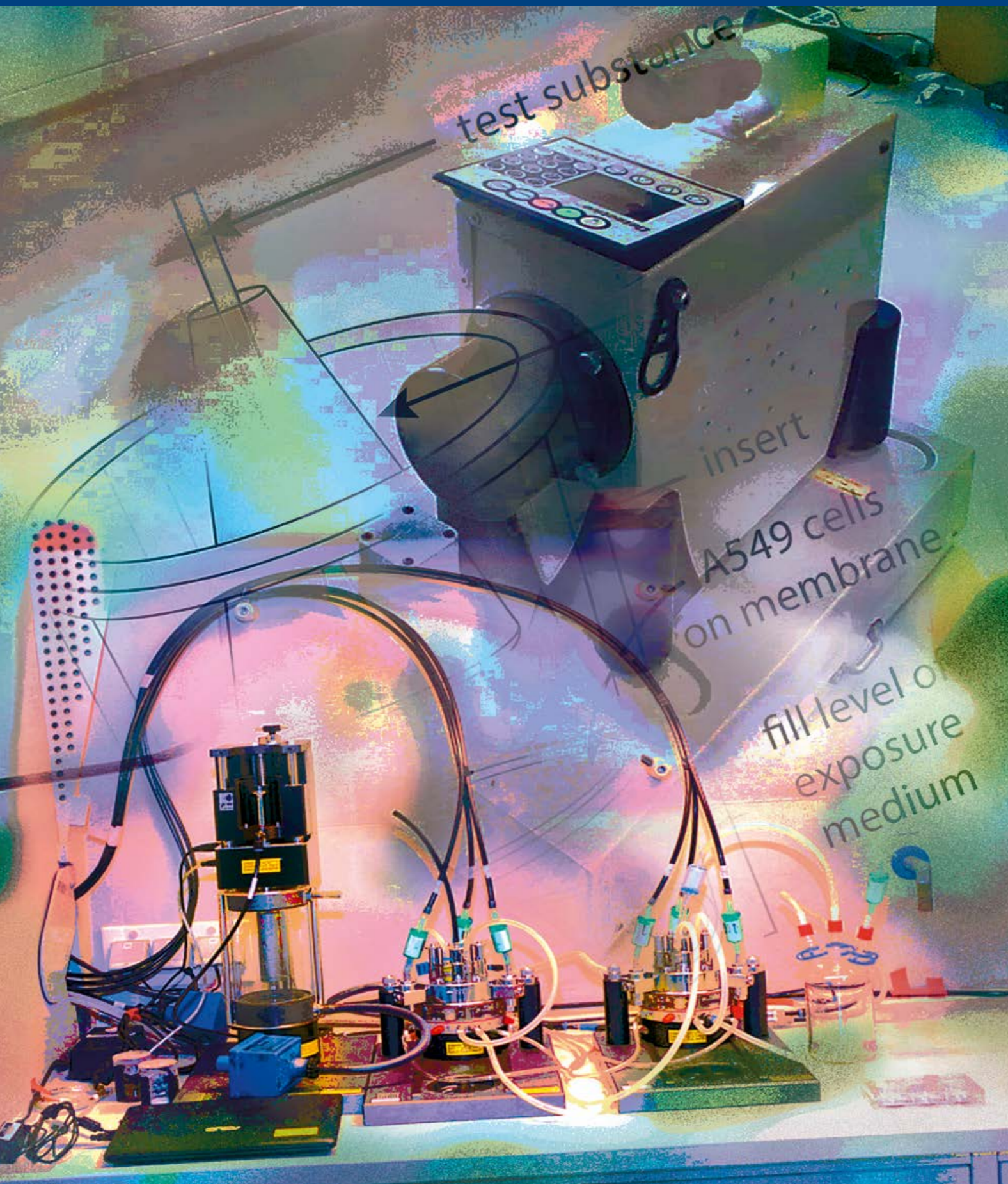
Physical fitness is a necessary requirement for service in the armed forces but has considerably worsened among newly recruited soldiers due to changes in lifestyle. The Bundeswehr

Institute of Preventive Medicine describes a new sports training programme for significantly increasing physical fitness during the first few weeks of military training.

The Naval Institute of Maritime Medicine has developed and tested a new naval patient survival and transportation bag that protects incapacitated patients in heavy seas or during the rapid evacuation of a seagoing unit. It can also be used to save people who have fallen into the water from drowning and hypothermia.

The Air Force Centre of Aerospace Medicine presents methods of diagnostic molecular pathology which are used for the forensic investigation of aircraft accidents. These methods may also be employed for examining physiological strain on the lungs.

Suicides and attempted suicides are the tragic consequences of insufficiently diagnosed and treated psychological conditions and of serious personal crises. Together with other research agencies of the Bundeswehr, the Bundeswehr Centre of Military Mental Health at the Bundeswehr Hospital Berlin has conducted a case-based analysis of suicides and suicide attempts in the Bundeswehr. This analysis will serve as an indispensable foundation for effective strategies of early recognition, suicide prevention, and long-term effective assistance for soldiers at risk.



Analysis of phylogenetic relationships of the anthrax pathogen in an endemic region

Anthrax is a zoonotic infectious disease that is still common in many parts of the world, including in operational theatres of the Bundeswehr. In an international project with Turkish, Welsh and Georgian colleagues, we succeeded in clarifying the cross-border phylogenetic relationships of the anthrax pathogen *Bacillus anthracis* in an endemic region in western Asia.

Anthrax is a rare zoonosis in western Europe and is caused by the bacterium *Bacillus anthracis*. The pathogen is endemic in much of sub-Saharan Africa and south Asia. This includes theaters of operation of the Bundeswehr such as Afghanistan.

In the event of an infection, adequate therapy must be provided. The pathogen must also be genetically analysed. This is particularly necessary if multiple cases of infection occur within a short period of time. In this instance, we must differentiate natural outbreaks from the deliberate release of anthrax. To meet this need, the Bundeswehr Institute of Microbiology has supplemented its long-standing anthrax reference laboratory with an expert group specialising in genomics with strong expertise in bioinformatics. This group is unique in the German Ministry of Defence and thus strongly supports defence-related research.

The Bundeswehr Institute of Microbiology recently worked together with research partners from Turkey, Georgia and Wales to conduct a high-resolution, genomic and phylogenetic analysis of *B. anthracis* isolates from eastern Anatolia and Georgia. Some of the pathogens originated from animal and human

infections in the Turkish district of Kars, which borders on Armenia and is close to Georgia (Fig. 1). The district of Kars has a record of frequent anthrax outbreaks (19.7 % of all cases in Turkey from 1995 to 2005 were in Kars, which represents only 1 % of Turkey in terms of area).

Of 30 *B. anthracis* DNAs, 7 were selected as representatives for whole genome sequencing. High-resolution phylogenetic relationships were identified on the basis of differences in DNA sequences (single nucleotide polymorphisms; SNPs) between these isolates and sequences in public databases (Fig. 2). All isolates from eastern Turkey and Georgia are closely related to another. Three new groups were identified (Kafkas-Geo groups 1 to 3). Each of these groups is defined by at least one SNP, which differentiates them from all other anthrax strains worldwide. This means that if there is a new *B. anthracis* strain found with exactly one of these unique SNP alleles, we can assume that this strain originated in the south Caucasus region.

Based on these genomic findings, three new polymerase chain reaction (PCR) assays were designed in order to assign additional DNAs to the three Kafkas-Geo groups (Fig. 3). Unexpectedly, we were unable to assign three DNAs to any of these new Kafkas-Geo groups. We therefore employed supplementary PCR-based analyses of published assays from our Georgian partners to gain more information. We were then able to propose that these three isolates branch off from Kafkas-Geo groups 1 to 3 and therefore likely constitute an additional group, Kafkas-Geo group 4 (Fig. 2).

By combining an analysis of already published data (from Georgia), in-house whole genome sequencing, and PCR assays,

we were able to paint a more detailed picture of the diversity and phylogeny of anthrax strains in western Asia. As a result, it is now possible to attribute such pathogens to a defined geographic area in the event of unusual outbreaks.

In addition, high-resolution phylogeographic typing data will facilitate a deeper understanding of the spread of such pathogens. It is likely that western European relatives of the strains analysed here were imported in the past by anthropogenic activities (such as trade involving contaminated animal products) from the south Caucasus.



Fig. 1: Map of the south Caucasus region illustrating the spread of genotypes of *B. anthracis*. Numbers denote different pathogen genotypes identified by previous work in the region (??? = unknown types). The administrative district of Kars is shown

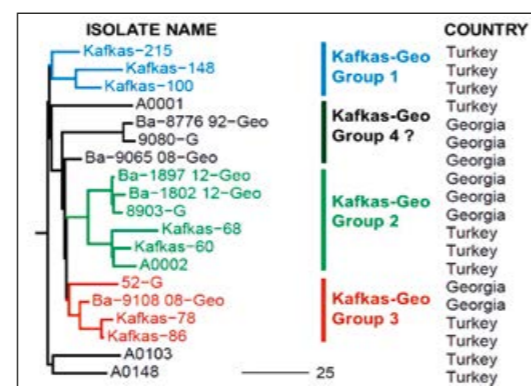


Fig. 2: Phylogenetic placement of seven new *B. anthracis* strains (Kafkas) and definition of three new branches specific to the region Turkey and Georgia (Kafkas-Geo 1–3). An additional group (Kafkas-Geo 4) is postulated

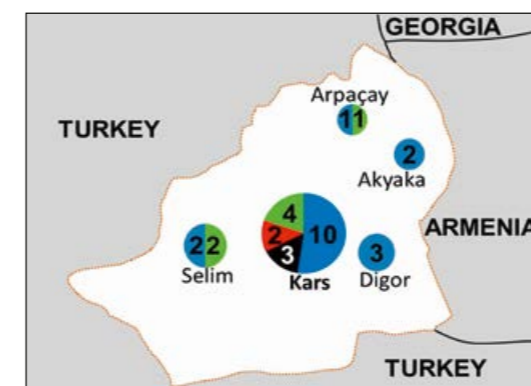


Fig. 3: Geographic distribution of Kafkas-Geo groups 1–4 of *B. anthracis* in the district of Kars. According to DNA analyses of 30 isolates, newly defined genotypes were assigned to the counties in which the pathogen was isolated (color-coding as in Fig. 2 with postulated Kafkas-Geo 4 group in black)

Hauptmann Amelie Tsoutsouloupoulos M.Sc.
Institut für Pharmakologie und Toxikologie der Bundeswehr
München

Institut fuerPharmakologieundToxikologie@bundeswehr.org

Oberfeldarzt PD Dr. Dirk Steinritz
Institut für Pharmakologie und Toxikologie der Bundeswehr
München

Institut fuerPharmakologieundToxikologie@bundeswehr.org

Establishment of an exposure system as an animal replacement model for the evaluation of the acute toxicity of inhalable substances

As part of a research project funded by the German Ministry of Education and Research, the Bundeswehr Institute of Pharmacology and Toxicology has successfully contributed to the validation of a prediction model for the assessment of the acute inhalation toxicity of airborne particles. The CULTEX® RFS is based on the direct exposure of human lung cells at the air-liquid interface and represents a promising alternative to animal testing.

Toxicological risk assessments of airborne particles represent a major task due to the increasing number of chemicals on the market and their ubiquitous use in industry and pharmacy. Depending on the type of substance, inhalation can cause serious acute or chronic lung injuries. Since 2006, the EU chemicals regulation REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) stipulates that all chemicals that are new or currently on the market must undergo a toxicological risk assessment that takes into consideration potential inhalation hazards.

Most data for assessing acute inhalation toxicity rely on animal models. According to estimates, 1–2 % of all laboratory animals (approximately 100,000 – 200,000 animals) have been used for inhalation toxicity tests. Animal studies are, however, ethically, scientifically and economically questionable, have limitations when it comes to the extrapolation of results to humans, and should be reduced (“3R principle”). Alternatives to animal experiments are thus urgently required but are not available in the field of pulmonary toxicology.

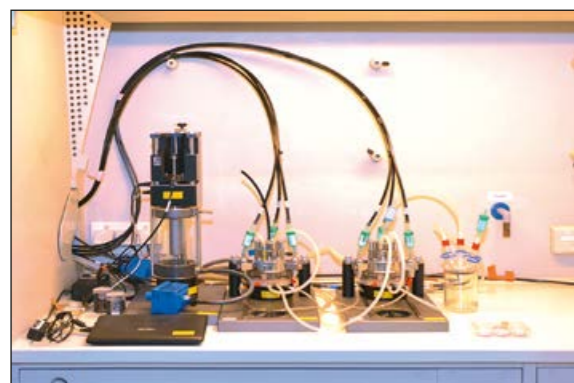


Fig. 1: Overview of the CULTEX® RFS (Source: Tsoutsouloupoulos et al., Optimization of the CULTEX® radial flow system for in vitro investigation of lung damaging agents, Toxicology Letters 244 (2016), p. 28-34)

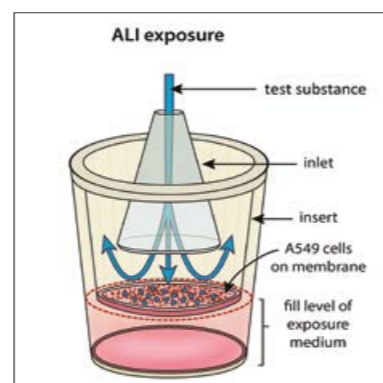


Fig. 2: Experimental set-up for exposure experiments at the ALI (Source modified: Tsoutsouloupoulos et al., A novel exposure system generating nebulized aerosol of sulfur mustard in comparison to the standard submerge exposure, Chemo-Biological Interactions 298 (2019), p. 121-128)

Significant research efforts have been undertaken to develop adequate non-animal testing models. The assessment of toxic inhalation hazards in *in vitro* studies is typically performed using cell cultures exposed under submerged conditions. Particle exposure under submerged conditions does not, however, correspond to the *in vivo* situation. The interaction of particles with the exposure medium may affect and alter the physicochemical and thus the toxic properties of a test substance. Efforts have therefore been made to develop special devices for the direct exposure of cells at the air-liquid interface (ALI).

The CULTEX® Radial Flow System (RFS) is a modular *in vitro* exposure system that is based on the homogeneous and direct exposure of human lung epithelial cells to test substances at the ALI.

In a research project funded by the Germany Ministry of Education and Research, a prediction model was successfully validated and refined by optimising the CULTEX® RFS method.

The cell viability of A549 cells after ALI exposure to 20 pre-selected test substances was measured in three independent laboratories, including the Bundeswehr Institute of Pharmacology and Toxicology. Each laboratory tested 13 substances three times and seven substances once in a blind manner. A total of 138 experiments were thus conducted. The acute cytotoxicity of the test substances was compared to the respective incubator controls (non-exposed cell cultures) and used as an indicator of toxicity. Test substances that led to a decrease in cell viability below 75 % (prediction model 75 % = PM 75 %) or 50 % (PM 50 %) in any of the three exposure periods (15, 30

and 60 minutes) were considered to be an acute inhalation hazard.

A comparison of the results with existing *in vivo* data showed an overall agreement of 85 %, a specificity of 83 %, and a sensitivity of 88 %. Depending on the applied prediction model, the reproducibility within and between the laboratories ranged from 90 to 100 %.

The CULTEX® RFS thus proved to be a transferable, reproducible and predictive method for assessing the acute pulmonary toxicity of airborne particles and a promising alternative to animal testing. What is more, the CULTEX® method may play an important role in experiments on airborne particles that are relevant to military medicine.

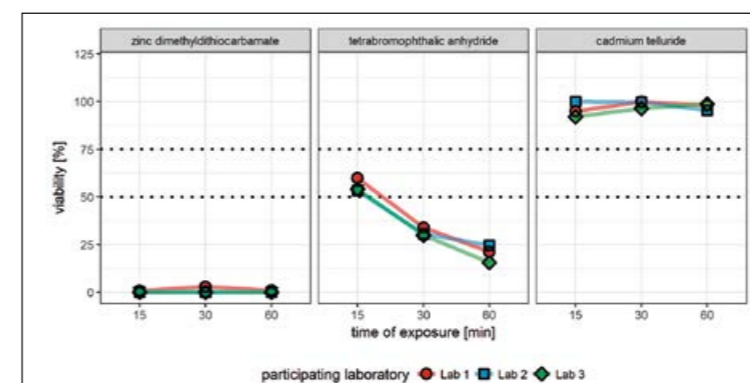


Fig. 3: Viability data of A549 cells after exposure to test substances (Source: Tsoutsouloupoulos et al., Validation of the CULTEX® Radial Flow System for the assessment of the acute inhalation toxicity of airborne particles, Toxicology in Vitro (2019))

OTA Dr. Ulrich Rohde
 Institut für Präventivmedizin der Bundeswehr
 Andernach

InstPraevMedBw@bundeswehr.org

OTA Prof. Dr. Dr. Dieter Leyk
 Institut für Präventivmedizin der Bundeswehr
 Andernach

InstPraevMedBw@bundeswehr.org

“Increasing physical fitness from day one”: Findings from a pilot study on restructuring basic training in the German Army

Establishing and maintaining adequate levels of physical fitness is necessary in order to ensure the operational readiness of the Bundeswehr. Declining levels of fitness among applicants necessitate new concepts for basic training. Restructured basic training with increased emphasis on sports (increased amount, different performance groups, full-time training instructors) has yielded improvements in performance.

Pre-deployment training and deployments themselves place great demands on an individual’s physical fitness. For this reason, establishing and maintaining adequate levels of physical fitness is necessary in order to ensure operational readiness and is an important goal of training in the Bundeswehr.

Poor physical fitness is, however, a growing problem among young adults. Those who apply for service in the Bundeswehr are often untrained and sport averse. As a result, the physical fitness levels of recruits are often too low to meet the demands of basic training. In addition to this performance aspect inadequate fitness is an important predictor of injuries and disease during military training (prevention).

There is thus a need for new training programmes that are tailored to individual fitness levels providing individualised training focussed on eliminating deficits and increasing physical fitness.

The Chief of the German Army has initiated a pilot project aimed at restructuring basic training in the Army. This project has been

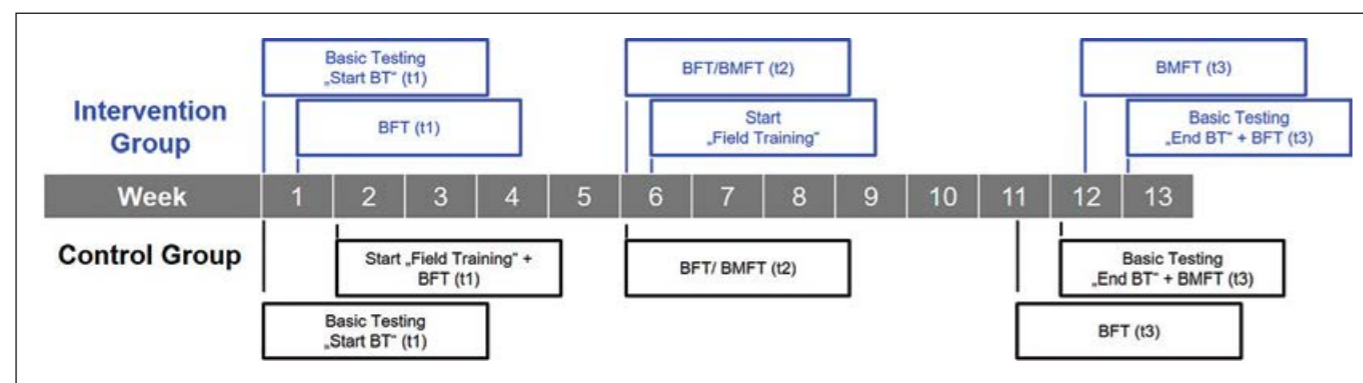


Fig. 1: Data collection timeline for the intervention group (restructured basic training, blue) and the control group (black) at the beginning (t1), middle (t2) and end (t3) of Basic Training (BT). Basic testing included anthropometric measures and isometric maximal forces; BFT = Basis Fitness Test; BMFT = Basic Military Fitness Tool

OTL i.G. Michael Krause
 Kommando Heer
 Strausberg

Kdohi33indivausb@bundeswehr.org

OTL Dipl.-SportWiss. (univ.) Marcus Wesseler
 Sportschule der Bundeswehr
 Warendorf

SportSBwGrpWE@bundeswehr.org

jointly planned, conducted and scientifically analysed by the Army, the Joint Support and Enabling Service, and the Bundeswehr Medical Service.

Key features of this study were:

- establishing three performance groups based on the Basis Fitness Test at the beginning of basic training
- tailoring and customising training in the three performance groups
- increasing the proportion of sports training at the expense of other types of training; no combat training during the first 6 weeks
- physical training is supervised and conducted by full-time physical training instructors

During the pilot study, anthropometric and fitness data were collected at the beginning, middle and end of basic training from all recruits in the intervention group and a matched control group undergoing unmodified basic training (Fig. 1). In this way, changes in fitness in both groups was documented and analysed.

The most important finding was that more pronounced performance increases were achieved for recruits in the intervention group undergoing restructured basic training in comparison

to the control group (Fig. 2). The lowest ranking performance group profited most from the tailored and customised training (Fig. 3).

The most important reasons for the improvements were individualised and extended sports training, the introduction of different performance groups, and the use of full-time physical training instructors. This underlines the necessity of deploying highly qualified, full-time physical training instructors who have a sound knowledge of exercise physiology and training and who are better equipped to deal with untrained recruits.

Despite methodological limitations (number of participants, limited comparability on account of different conditions), the results underline the advantages of a tailored and customised training programme with more and higher-quality sports training. The programme will be used Army-wide beginning in May 2019. Standardised data collection and the creation of a fitness register “Basic Training Army” will be introduced for the preparation of situation reports and for conceptual development.

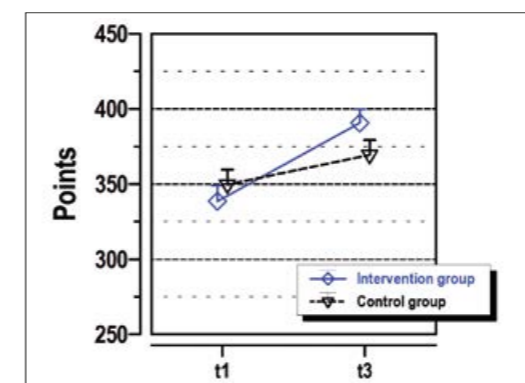


Fig. 2: Example of performance improvements during basic training: Compound results of the Basis Fitness Test (mean ± standard error). Higher increase in the intervention group (blue, 36 males) compared to the control group (black, 14 males). t1 = start of basic training, t3 = end of basic training

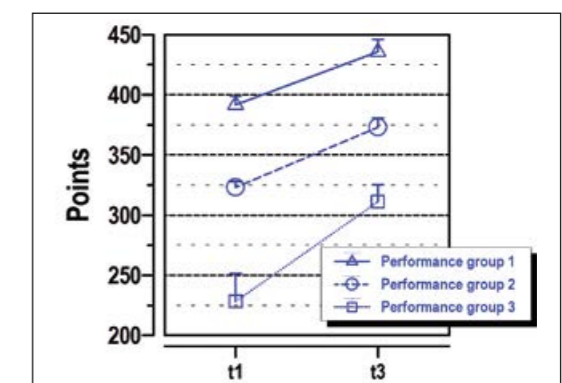


Fig. 3: Compound Basis Fitness Test score (mean ± standard error) of male participants in the three performance groups. t1 = start of basic training, t3 = end of basic training

FTLA PD Dr. med. Alexis Rump, MHBA
Institut für Radiobiologie der Bundeswehr
München

InstitutfuerRadiobiologie@bundeswehr.org

OFA Dr. med. Stefan Eder
Institut für Radiobiologie der Bundeswehr
München

InstitutfuerRadiobiologie@bundeswehr.org

OSA Dr. med. Matthäus Majewski
Institut für Radiobiologie der Bundeswehr
München

InstitutfuerRadiobiologie@bundeswehr.org

Simulation studies for improving medical preparedness in the event of a “dirty bomb” attack

An attack involving a “dirty bomb” will result in a large number of people who are contaminated with radiation. The elimination of radionuclides from the body can be enhanced by early treatment with decorporation agents. Large amounts of antidotes may be required. Screening can be used to rapidly identify victims requiring treatment, which reduces the need for antidotes.

Dirty bombs are explosive devices contaminated with radioactive material. They are relatively easy to build. An attack involving a dirty bomb is one of the most serious terrorist threats. It is impossible to predict how a terrorist attack will be carried out, but radionuclides widely used in industry, medicine and research are of particular concern (e.g. cesium-137 and plutonium-238). In addition to blast injuries, a large number of people will be externally contaminated with radioactive material to varying degrees. Some will incorporate radioactive material by inhalation, ingestion or through wounds, which leads to an internal contamination of organs and tissues. Although the likelihood of developing acute radiation syndrome is rather low in a dirty bomb scenario, internal contamination leads to the long-lasting exposure of organs to radiation, resulting in an increased likelihood of cancer (stochastic damage).

After radionuclides are identified (Fig. 1), their elimination from the body can be accelerated by decorporation agents (chelators, e.g. Prussian Blue) in order to reduce the radioactive load. To be fully effective, however, antidotes must be administered at an early stage, as many radionuclides accumulate



Fig. 1: Micro-Detective, a mobile radiation-detection system for rapid radionuclide identification based on gamma spectroscopy (Ortec, Oak Ridge, USA)

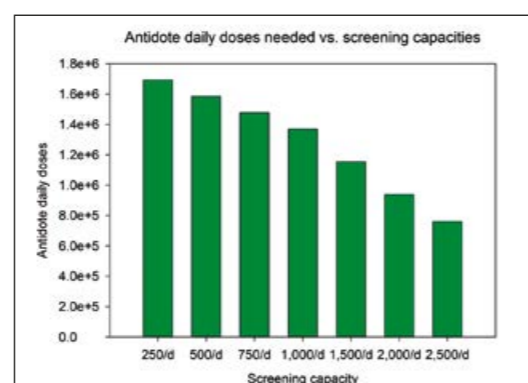


Fig. 2: Number of antidote daily doses required depending on screening capacities in a large-scale dirty bomb scenario with 60,000 people potentially contaminated and 1% of them having incorporated substantial amounts of radioactivity and actually requiring treatment. Duration of treatment: 30 days (Source: Rump et al., Am J. Disaster Med 2017; 12(4): 227-241)

OSA Dr. med. Patrick Ostheim
Institut für Radiobiologie der Bundeswehr
München

InstitutfuerRadiobiologie@bundeswehr.org

OTA Prof. Dr. med. Michael Abend M.Sc.
Institut für Radiobiologie der Bundeswehr
München

InstitutfuerRadiobiologie@bundeswehr.org

OTA Prof Dr. med. Matthias Port
Institut für Radiobiologie der Bundeswehr
München

InstitutfuerRadiobiologie@bundeswehr.org

in tissues that chelators cannot penetrate. Although there is no international consensus on this issue, several institutions that specialise in the management of radiological and nuclear accidents, including the Bundeswehr Institute of Radiobiology, recommend treating all victims who may have incorporated radioactive materials as soon as possible (urgent approach) until relevant internal contamination can be ruled out.

The number of victims potentially contaminated with radioactivity may be very large, possibly even several thousand people (for example, if a dirty bomb were to be detonated in a stadium). For this reason, early treatment for all victims is an organisational and logistical challenge that requires a large stockpile of antidotes. The number of necessary daily doses may amount to several hundred thousand or several million in large-scale scenarios, depending on the therapeutic approach (Fig. 2).

It is likely that only a small percentage of externally contaminated people incorporate relevant amounts of radioactivity and actually require treatment. Identifying these people as quickly as possible may be the most effective way of reducing antidote needs. These victims cannot, however, be identified by a simple clinical examination. Instead, sensitive measurement techniques are required. After external decontamination, mobile whole-

body counters or highly sensitive gamma monitoring portals allow the rapid identification of victims who actually require decorporation treatment (Fig. 3). The availability of sufficient screening capacities can reduce quantitative requirements for antidote stockpiles and reduce the total cost of a given level of preparedness. Based on possible dirty bomb scenarios, the Bundeswehr Institute of Radiobiology is assessing the optimal levels of required resources (screening capacities and antidote stockpiles).

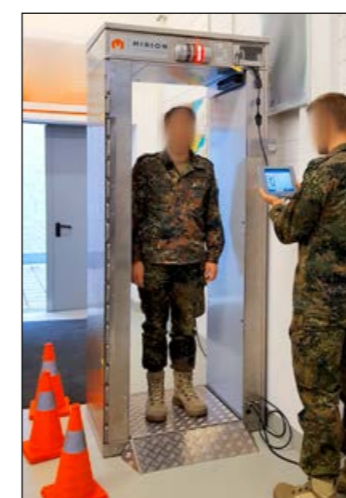


Fig. 3: Gamma portal monitor for detecting contamination. Different measurement modes are possible (“wait-in”, “fast track”, “walk through”) and are associated with different detection limits. Measurement times of 2–3 seconds per person screened

Oberstarzt Dr. Gerd-Dieter Willmund
Psychotraumazentrum der Bundeswehr
Berlin

Oberstabsarzt Dr. Christian Helms
Psychotraumazentrum der Bundeswehr
Berlin

Oberstarzt Dr. Peter Lutz Zimmermann
Psychotraumazentrum der Bundeswehr
Berlin

bwkrhsberlinpsychotraumazentrum
@bundeswehr.org

bwkrhsberlinpsychotraumazentrum
@bundeswehr.org

bwkrhsberlinpsychotraumazentrum
@bundeswehr.org

MedDir Kai-Uwe Spaniol
Institut für Präventivmedizin der Bundeswehr
Andernach

Dr. Anja Seiffert
Zentrum für Militärgeschichte und Sozial-
wissenschaften der Bundeswehr
Potsdam

Dr. Julius Heß
Zentrum für Militärgeschichte und Sozial-
wissenschaften der Bundeswehr
Potsdam

InstPraevMedBw@bundeswehr.org

ZMSBwAbteilungEinsatz@bundeswehr.org

ZMSBwAbteilungEinsatz@bundeswehr.org

Suicidality in the German Armed Forces: A risk-factor analysis of suicide and attempted suicide among German military service members

Over the last two decades, several armed forces have reported a rise in military personnel suicide rates. Around the world, several research projects have been initiated to clarify this increase. In Germany, analyses of risk factors and differences in risk groups of suicidal behaviour were also examined in order to develop risk group-focused interventions.

With a 12-month prevalence of more than 20 %, mental disorders of military personnel are a common medical condition in the Bundeswehr. Despite good treatment options, relatively few patients seek the help of military physicians. As a result, mental disorders may become chronic and the risk of suicidal behaviour increases. It is generally known that suicide is one of the most frequent causes of death among active soldiers, representing 25 – 30 % of deaths among German as well as American service members. In addition, there have been controversial discussions about the effects of deployments abroad on military personnel and whether there is an increasing risk of suicidal behaviour.

In the German Armed Forces, an interdisciplinary, multi-centre research group was formed to study whether and how suicidality is changing. A central aim was to identify factors associated with an increased risk of suicidal behaviour.

These questions have been examined in several smaller projects. A dissertation project examined differences in socio-demographic and medical parameters between suicides and

suicide attempts from 2010 to 2014. The project found risk factor profiles that were comparable to those in the general German population. It also found that, based on medical records, suicidal behaviour was associated with mood disorders, anxiety disorders and stress disorders in 58 % of cases. Differences between the two groups were seen with regard to age, military rank category, length of military service, and sex.

In both groups of the sample, stress at home was detected in over 75 % of the cases on the basis of medical records. Duty-related problems and problems with other soldiers were significantly more frequent in the group of non-lethal suicide attempts than in the case of lethal suicides.

Using a statistical model, another project examined data from a “suicide registry” of the years 2010 – 2014, which was based mainly on an evaluation of the medical records of service members who committed suicide, and data from a representative survey of service members. The aim was to ensure a representative interpretation of the data from the suicide registry.

The project showed that the sociodemographic parameters of the suicide registry differed considerably from those of the armed forces survey. In comparison to the representative data set for the German armed forces, the suicide registry had a

higher percentage of young service members who were in the first or second year of service.

In addition, soldiers who had served for more than 20 years were more frequently represented in the suicide registry sample. Similar effects were found in the age groups, for example soldiers older than 45 years were more strongly represented in the suicide registry sample. Risk groups were identified with regard to suicides (see Fig. 3). Trend analyses were calculated (Fig. 1) and comparisons with the general population were made (Fig. 2) by examining data collected since the suicide register (Fig. 1).

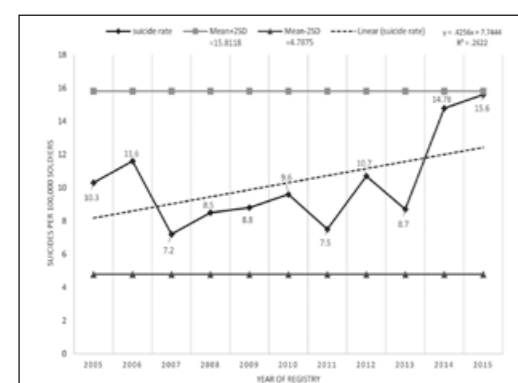


Fig. 1: Suicide rates (suicides/100,000 soldiers): German Armed Forces 2005-2015. Note: Gender-unweighted (mixed) suicide rates in the German Armed Forces and results of a trend analysis as a mean linear function, based on s-registry data from the years 2005-2015. Data provided by the Psychotrauma Centre of the Bundeswehr (modified according to Willmund et al., 2017)

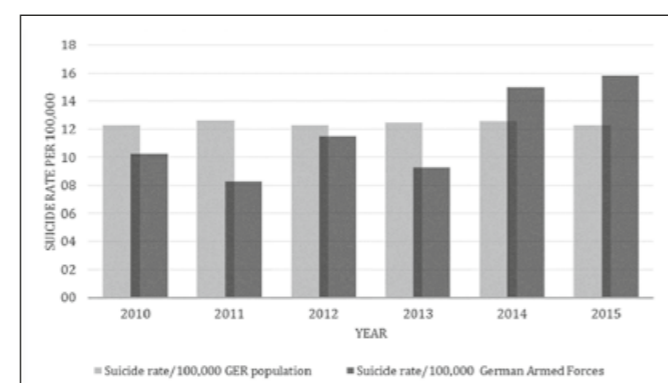


Fig. 2: Suicide rates per 100,000 individuals: general German population versus German Armed Forces 2010-2015 (modified according to Helms, Wesemann, Zimmermann & Willmund et al., 2017)

Variable	B (standard error)	Odds ratio: Exp(B)	Significance (p-value)	95 % C.I. for Exp(B) Lower	95 % C.I. for Exp(B) Upper
Gender: male*	2.148 (1.017)	8.6	.035	1.2	62.9
Single***	1.791 (0.242)	6.0	<.001	3.7	9.6
Older than 45 years***	1.502 (0.298)	4.5	<.001	2.5	8.1
First/second year of service ¹	0.808 (0.454)	2.2	.075	0.9	5.5
Lower secondary education or less*	0.682 (0.267)	2.0	.011	1.2	3.3
Fewer than 2 deployments abroad*	0.688 (0.335)	2.0	.040	1.0	3.8
N	1580				
Significance of the model	.000				
Nagelkerke R ²	.16				

Fig. 3: Suicide risk groups, results of a multivariate logistic regression analysis (table modified according to Willmund, G.D., Heß, J., Helms, C., Wertenaue, F., Seiffert, A., Nolte, A., Zimmermann, P.L. (2018). Suicides between 2010 and 2014 in the German Armed Forces. Comparison of Suicide Registry Data and a German Armed Forces Survey. Suicide and Life Threatening Behaviour. Epub. doi: 10.1111/sltb.12534)

OFA Dr. med. Michael J. Schwere
Zentrum für Luft- und Raumfahrtmedizin der Luftwaffe
Fürstenfeldbruck

ZentrLuRMedLwI4Rechtsmedizin@flugunfall@bundeswehr.org

Molecular pathology diagnosis in forensic aircraft accident investigations

The forensic examination of victims of aviation accidents has been significantly refined by the establishment of molecular pathological procedures. Determining the cause of death and diagnosing pre-existing diseases in fire victims and putrefied bodies are especially improved by DNA- and RNA-based procedures, regardless of morphological criteria.

As part of investigations by public prosecutors, forensic pathologists are responsible for the examination of victims of aviation accidents. This is generally done by way of autopsies. Additional diagnostic procedures are frequently necessary as a result of complex injuries, pre-existing diseases, or secondary changes to corpses such as burns.

One such procedure is molecular pathology, in particular PCR-based procedures. Sequencing techniques, in particular pyrosequencing, are also applied. Target sequences from infective organisms and methylations of predefined DNA regions are assessed.

In cooperation with the Institute of Legal Medicine in Munich, we established a real-time PCR-based assay of DNA from diatoms (microalgae) and *Aeromonas* species (fresh water bacteria) in blood and muscle samples from the lower limbs of drowned persons. This allows us to determine, independently of morphological organ findings, whether an accident victim was alive when the aircraft hit the water. This allows us to rule out whether circulatory failure took place prior to immersion.

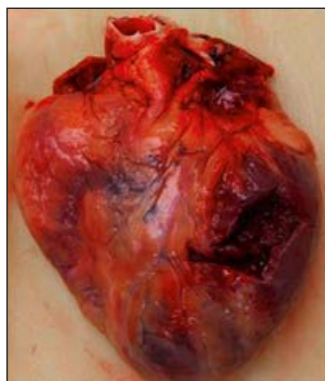


Fig. 1: Macroscopic view of the hypertrophic heart of a pilot who died in an aircraft accident. Rupture of the anterolateral wall of the left chamber resulting from a penetrating rib fracture. Morphological criteria of pre-existing heart disease cannot be reliably obtained from this tissue area (photograph courtesy of the Institute of Legal Medicine in Munich)

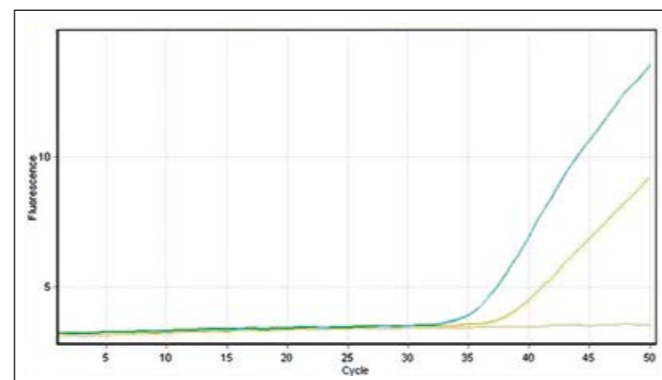


Fig. 2: Real-time PCR results showing the identification of DNA from *Aeromonas* species in blood collected from the femoral vein of a drowning victim. Positive amplification signals, using two different probes in a multiplex PCR assay. No increase in fluorescence was observed in a specimen from a body without immersion into fresh water used as a negative control

The assessment of the HIF-1 (hypoxia-inducible factor 1) pathway in our studies showed that it is possible to detect the effects of pre-existing ischemia, regardless of morphological criteria. This includes intermittent ischemic episodes in the cardiac muscle. Our studies have shown that such pre-existing defects in the heart can be found in up to 50 % of pilots of average age and older. Reduced tissue oxygenation activates HIF-1 and its effector genes. Additional results can be obtained by studying regulatory microRNAs in cardiac muscle samples. These methods use short DNA and RNA strands and can be successfully applied even in corpses with secondary changes.

We conducted additional studies on the identification of the origin of circulating cell-free DNA in the bloodstream. Fragments of DNA are released from damaged tissue into the bloodstream. A comparative analysis of organ samples allowed us to define the reduced degree of methylation in the promoter region of genes expressed in a tissue-specific manner. This is a valid indicator for the origin of circulating cell-free DNA. This method can also be used for the examination of living persons. For example, the gene for surfactant protein was studied in blood samples of pilots undergoing centrifuge training. This is important if we are to determine whether g-forces and positive pressure breathing can lead to increased pulmonary stress.

The same technique can also be used to examine age-dependent DNA methylation. The correlation between reference data from samples of known age with pyrosequencing results from an unknown victim allows us to estimate the unknown person's age. Our assessments with the ELO-VL2 gene, which is especially suitable for blood samples, demonstrated the applicability

of this method in material from burn victims and decomposed bodies. Furthermore, we showed the applicability of this procedure when it comes to samples from solid tissues such as the spleen. Using this method, we can better compare an unknown victim, e.g. on the ground after an aircraft crash but also after a mass disaster like a tsunami, with pictures on a missing persons list because it is easier to estimate the age of the victim.

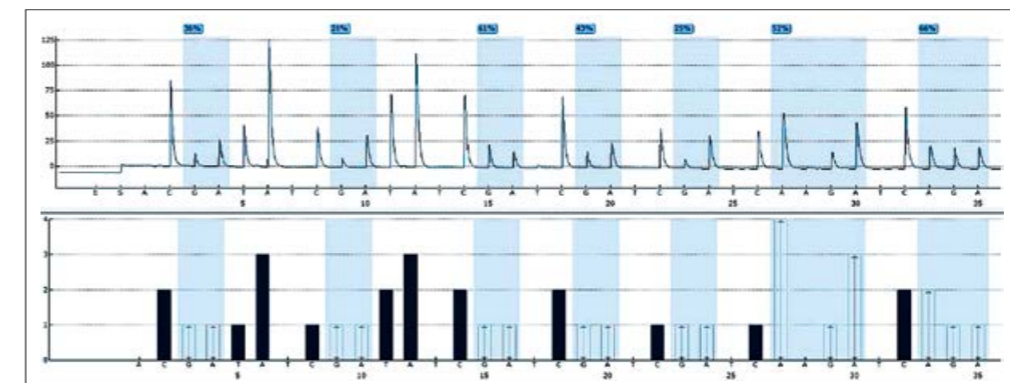


Fig. 3: Results obtained from pyrosequencing showing the methylation values in 7 positions in the ELO-VL2 gene. The values change with ageing. This allows us to estimate the biological age of an accident victim on the basis of a DNA sample from the spleen

Flottenarzt Dr. med. Ulrich van Laak
Schiffahrtsmedizinisches Institut der Marine
Kronshagen

SchiffMedInstM@bundeswehr.org

Flottenarzt Prof. Dr. med. Andreas Koch
Schiffahrtsmedizinisches Institut der Marine
Kronshagen

SchiffMedInstM@bundeswehr.org

Immersion and survival kit for use in the Navy

On the basis of personal survival equipment currently issued to sailors and airmen, we are designing a special protection system to ensure the survival of patients at sea who are transported on stretchers, both with and without life support systems.

We are researching a way to increase the chances of survival in the event of an immersion accident during patient transport at or over sea, for example when a ship is being evacuated in an emergency. This type of accident is conceivable in a naval environment.

Healthy travellers and crew members are equipped with a number of safety devices, but people who are injured are often not able to use such equipment. The latter are exposed to dangers including cold shock, motor skills failure, hypothermia, inhalation of water, drowning and rescue collapse. It would be almost impossible, for example, for such people to evacuate a helicopter that had made an emergency landing on water.

The solution presented here is a watertight survival kit, a bag-like implement that encases the patient. It is compatible with various patient transport devices and therefore needs no additional specialised equipment. The survival kit is a rectangular bag with a watertight zipper on three sides which unzips to form two halves, top and bottom. Additionally, there is also



Fig. 1: Empty survival kit



Fig. 2: Survival kit floating in water



Fig. 3: Survival kit attached to a helicopter hoist cable

Flottenarzt Dr. med. Henning Werr
Schiffahrtsmedizinisches Institut der Marine
Kronshagen

SchiffMedInstM@bundeswehr.org

Oberstabsapotheker Katrin Kober
Schiffahrtsmedizinisches Institut der Marine
Kronshagen

SchiffMedInstM@bundeswehr.org

a reinforced outer textile element to safeguard the bottom of the kit from wear and tear and to attach the kit to a helicopter hoist cable or other lifting device at sea.

Since the survival kit is not insulated, we tested four standard methods of insulation which are available on board naval vessels at sea. They are wrapping the patient in a woollen blanket, wrapping the patient in a disposable rescue blanket that chemically provides heat in addition to a woollen blanket, using a disposable rescue blanket with air pockets, and finally placing the patient on a vacuum mattress that contains styrofoam and covering the patient with a woollen blanket.

The prototype was tested together with an independent civilian institute for textile research. A mannequin was used that simulates human body temperature. The prototype was immersed in cold water with each of the above-mentioned insulation methods, and the temperature of the mannequin was taken. Findings showed that insulation against cold was comparable to or even better than that of a typical wet suit.

Gas composition within the survival kit plays an important role. Tests under laboratory conditions without additional gas supply showed only minor changes in the vital functions of volunteers after 30 minutes. This could be explained by the

fact that the kit itself is made of semi-permeable synthetic material. Initial tests have been conducted with an internal long-term oxygen supply and simultaneous carbon dioxide elimination.

Practical trials conducted in open water as well as in simulation scenarios have yielded positive results.

We predict that a survival system for stretcher patients will be available in the near future and will meet the same standards as personal safety gear currently issued to seafaring personnel (life jackets, immersion suits, spray hoods).

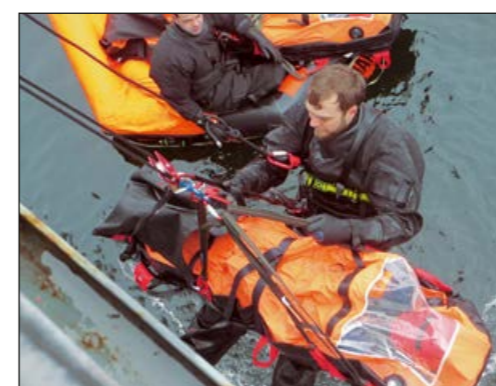


Fig. 4: Evacuation with survival kit at the side of a ship



Fig. 5: Insulation measurement



Fig. 6: Study of air supply and interior conditions

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 with a view to actively shaping the public debate about military and security issues in Germany through its academic findings. The ZMSBw researches German military history in accordance with the generally accepted methods and standards applied in the science of history, taking into account the interrelationships between the military, politics, economy, society and culture.

Through its social science research the ZMSBw contributes to the continued development of the social sciences as well as to academically based political consultations. The intertwined nature of the science of history and the social sciences broadens the range of opportunities in the field of research and in the application of its findings in history education.

The contribution made by the ZMSBw helps to better understand the role of armed forces in a pluralistic society. The social sciences, being thematically interlinked with military history, feed into the research on, and interpretation of, new conflicts and special operational scenarios of the Bundeswehr.

Through their work the researchers at the ZMSBw are members of the academic community. They foster and maintain contacts with organisations, institutions and agencies at home and abroad as well as with university and non-university research facilities. Of increasing importance is cooperation with other Bundeswehr institutions engaged in training, research and education. The ZMSBw supports Bundeswehr missions through historical and social science analyses.



Wissenschaftlicher Oberrat Dr. Frank Reichherzer
Zentrum für Militärgeschichte und Sozialwissenschaften der Bundeswehr
Potsdam

ZMSBwEingang@bundeswehr.org

Military times – a history of time in the modern age

Time – almost every part of the military is affected by it. This project identifies places and objects, individuals and practices that allow us to observe time in its various manifestations. It addresses ways in which the military deals with time constraints as well as the military's role in shaping time and establishing specifically modern time regimes. The project will thus help us to better understand the present and encourage us to reflect on things we would normally take for granted.

The military – both in war and peace – is confronted with “time” in a variety of ways, whether planning a battle, developing, manufacturing and procuring arms, engaging targets, implementing Directive 2003/88/EC concerning certain aspects of the organisation of working time, or dealing with the issue of military traditions. It becomes clear that time is not only a resource but also a problem. Time can also be shaped. Seen through the lens of the military, time appears manifold. This project aims to shed light on the many different forms of time, on how they are all interconnected and on how the military deals with them. This will not only deepen our knowledge about the military as an organisation and about the phenomenon of war, but also provide a history of time in the modern age.

How can we grasp the concept of time? Every aspect of our daily life is affected by time – something we can neither see nor touch – in a variety of obvious and not so obvious ways. For this reason, the project first attempts to identify different ways of managing time. First, we will take a look at places where time plays a central role, such as barracks, bunkers or war museums. Second, by focusing on certain individuals

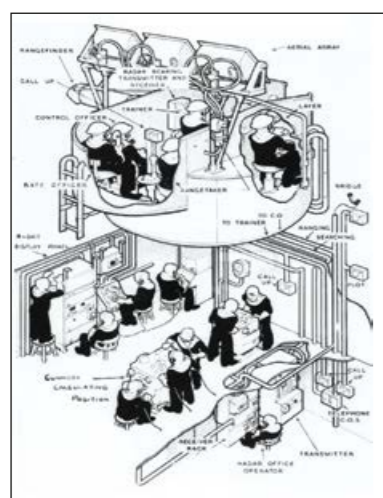


Fig. 1: Sketch showing part of the fire control system of a British K class destroyer with type 285 radar, 1939-45 (Source: https://upload.wikimedia.org/wikipedia/commons/a/a5/Radar_and_Electronic_Warfare_1939-1945_A28824.jpg)



Fig. 2: Wristwatches from WWI. From: University of Oxford First World War Poetry Digital Archive (Source: <http://ww1lit.nsms.ox.ac.uk/ww1lit/items/show/5979>)



Fig. 3: 1:10,000 scale Passchendaele army barrage map, 1917. From: War Diaries of the General Staff Headquarters, 1st ANZAC Corps – Part 6 of 6 for October 1917 (Source: [https://commons.wikimedia.org/wiki/File:Second_Battle_of_Passchendaele_-_First_Stage_\(October_26\)_Barrage_Map.jpg](https://commons.wikimedia.org/wiki/File:Second_Battle_of_Passchendaele_-_First_Stage_(October_26)_Barrage_Map.jpg))

such as officers, draftees and prisoners of war, economies of time become apparent. Third, objects such as watches, military bicycles and machine guns help us to visualise other forms of time. And fourth, practices such as giving orders, marching and fighting reveal fundamental time structures.

A wristwatch dating back to World War I provides valuable insights into the concept of time. A watch could be seen on nearly every soldier's wrist during World War I. The watch, usually part of the soldier's personal belongings, became an indispensable item of military equipment. A handbook for British officers recommended the “illuminous wristwatch” as the number one item to buy prior to deployment – even before a revolver, binoculars or waterproof trenchcoat. But why was the wristwatch so important? I believe that it transformed time into a linear, mathematical and even mechanical concept. Under the specific conditions of industrialised warfare, the abstraction of time became a critical means of conducting war and the wristwatch a symbol of modern warfare.

Approximate references to time such as “at dawn”, which were open to interpretation, were common until the second half of the 19th century in military operations and orders. During World War I, military manuals stated that time deviations should not exceed 30 seconds. The Great War became a war against, and for, time. Time and the watch evolved into an instrument – if not to say a meta-weapon – of industrialised warfare. From the “Big Strategy” to small skirmishes, warfare increasingly depended on the synchronisation of complex and interwoven processes. But the reverse was also true as the enemy could be attacked by desynchronising its time sequences.

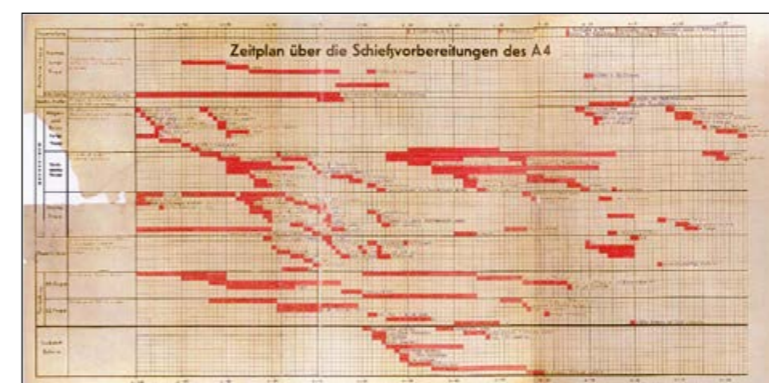


Fig. 4: Timetable for preparing and firing an A4 (V2 rocket). From: A4-Fibel, 1944 (Source: https://archive.org/details/A4-Fibel_1944_167p/page/n165)



Fig. 5: Four “stick” commanders of 22nd Independent Parachute Company, British 6th Airborne Division, synchronising their watches at about 11 pm on 5 June, the day before D-Day, Allied Landing in Normandy (Source: <https://www.iwm.org.uk/collections/item/object/205193035>)

The wristwatch had become not only a military tool but also a symbol and icon that seemed to give credence to the illusion that managing time was the key to controlling the chaos of war. Beyond helping to organise warfare, the watch's steady ticking and the movement of its hands gave the soldier a sense of structure and orientation amid the chaos and prevented him from becoming lost as the war distorted the normal perception of time.

This project illustrates the evolution of a modern and specifically Western concept of time. It also highlights coexisting and conflicting concepts of time and ways of dealing with them. This will help us to better understand the present and encourage us to reflect on things we normally take for granted, such as time. This will in turn open up new perspectives that can benefit our daily lives.

Jéronimo L. S. BARBIN, M.A.
Zentrum für Militärgeschichte und Sozialwissenschaften
der Bundeswehr (ZMSBw)
Potsdam

ZMSBwEingang@bundeswehr.org

Military doctrines as a research topic

The PhD project “From Stabilisation to Counterinsurgency. Doctrinal Change in Germany and France” examines the doctrinal adjustments of German and French forces during their deployment in Afghanistan between 2001 and 2014.

Military doctrines are important security policy documents that set out principles for undertaking military action. Armed forces operate in accordance with these principles. Decades of increased multinationalisation of military operations as well as the integration of military units and membership in international organisations has led to extensive harmonisation of doctrines among Western armed forces.

Nevertheless, numerous substantive and formal differences between national military doctrines can still be identified, with subsequent consequences for multinational military operations. These military “styles” can lead to confusion and misunderstandings between partners, make cooperation difficult or even jeopardise interoperability and the success of multinational missions.

Such national divergences came to light particularly during the Afghanistan mission, when the local security environment changed dramatically in 2007 and the original stabilisation mission evolved into a counterinsurgency operation.



Fig. 1: US, French and German counterinsurgency doctrines



Fig. 2: Bundeswehr soldiers in Afghanistan (Source: ISAF HQ Public Affairs Office, 2009)

The more than 40 participating countries of the International Security Assistance Force (ISAF) reacted in very different ways to these changes, a prime example being the divergent doctrinal adjustments of the French and German armed forces.

While the former released a tactical counterinsurgency doctrine in 2009, followed by a joint doctrine in 2010, the Bundeswehr published the “Leitfaden Aufstandsbewältigung” only in 2013 after considerable hesitation and difficult preparatory work – a guideline that has never become official doctrine.

The PhD project “From Stabilisation to Counterinsurgency. Doctrinal Change in Germany and France” investigates why the doctrinal adjustments of the French and German armed forces between 2001 and 2014 differed in so many ways. In order to answer this question, three different theoretical explanations of doctrinal change are examined at the interface between military sociology, political science and the theory of international relations.

These approaches were selected on the premise that armed forces have to take into account international demands, domestic expectations, organisational culture and micro-political self-interests and that military doctrines develop under these conditions.

Academic research on the evolution of German and French military doctrines is still in its infancy. This project therefore aims to fill an obvious research gap. At the same time, it strives to create transparency in this rather non-transparent but essential field. For one thing, democratic control of armed forces will only be effective if the basic patterns and premises

of military action are understood. And for another, knowledge about differences and similarities can facilitate multinational cooperation and the integration of European armed forces.



Fig. 3: French soldier in Afghanistan (Source: US Army, 2009)

4

Geoscientific Research

Geofactors are of key significance for all military capabilities and operations. The diverse and challenging responsibilities of the Bundeswehr mean that there is continuing growth in demand for valid information on the spatiotemporal variability of geospatial factors. This applies both to international crisis management operations and to national and collective defence, which is now being more greatly accentuated and includes deterrence measures being undertaken by NATO and the EU on the periphery of the Alliance, or also to humanitarian emergency and disaster relief.

The Bundeswehr Geoinformation Centre (BGIC) is the central institution of the Bundeswehr with geoscientific expertise.

It always provides up-to-date science-based information for all geospatial activities of the Federal Ministry of Defence (FMoD) and the Bundeswehr and addresses both short-term and medium-to-long-term tasks and issues. The geoscientific research activities are concentrated within the Applied Geosciences Directorate.

Acting as an interface between science and practice, the Applied Geosciences Directorate does the scientific groundwork for the transfer of knowledge and expertise for military use by the Bundeswehr.

The demand for research and development ensues from the necessity to

- identify mission-relevant geofactors and environmental influences at all times and at all locations and to assess their impacts on the conduct of operations,
- provide current and quality-assured geoinformation in preparation for operations and in-theatre deployment and
- render geoscientific advice and support to field forces and the FMoD.

Such comprehensive geoinformation support is ensured through the research and development work carried out in 18 geoscientific disciplines.

The following articles highlight four examples of geoscientific research conducted in 2018. They are indicative of the wide range of geoinformation support required by the Bundeswehr in international crisis management as well as for national and collective defence.



ORR'in Dr.-Ing. Barbara Görres
Zentrum für Geoinformationswesen der Bundeswehr
Euskirchen

ZGeoBwChdSt@bundeswehr.org

OPTIMAP: Software for providing space weather information

Space weather influences a wide range of technical systems of the Bundeswehr and may affect how they function and, in extreme cases, even cause their failure. The evaluation of many different geodetic observations and their combination with solar physics using the new OPTIMAP software allows us not only to accurately describe space weather but, in particular, to forecast it.

Occurrences and changes in near-earth space that are caused by solar radiation are referred to as "space weather". Space weather may have an effect on technical systems of the Bundeswehr. In the case of what are known as solar storms, which cause ionospheric disturbances in the atmosphere, it may affect how these systems function and, in exceptional cases, even cause them to fail. Depending on the event, it may take a few minutes or hours, sometimes even days, between the occurrence on the sun and the initial occurrence on earth.

This applies to high-frequency and satellite communications, the operation and utilisation of satellite navigation systems (GPS and other GNSS) and of remote sensing satellites, as well as other technical infrastructure. As a result, there is extensive need for relevant advice in the Bundeswehr. Particularly for the planning of operations in the context of missions and exercises, it is necessary to assess and take into consideration the effects of the ionosphere on the aforementioned systems. A forecast is imperative. As an interministerial establishment, the German Space Situational Awareness Centre also requires relevant information.



Fig. 1: OPTIMAP logo

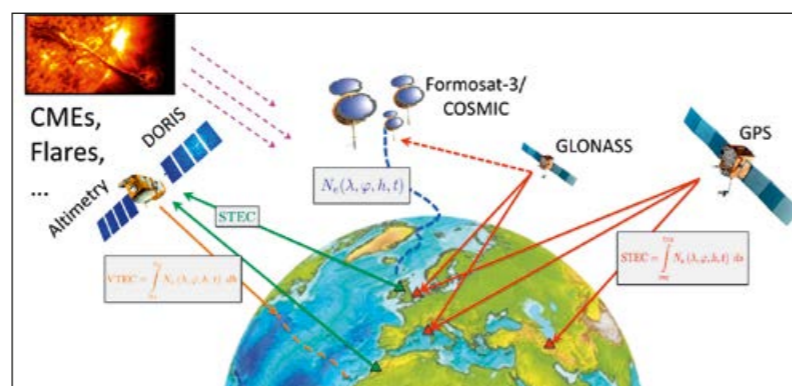


Fig. 2: Combination of geodetic observation techniques and methods of solar physics

The principal objective of this project is to establish an operational service for providing ionospheric information (OPTIMAP) at the Space Situational Awareness Centre (Fig. 1). This involves developing the necessary software. The OPTIMAP project focuses on combining space geodetic observations with solar observations and solar wind data of solar physics (Fig. 2). Hourly blocks of observation are evaluated sequentially by means of Kalman filtering. For the purpose of global modelling of VTEC (vertical total electron content), two-dimensional basis functions are used. Polynomial B-splines are used to represent latitudinal variations in VTEC, trigonometric B-splines to represent longitudinal variations. They allow the generation of multi-scale representation based on B-spline wavelet functions (Fig. 3). This replaces the more traditional means of representation using spherical harmonics since, compared to the latter, they have a localising character. They are suited to modelling an irregular distribution of input data and may be used for multi-scale modelling, which makes it possible to combine global and regional modelling approaches.

Two-dimensional VTEC maps (Fig. 4) for current points in time are created as a product, dependent on the latency period up to the availability of observation data but mainly for the purpose of prediction for the following days. Finally, the computed electron density model also allows a three-dimensional representation of the ionosphere to specify any amount of VTEC values.

The results are validated by comparing the VTEC values with the results of the IGS (International GNSS Service) and its analysis centres, and the validation reveals that the deviations of the OPTIMAP results are at a level usual for these analysis centres.

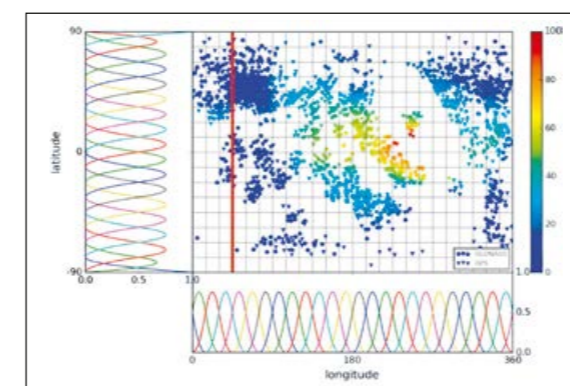


Fig. 3: VTEC modelling using polynomial (latitude) and trigonometric B-spline functions (longitude)

Whereas the OPTIMAP maps are already available in three hours, it may take up to three weeks for IGS products.

Finally, aside from providing information on the current state of the ionosphere, OPTIMAP also makes it possible for the Bundeswehr to forecast space weather, which as time elapses is similar to an increasingly reliable early warning, so that appropriate protection measures can be taken or alternative procedures implemented. The forecast period is currently five days.

The required algorithms and the associated software were introduced during several international expert meetings. The first part of the specialist project was completed in autumn 2018.

The next step will be to extend OPTIMAP to include the real-time processing of observation data and analysis of ionospheric structures – the latter causing what are known as scintillations. Significant improvements are anticipated in particular for operational in-theatre use.

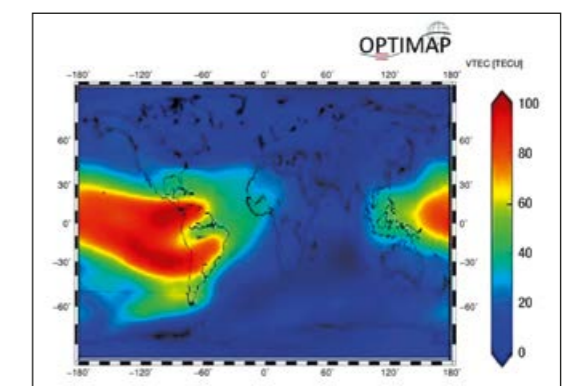


Fig. 4: VTEC map during the St. Patrick's Day solar storm in March 2015

OTL Dr. Stefan Wirtz
Zentrum für Geoinformationswesen der Bundeswehr
Euskirchen

zgeobwv2geoinformatik@bundeswehr.org

Prof. Dr. Wolfgang Reinhardt
Universität der Bundeswehr München
Neubiberg

internetgis@unibw.de

Quality evaluation of geo-web services

As part of a cooperation agreement between the Bundeswehr Geoinformation Centre in Euskirchen and the geoinformatics department at the Bundeswehr University Munich, a quality evaluation model was developed for geo-web services along with a sub-service for delivering the quality information to the user. The concepts were implemented in a prototype and tested successfully.

The GeoInfo database of the Bundeswehr provides data through geo-web services (GWS) (Fig. 1). These services must meet ISO (International Organisation for Standardisation) and OGC (Open Geospatial Consortium) standards as well as DGIWG (Defence Geospatial Information Working Group) profiles. At the same time, certain quality standards must be met.

According to the ISO definition, the term quality is generally understood as “fitness for use”. However, in order to translate this general term into a useful structure, it is necessary to define quality elements as well as measuring methods with which to quantify the quality of these elements.

No standard is available for the purpose of evaluating the quality of GWS. Proposals have been made by several organisations for services in general and one proposal for GWS by INSPIRE (Infrastructure for Spatial Information in Europe), but no approach has been agreed on in the geoinformation community.



Fig. 1: Providing geoinformation using different geo-web services

Name	Definition	Multiplicity	Obligation
Accessibility	Represents whether the web service is operational, meaning that the service is capable of serving the client's requests.	Once	M
Interoperability	Describes with which client software the service can be used.	Zero or once	O
Regulatory	Describes to which standards and regulations the service complies with.	Zero or once	O
Security	Describes, which security measures are taken into account for running the service.	Zero or once	O
Robustness	Describes how incomplete or false inputs are handled.	Zero or once	O
Correctness of response	Percentage of responses that are correct. The precondition is, that a valid request was send to the service and a response was send to the client, which is not an error message.	Zero or once	O
Performance	Time, that the server needs to handle the maximum amount of requests with the given reliability.	Once	M
Capacity	Number of requests the server is able to handle in a certain time interval	Zero or once	O

M – Mandatory, O – Optional

Fig. 2: Overview of name, definition, multiplicity and obligation for all selected quality elements

The project consisted of four work packages (WP):

- WP1: Concept of a general quality model for GWS
- WP2: Definition of a workflow for measuring quality elements
- WP3: Technical implementation of the concept to evaluate their feasibility
- WP4: Development of a concept to deliver the quality information to the user

WP1 involved defining a set of elements describing the quality of GWS, referred to as Quality of Service (QoS), on the basis of a review of the relevant literature and on specialist knowledge. The chosen elements were accessibility, interoperability, compliance, security, robustness, correctness of response, performance, capacity (Fig. 2).

WP2 focused on defining a workflow for measuring the quality elements. The workflows for all the quality elements to be examined were described in relation to the mandatory requirements of WMS (web-map service) and WFS (web-feature service). For all workflows that would require a large amount of manual input, Java-based client applications were developed to automate the process.

WP3 consisted of the technical implementation of the concept in the form of a prototype with a view to testing the developed concepts. The main steps for this WP involved setting up the virtual machines, installing and configuring the software and finally testing the concept (creating the test plan, carrying out the tests, evaluation and, if necessary, reworking). The virtual machines were set up in a test bed and all the software tools developed were included in this test environment (Fig. 3).

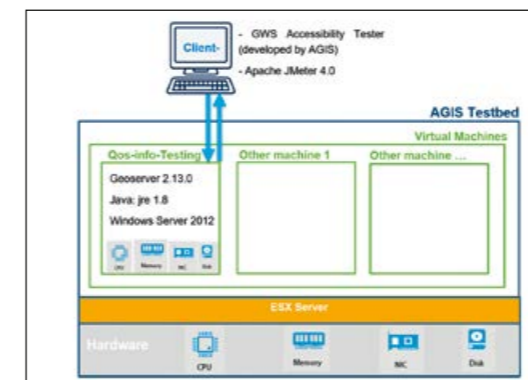


Fig. 3: The test bed

For test purposes, a number of specific geospatial datasets were used that consisted of vector data as well as raster data with variations in the parameters image size, bounding box and number of layers in the case of WMS.

WP4 focused on developing a concept for delivering the quality information to the user. To convey the quality information to the user, the information was modelled in an appropriate format. This model provides a data schema (the quality information in this case), which stores the data in a well-defined format. This quality information includes information about the QoS elements for WMS (WMS_QualityInfo) and WFS (WFS_QualityInfo) as well as the corresponding requests. To formalise this quality information, the XML Schema Definition (XSD) technique was used.

There are two options for delivering the quality information to the user: (1) Include the quality information in the Get-Capability request and the corresponding WMS or WFS document or (2) Define a new sub-service for WMS and WFS.

Due to the excess of information in the GetCapability XML documents for GWS, the second option was chosen. This involved implementing a new sub-service called GetQualityInfo for GWS, which delivers the quality information for the GWS to the user in XML format. The required sub-services for WMS and WFS were implemented and tested successfully.

To sum up, a quality model for geo-web services and a sub-service for delivering the quality information to the user were developed. The concepts were implemented in the form of a prototype and tested successfully.

Dr. Steffen Schobel
Zentrum für Geoinformationswesen der Bundeswehr
Euskirchen

ZGeoBwChdSt@bundeswehr.org

Security risks and conflict constellations caused by global sea-level rise

A study is being conducted to assess the impact of sea-level rise on national and international security and its potential to cause migration and initiate or intensify crises and conflicts.

The rising sea level is just a physical consequence of global warming, which is causing an increasing sea water volume due to water expansion as well as the inflow of meltwater from glaciers and the pole caps. This will inevitably result in the loss of mainland areas and islands and in changes to coastlines. Consequently, the borders of national territories, including land areas, territorial waters and airspace, are subject to dynamic shifts that may even lead to complete loss of the territory.

The environment, settlement and economic areas, infrastructure, private property, seaports and (mega) cities are all under threat and millions of people are affected. The conflict potential is extremely high all over the world and the stressor is increasing in both a cumulative and non-linear manner.

As there are considerable uncertainties concerning the extent of sea-level rise in terms of space and time, the scenarios vary greatly. They range from a rise of 0.3 m to 2 m by the year 2100 to a rise of 2.5 m to 5 m by 2300. In the event of the ice sheets completely melting, it is even estimated that the sea level will

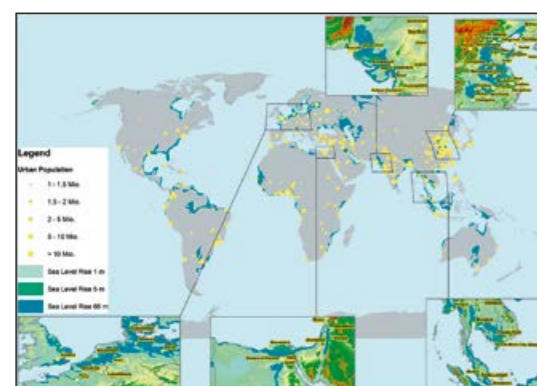


Fig. 1: Global flooded areas for the scenarios: 1 m, 5 m and 66 m sea-level rise (Design: Albrecht; Source: BwGIC)

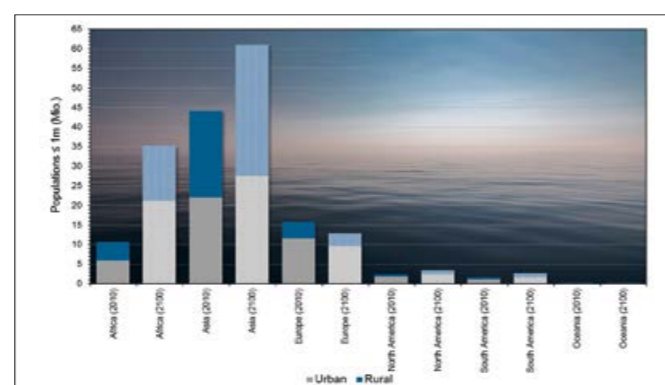


Fig. 2: Urban-rural population in coastal regions (≤ 1 m above sea level) for the years 2010 and 2100 (Design: Schobel; Source: Center for International Earth Science Information Network (CIESIN)/Columbia University, 2013. Low Elevation Coastal Zone (LECZ) Urban-Rural Population and Land Area Estimates, Version 2. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). <https://doi.org/10.7927/H4MW2F2J>, 08. 04. 2019)

rise by up to 70 m. Valid empirical evidence of this can be found in the earth's recent history (interglacial period of the Pleistocene).

A rise of the sea level by no more than 1 m will not only affect many island states but also result in the loss of substantial mainland areas. This will lead to changes to the borders of the national territories concerned and, consequently, to their sovereign rights (Fig. 1). The United Nations Convention on the Law of the Sea (UNCLOS) governs a state's use of the seas. The low-water line serves as the base line for delimiting the maritime zones that, with increasing distance, have graduated levels of territorial sovereign rights. In the Exclusive Economic Zone (EEZ, 200 nautical miles), for example, sovereign rights apply to all submarine resources (oil, gas, fish). If the sea level rises, the base line will change and with it all the maritime zones it defines, along with their specific sovereign rights.

There is, however, no international arrangement on how to handle a dynamically changing base line. Currently, conflict constellations in the Arctic and in the South China Sea demonstrate the geopolitical relevance of claims to power related to the EEZ. Other conflicts are therefore very likely to arise.

In 2010, about 75 million people lived in coastal regions lying less than 1 m above sea level. By 2100, their number will have increased to about 116 million, and in the event of the sea level rising by 5 m, the number could reach 490 million (Fig. 2). Even if sea-level rise has a global impact, its effects differ from area to area, as coastal morphology and height above sea level affect the vulnerability of coastal regions. The coastal states



Fig. 3: Flooded hut in Bangladesh (Source: Climate Centre, <https://www.flickr.com/>, CC BY-NC 2.0, 08. 04. 2019)

concerned differ considerably in socio-economic terms and, consequently, in term of their potential for adjustment. Developing countries have low resilience (fragile statehood, poverty, low food security, poor health care, etc.; Fig. 3). The stressor "sea-level rise" has a de-stabilising effect such that migration and conflicts are very likely to occur as a result. Industrial countries have better financial and technological means, but maintaining the status quo will increasingly put pressure on the national economies concerned and place them at a disadvantage in international competition (Fig. 4).

With a sea-level rise of no more than 1 – 2 m, even industrial countries will be unable to adequately protect their coasts. The European controversy concerning the current refugee situation, but also the outbreaks of violence after the floods in New Orleans, suggest that crisis potential and its destabilising effect can even be found in states thought to be resilient.



Fig. 4: Thames Barrier prevents the floodplain of most of Greater London from being flooded (Source: diamond greezer, <https://www.flickr.com/>, CC BY-NC-ND 2.0, 08. 04. 2019)

OTL Andreas Roitzsch
Zentrum für Geoinformationswesen der Bundeswehr
Euskirchen

ZGeoBwChdSt@bundeswehr.org

Use of hyperspectral data

In preparation for the use of hyperspectral data from the EnMAP (Environmental Mapping and Analysis Programme) satellite mission, it is necessary to assess the relevant potential and current state of the art with regard to existing methods, especially in the context of geoinformation support in the planning of Bundeswehr amphibious operations.

The success of amphibious operations depends to a large extent on detailed knowledge of the geospatial factors of the landing area. Due to the physical distance to the mission areas of the naval forces and the often limited access to these areas, mostly the only option for geospatial assessment is to use remote sensing data.

The aim of this technical project is to develop a procedure for supporting amphibious operations of the naval forces by determining the depth of coastal waters, making a bathymetric map that is seamless in the transition from shore to sea, and identifying the land cover (vegetation, ground material) in the shore area without having in-situ information.

In order to achieve this goal, it was necessary to develop new procedures and techniques for the evaluation of hyperspectral remote sensing data. Therefore, a performance contract was concluded by the German Aerospace Centre (DLR), the Fraunhofer Institute of Optronics, System Technologies and Image Exploitation (Fraunhofer IOSB) and the Bundeswehr Geoinformation Centre.

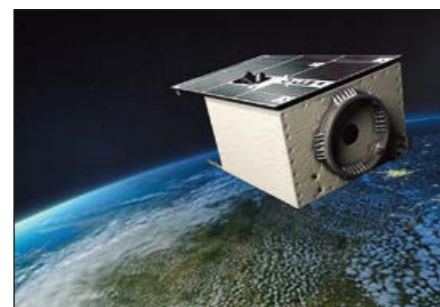


Fig. 1: EnMAP – Germany's hyperspectral satellite for earth observation (Source: DLR)



Fig. 2: Airborne laser scanner RIEGL VQ-580 (Source: Fraunhofer IOSB)



Fig. 3: Aerial image of the survey area in the Bay of Wismar (Source: Fraunhofer IOSB)

This technical project focuses on tapping into the potential of hyperspectral data for geoinformation support in preparation for the operational availability of data from the EnMAP hyperspectral sensor. The first German EnMAP hyperspectral satellite mission is due to be launched in December 2020.

As no real EnMAP data was available, procedural development was based on the airborne acquisition of hyperspectral data. An aircraft with a hyperspectral sensor system acquired data over a test area in the Bay of Wismar. In a simulation, artificial EnMAP data with a spatial resolution of 30 m was generated on the basis of this high-resolution hyperspectral data. The electromagnetic range covered and the spectral resolution of the sensor system are comparable to the characteristics of EnMAP. As this photo flight campaign was being conducted, comparison data was sampled in the shore area both above and below water.

Procedural development focused on three core areas: data fusion, classification and bathymetry.

The fusion of hyperspectral and multispectral satellite image data allows a combination of high levels of spatial and spectral resolution. This is helpful in the subsequent step, i.e. classification, where the land cover can be better categorised.

The unsupervised procedure for “land” classification is based on a decision tree that draws on scientific findings. The water-land module first generates a water-land mask using information from multiple channels of the hyperspectral image. The module for the land cover portions determines the percentages of the three categories soil, water-repellent surface, and photo-

synthetically active and inactive vegetation. For water-repellent surfaces, the soil parameter module also determines the relative share of three main mineral groups.

The bathymetric information can be obtained from hyperspectral data and a spectral seabed database, as – depending on the wave length – water changes the reflection of the subsurface, with the spectral changes depending on the water depth. The procedure used for water areas is based on an algorithm developed by the German Aerospace Centre that models the wave length-dependent impact of water depth on reflection range and on the basis of this calculates the water depth. In addition, it is possible to identify the type of land cover and to estimate water parameters.

For integration into an ESRI environment, the procedures developed for data fusion, land classification and bathymetry will be combined to create a user-friendly software tool. Upon completion of the project in April 2019, this plug-in will be available to the Bundeswehr Geoinformation Service for the purpose of providing geoinformation advice and support.



Fig. 4: Comparative measurements of the ground (ground truthing) in the Bay of Wismar (Source: Fraunhofer IOSB)



Fig. 5: DLR measuring system for spectral measurements (Source: DLR)

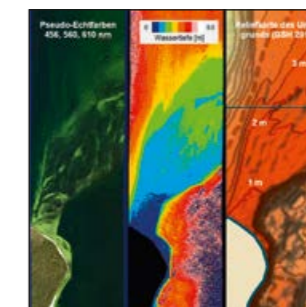


Fig. 6: Comparison of results from the bathymetric module. Left: section of a HySpex scene. Centre: calculated depth of water. Right: section of relief map No. 2943 provided by the Federal Maritime and Hydrographic Agency of Germany (2012) (Source: Fraunhofer IOSB)

5

Cyber and Information Technology Research

Military research in the fields of cyber and information technology takes place as a trade-off between civilian disruptive innovations and military constraints. Cyber and information technologies must be able to function quickly and reliably, even under extreme environmental, operational and combat conditions.

Both the spectrum of operational demands and the requirements regarding interoperability with national and international partners and supranational organisations are challenges for which optimum solutions are continuously sought. For this reason, innovations appearing on the market need to be made available for the information and communication network of the Bundeswehr as quickly as possible.

The fields of research relating to cyber and information technologies touch on individual topics of classical cyber security – for example firmware analysis – as well as communication within heterogeneous networks and associated applications, such as designing a private cloud that can operate in a military environment.



TORR Stefan Rechmeier
 Bundesamt für Ausrüstung, Informationstechnik und Nutzung
 der Bundeswehr (BAAINBw)
 Koblenz

BAAINBwPosteingang@bundeswehr.org

Interoperable Cloud Computing (IOCC)

In 2018 it was possible to continue cloud computing activities in a targeted manner. These focused on conceptual approaches to enhancing the existing test bed and on developing a target architecture. Moreover, both the creation and evaluation of user-specific solutions will serve as a basis for future studies.

The objective of the “Interoperable Cloud Computing (IOCC)” R&T project is to examine how cloud technology could be used within the Bundeswehr IT System and to ascertain how valuable this technology could be to support military operations.

In this context, the focus is on making the technology available independent of location, time or terminal, and in a simplified manner, such as by means of self-service portals. In addition, we focus in particular on military demands with regard to self-sufficiency, data control and IT security.

Available public clouds do not meet these demands. For this reason, commercial private cloud solutions will be analysed which can be operated by the Bundeswehr itself or by external service providers using federally owned IT infrastructure. This will be the Bundeswehr's private cloud.

In earlier studies (IOCC 1 – 4) both a cloud computing reference architecture for the Bundeswehr (Fig. 1) and several cloud service management concepts were developed. It was also possible to gain valuable knowledge regarding cloud

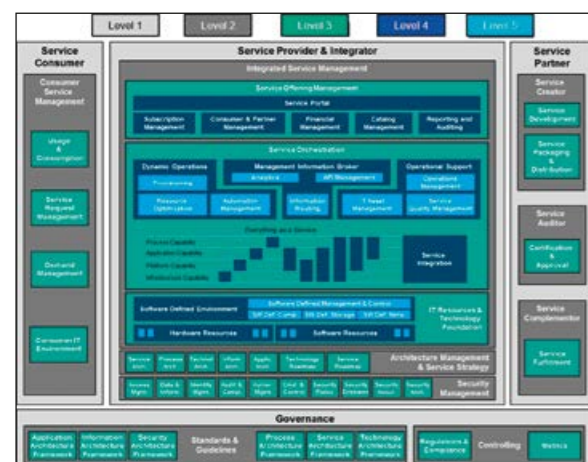


Fig. 1: Cloud computing reference architecture for the Bundeswehr (Source: BWI GmbH – in the context of IOCC)

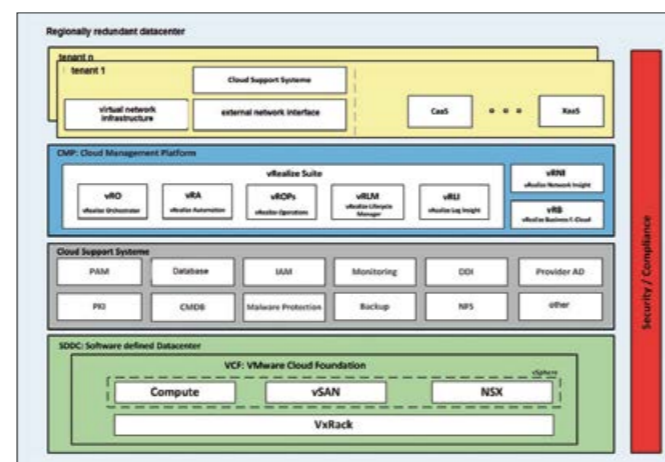


Fig. 2: IOCC test bed (Source: BWI GmbH – in the context of IOCC)

computing involving virtual desktop infrastructures, which were derived essentially from the operation of a prototype test bed. Additional results include use cases that served as a basis for subsequent trials.

IOCC 5, which ran in 2018, focused on enhancing cloud service management, on preparing service documentation for the test bed (Fig. 2), including its planned expansion, and on developing a private cloud architecture for the Bundeswehr. Furthermore, complementary cloud computing services were analysed.

Existing IT service management concepts were adapted and a training concept for the Bundeswehr service development framework, including a trial phase, was established. Based on functional analysis of selected parts of the Bundeswehr IT System, a target architecture could be identified along with the necessary tests. In addition, innovative technical solutions were analysed and tested such as the flexible provision of geospatial information using cloud computing technologies.

Figure 3 illustrates an operational approach developed in IOCC 5, including

- activities in and from Germany in support of operations (stationary operation in Germany and for agencies abroad)
- operations abroad (relocatability) and
- external partners (interoperability with partners on operations, exercises and in connection with activities in and from Germany in support of operations).

It also represents various management elements of an overall cloud management system (CMS).

In this context, the central CMS enables comprehensive cloud management for all core nodes and security domains. Stationary core nodes as well as relocatable mission nodes consist of a management and service provision element. User nodes, which are merely user interfaces, do not have a management element. Nor do edge nodes, which connect mission nodes with user nodes.

The current test bed is due to be expanded in 2019. The improved installation will allow practical testing of recently obtained results, including in particular CMS elements.

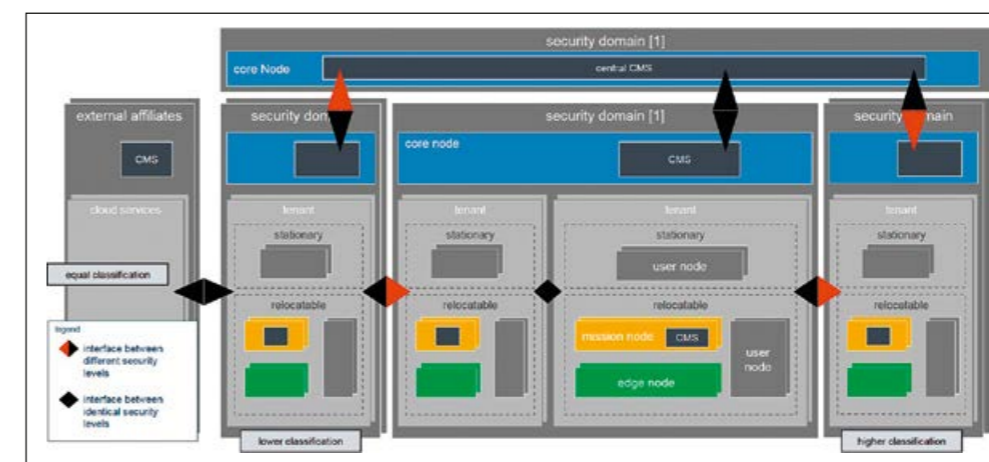


Fig. 3: Operational approach (Source: BWI GmbH – in the context of IOCC)

TRR Andreas Meisenheimer
 Wehrtechnische Dienststelle für Informationstechnologie
 und Elektronik (WTD 81)
 Greiding

wtd81210@bundeswehr.org

TORR Stefan Kolm
 Wehrtechnische Dienststelle für Informationstechnologie
 und Elektronik (WTD 81)
 Greiding

wtd81210@bundeswehr.org

Firmware analysis

Cyber attacks are being conducted more and more frequently by state actors and are thus acquiring a new dimension. Methods are being explored to identify outdated software in devices. Within the Bundeswehr, devices must be tested by manufacturers for their vulnerability to cyber attacks. In most cases, there is no source code available.

Most functions of modern devices are not wire-based but implemented by means of software. As is the case with servers and desktop PCs, the software consists of an operating system and application and server software specific to the function of the device. In the case of networked devices, the software pre-installed by the manufacturer is referred to as “firmware”. Since software development and maintenance costs are high, manufacturers seldom develop all of the necessary software themselves, but buy it or use open-source products.

The easiest way to determine vulnerabilities is by identifying the software and its specific version contained in the firmware. This simply needs to be compared with a vulnerabilities database, e.g. Common Vulnerabilities and Exposures (CVE). Figure 1 illustrates the severity of the problem of outdated software in networked devices. It shows that 70 % of Linux-based devices in the Fraunhofer FKIE firmware database still use a 2.6 kernel. The last security update for this kernel was published in March 2016. This means that at least 70% of the Linux-based devices in the database are susceptible to a large number of security gaps in the Linux kernel that have been identified over the past

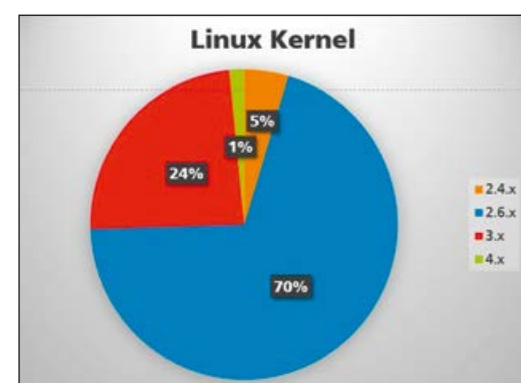


Fig. 1: Linux kernel versions in the Fraunhofer FKIE firmware database (Source: Fraunhofer FKIE)



Fig. 2: Firmware Analysis and Comparison Tool (Source: https://github.com/fkie-cad/FACT_core)

two years. Such outdated software versions can be detected very effectively by means of pattern matching as used by the Firmware Analysis and Comparison Tool (FACT).

The problem with this approach is the automated generation of patterns which – independent of the architecture – identify just one software version and do not generate any false positives. For this purpose, a large representative test corpus – the first of its kind in this field of research – was compiled from various open-source programmes that are often contained in firmware. These programmes were adapted to different architectures and optimisation levels. Based on this ground truth, three procedures were evaluated. The first procedure is based on selecting common byte sequences that should be as unambiguous as possible. The second procedure uses API (Application Programming Interface) call sequences in order to clearly identify functions. The third procedure constitutes a further development of the first procedure and uses regular expressions in addition to common byte sequences in order to identify the version number in the binary file.

In many cases, it is only with considerable effort that the firmware contained in devices can be accessed. For this reason, black box approaches are of interest since the devices can be analysed without knowing anything about the firmware and without manipulating the hardware.

Depending on the procedure, it is also possible to identify previously unknown security gaps in the software of the device. Initially, a test bed was developed that integrates the devices to be tested into an Ethernet or wireless network and at the same time makes it possible to monitor the entire network

traffic of the device and to transmit any network packages to it. Based on this, the Automated Black Box Analysis Tool (ABBA) was developed. This tool initially tries to identify services and the underlying software of the devices to be tested. Subsequently, plug-ins are used in order to identify security gaps in these services. To this end, a password cracker for web services and a fuzzer for the Dynamic Host Configuration Protocol (DHCP) were implemented initially on a prototype basis. The DHCP fuzzer transmits DHCP packages to the device which include random values usually not specified in the protocol. If the device or individual services of the device crash, or if the response times of the device increase considerably, it is likely that implementation errors have been identified which indicate possible security gaps.

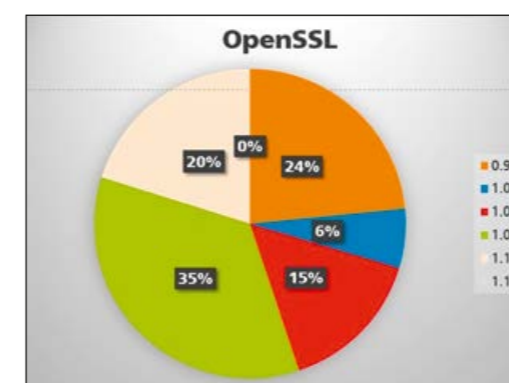


Fig. 3: OpenSSL versions in the Fraunhofer FKIE firmware database (Source: Fraunhofer FKIE)



6

Appendix





Bundesministerium
der Verteidigung

Bundesministerium
der Verteidigung
Postfach 13 28
53003 Bonn
Internet: www.bmvg.de

Abteilung Ausrüstung - A II 5
phone: +49 (0) 228 / 99 24 - 1 41 66
fax: +49 (0) 228 / 99 24 - 35 94
email: BMVgAII5@bmvg.bund.de

Abteilung Ausrüstung - A II 6
phone: +49 (0) 228 / 99 24 - 1 41 80
fax: +49 (0) 228 / 99 24 - 4 41 89
email: BMVgAII6@bmvg.bund.de

Abteilung Cyber / Informationstechnik
- CIT I 2
phone: +49 (0) 228 / 99 24 - 2 61 22
fax: +49 (0) 228 / 99 24 - 3 35 61 21
email: BMVgCITI2@bmvg.bund.de

Abteilung Führung Streitkräfte - FüSK III 3
phone: +49 (0) 30 / 2004 - 2 48 38
fax: +49 (0) 30 / 2004 - 18 03 68 13
email: BMVgFueSKIII3@bmvg.bund.de

Abteilung Führung Streitkräfte - FüSK III 5
phone: +49 (0) 30 / 20 04 - 2 48 54
fax: +49 (0) 30 / 20 04 - 8 97 00
email: BMVgFueSKIII5@bmvg.bund.de

Abteilung Personal - P I 5
phone: +49 (0) 30 / 18 24 - 2 31 57
fax: +49 (0) 30 / 18 24 - 8 95 40
email: BMVgPI5@bmvg.bund.de

Abteilung Personal - P III 5
phone: +49 (0) 228 / 99 24 - 1 33 51
fax: +49 (0) 228 / 99 24 - 4 35 30
email: BMVgPIII5@bmvg.bund.de



Bundesamt für Ausrüstung, Informations-
technik und Nutzung der Bundeswehr
(BAAINBw)
Ferdinand-Sauerbruch-Straße 1
56073 Koblenz
phone: +49 (0) 261 / 400 - 0
fax: +49 (0) 261 / 400 - 3866
email:
BAAINBwPosteingang@bundeswehr.org
Internet: www.baainbw.de



Helmut-Schmidt-Universität /
Universität der Bundeswehr Hamburg
Postfach 70 08 22
22008 Hamburg
phone: +49 (0) 40 / 65 41 - 1
fax: +49 (0) 40 / 65 41 - 28 69
email: forschung@hsu-hh.de
Internet: www.hsu-hh.de

Universität München

Universität der Bundeswehr München
Werner-Heisenberg-Weg 39
85579 Neubiberg
phone: +49 (0) 89 / 60 04 - 0
fax: +49 (0) 89 / 60 04 - 35 60
email: info@unibw.de
Internet: www.unibw.de



Kommando Heer
von-Hardenberg-Kaserne
Prötzelner Chaussee 25
15344 Strausberg
phone: +49 (0) 3341 / 58 - 1511
fax: +49 (0) 3341 / 58 - 1519
email: PIZHeer@Bundeswehr.org



Wehrtechnische Dienststelle für landgebundene
Fahrzeugsysteme, Pionier- und Truppentechnik
(WTD 41)
Kolonnenweg
54296 Trier - Grüneberg
phone: +49 (0) 651 / 91 29 - 0
fax: +49 (0) 651 / 91 29 - 26 00
email: WTD41posteingang@bundeswehr.org
Internet: www.baainbw.de/wtd41



Wehrtechnische Dienststelle
für Schutz- und Sondertechnik
(WTD 52)
Oberjettenberg
83458 Schneizlreuth
phone: +49 (0) 86 51 / 76 82 - 10 01
fax: +49 (0) 86 51 / 16 00
email: WTD52posteingang@bundeswehr.org
Internet: www.baainbw.de/wtd52



Wehrtechnische Dienststelle
für Luftfahrzeuge - Musterprüfwesen
für Luftfahrtgerät der Bundeswehr
(WTD 61)
Flugplatz
85077 Manching
phone: +49 (0) 84 59 / 80 - 1
fax: +49 (0) 84 59 / 80 - 20 22
email: WTD61posteingang@bundeswehr.org
Internet: www.baainbw.de/wtd61



Wehrtechnische Dienststelle
für Schiffe und Marinewaffen,
Maritime Technologie und Forschung
(WTD 71)
Berliner Straße 115
24340 Eckernförde
phone: +49 (0) 43 51 / 467 - 0
fax: +49 (0) 43 51 / 467 - 120
email: WTD71posteingang@bundeswehr.org
Internet: www.baainbw.de/wtd71



Wehrtechnische Dienststelle
für Informationstechnologie und Elektronik
(WTD 81)
Bergstraße 18
91171 Greding
phone: +49 (0) 84 63 / 652 - 0
fax: +49 (0) 84 63 / 652 - 607
email: WTD81posteingang@bundeswehr.org
Internet: www.baainbw.de/wtd81



Wehrtechnische Dienststelle
für Waffen und Munition
(WTD 91)
Am Schießplatz
49716 Meppen
phone: +49 (0) 59 31 / 43 - 0
fax: +49 (0) 59 31 / 43 - 20 91
email: WTD91posteingang@bundeswehr.org
Internet: www.baainbw.de/wtd91



Wehrwissenschaftliches Institut
für Schutztechnologien - ABC-Schutz
(WIS)
Humboldtstraße 100
29633 Munster
phone: +49 (0) 51 92 / 136 - 201
fax: +49 (0) 51 92 / 136 - 355
email:
WISPosteingang@bundeswehr.org
Internet: www.baainbw.de/wis



Wehrwissenschaftliches Institut
für Werk- und Betriebsstoffe
(WIWeB)
Institutsweg 1
85435 Erding
phone: +49 (0) 81 22 / 95 90 - 0
fax: +49 (0) 81 22 / 95 90 - 39 02
email: WIWeB@bundeswehr.org
Internet: www.baainbw.de/wiweb



Zentrum für Geoinformationswesen
der Bundeswehr
Frauenberger Straße 250
53879 Euskirchen
phone: +49 (0) 22 51 / 953 - 0
fax: +49 (0) 22 51 / 953 - 50 55
email: ZGeoBwEingang@bundeswehr.org



Zentrum für Militärgeschichte und Sozialwissen-
schaften der Bundeswehr
Zeppelinstraße 127/128
14471 Potsdam
phone: +49 (0) 331 / 97 14 - 501
fax: +49 (0) 331 / 97 14 - 507
email: ZMSBWEingang@bundeswehr.org
Internet: www.zmsbw.de



Institut für Mikrobiologie der Bundeswehr
Neuherbergstraße 11
80937 München
phone: +49 (0) 89 / 99 26 92 - 39 82
fax: +49 (0) 89 / 99 26 92 - 39 83
email:
InstitutfuerMikrobiologie@bundeswehr.org



Institut für Pharmakologie und Toxikologie
der Bundeswehr
Neuherbergstraße 11
80937 München
phone: +49 (0) 89 / 99 26 92 - 29 26
fax: +49 (0) 89 / 99 26 92 - 23 33
email:
InstitutfuerPharmakologieundToxikologie
@bundeswehr.org



Institut für Radiobiologie der Bundeswehr
in Verbindung mit der Universität Ulm
Neuherbergstraße 11
80937 München
phone: +49 (0) 89 / 99 26 92 - 22 51
fax: +49 (0) 89 / 99 26 92 - 22 55
email:
InstitutfuerRadiobiologie@bundeswehr.org



Zentrum für Luft- und Raumfahrtmedizin
der Luftwaffe
Flughafenstraße 1
51147 Köln
phone: +49 (0) 22 03 / 9 08 - 16 10
fax: +49 (0) 22 03 / 9 08 - 16 14
email:
zentrlurmedlwpresseoea@bundeswehr.org



Zentrum für Softwarekompetenz der Bundeswehr
Abteilung II Entwicklung und Integration
Geierstraße 7
53881 Euskirchen
phone: +49 (0) 2255 / 94571 - 3000
email: ZSwKBw@bundeswehr.org



Schiffahrtmedizinisches Institut
der Marine
Kopperpähler Allee 120
24119 Kronshagen
phone: +49 (0) 431 / 54 09 - 17 01
fax: +49 (0) 431 / 54 09 - 17 78
email: SchiffMedInstM@bundeswehr.org
Internet: www.marine.de



Institut für Präventivmedizin
der Bundeswehr, Abteilung A
Aktienstraße 87
56626 Andernach
Dienstort:
Andernacher Straße 100
56070 Koblenz
phone: +49 (0) 261 / 896 - 7 70 01
fax: +49 (0) 261 / 896 - 7 70 99
email:
InstPraevMedBw@bundeswehr.org
Internet:
www.sanitaetsdienst-bundeswehr.de



Deutsch-Französisches
Forschungsinstitut Saint-Louis
Postfach 1260
79547 Weil am Rhein
5, rue du Général Cassagnou
F-68300 Saint-Louis
phone: +33 (0) 389 / 69 50 - 00
fax: +33 (0) 389 / 69 50 - 02
email: isl@isl.eu
Internet: www.isl.eu



Streitkräfteamt
Pascalstraße 10s
53123 Bonn
phone: +49 (0) 228 / 12 - 43 83
fax: +49 (0) 228 / 12 - 33 41
email: SKALdP@bundeswehr.org
Internet:
www.streitkraefteamt.bundeswehr.de



Bundeswehrkrankenhaus Ulm
Oberer Eselsberg 40
89081 Ulm
phone: +49 (0) 731 / 17 10 - 0
fax: +49 (0) 731 / 17 10 - 23 08
email: BwKrhsUlm@bundeswehr.org
Internet: www.ulm.bwkrankenhaus.de



Psychotraumazentrum der Bundeswehr
Im Bundeswehrkrankenhaus Berlin
Scharnhorststraße 13
10115 Berlin
phone: +49 (0) 30 / 28 41 - 22 89
fax: +49 (0) 30 / 28 41 - 10 43
email: BwKrhsBerlin@bundeswehr.org
Internet: www.berlin.bwkrankenhaus.de



Fraunhofer-Verbund
Verteidigungs- und
Sicherheitsforschung VVS
Fraunhoferstraße 1
76131 Karlsruhe
phone: +49 (0) 721 / 60 91 - 210
fax: +49 (0) 721 / 60 91 - 413
email: info@iosb.fraunhofer.de
Internet: www.vvs.fraunhofer.de



Fraunhofer-Institut für
Kurzzeitdynamik,
Ernst-Mach-Institut EMI
Ernst-Zermelo-Straße 4
79104 Freiburg
phone: +49 (0) 761 / 27 14 - 101
fax: +49 (0) 761 / 27 14 - 316
email: info@emi.fraunhofer.de
Internet: www.emi.fraunhofer.de



Fraunhofer-Institut für
Hochfrequenzphysik und
Radartechnik FHR
Fraunhoferstraße 20
53343 Wachtberg
phone: +49 (0) 228 / 94 35 - 227
fax: +49 (0) 228 / 94 35 - 627
email: info@fhr.fraunhofer.de
Internet: www.fhr.fraunhofer.de



Fraunhofer-Institut für
Kommunikation, Informations-
verarbeitung und Ergonomie
FKIE
Fraunhoferstraße 20
53343 Wachtberg
phone: +49 (0) 228 / 94 35 - 103
fax: +49 (0) 228 / 94 35 - 685
email: info@fkie.fraunhofer.de
Internet: www.fkie.fraunhofer.de



Fraunhofer-Institut für
Angewandte Festkörperphysik
IAF
Tullastraße 72
79108 Freiburg
phone: +49 (0) 761 / 51 59 - 458
fax: +49 (0) 761 / 51 59 - 714 58
email: info@iaf.fraunhofer.de
Internet: www.iaf.fraunhofer.de



Fraunhofer-Institut für
Chemische Technologie ICT
Joseph-von-Fraunhofer-Straße 7
76327 Pfinztal
phone: +49 (0) 721 / 46 40 - 123
fax: +49 (0) 721 / 46 40 - 442
email: info@ict.fraunhofer.de
Internet: www.ict.fraunhofer.de



Fraunhofer-Institut für
Integrierte Schaltungen IIS
Am Wolfsmantel 33
91058 Erlangen
phone: +49 (0) 91 31 / 776 - 0
fax: +49 (0) 91 31 / 776 - 20 19
email: info@iis.fraunhofer.de
Internet: www.iis.fraunhofer.de



Fraunhofer-Institut für
Naturwissenschaftlich-
Technische Trendanalysen INT
Postfach 14 91
53864 Euskirchen
phone: +49 (0) 22 51 / 18 - 0
fax: +49 (0) 22 51 / 18 - 277
email: info@int.fraunhofer.de
Internet: www.int.fraunhofer.de



Fraunhofer-Institut für
Optronik, Systemtechnik und
Bildauswertung IOSB
Standort Karlsruhe
Fraunhoferstraße 1
76131 Karlsruhe
phone: +49 (0) 721 / 60 91 - 210
fax: +49 (0) 721 / 60 91 - 413
Standort Ettlingen
Gutleuthausstraße 1
76275 Ettlingen
phone: +49 (0) 7243 / 992 - 131
fax: +49 (0) 7243 / 992 - 299
email: info@iosb.fraunhofer.de
Internet: www.iosb.fraunhofer.de



Deutsches Zentrum für Luft- und Raumfahrt
 Programmkoordination Sicherheitsforschung
 (PK-S)
 Linder Höhe
 51147 Köln
 phone: +49 (0) 2203 / 601 - 40 31
 fax: +49 (0) 2203 / 673 - 40 33
 email: info-pks@dlr.de
 Internet: www.dlr.de/sicherheit



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Aerolastik DLR AE
 Bunsenstraße 10
 37073 Göttingen
 phone: +49 (0) 551 / 709 - 23 41
 fax: +49 (0) 551 / 709 - 28 62
 email: info-pks@dlr.de
 Internet: www.dlr.de/ae



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Aerodynamik und
 Strömungstechnik DLR AS
 Braunschweig:
 Lilienthalplatz 7
 38108 Braunschweig
 phone: +49 (0) 531 / 295 - 24 00
 fax: +49 (0) 531 / 295 - 23 20
 Göttingen:
 Bunsenstr. 10
 37073 Göttingen
 phone: +49 (0) 551 / 709 - 21 77
 fax: +49 (0) 551 / 709 - 28 89
 email: info-pks@dlr.de
 Internet: www.dlr.de/as



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Antriebstechnik DLR AT
 Linder Höhe
 51147 Köln
 phone: +49 (0) 2203 / 601 - 21 44
 fax: +49 (0) 2203 / 673 - 10
 email: info-pks@dlr.de
 Internet: www.dlr.de/at



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Bauweisen und
 Strukturtechnologie DLR BT
 Pfaffenwaldring 38-40
 70569 Stuttgart
 phone: +49 (0) 711 / 6862 - 81 82
 fax: +49 (0) 711 / 6862 - 227
 email: info-pks@dlr.de
 Internet: www.dlr.de/bt



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Faserverbundleichtbau
 und Adaptionik DLR FA
 Lilienthalplatz 7
 38108 Braunschweig
 phone: +49 (0) 531 / 295 - 23 01
 fax: +49 (0) 531 / 295 - 28 75
 email: info-pks@dlr.de
 Internet: www.dlr.de/fa



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Flugführung DLR FL
 Lilienthalplatz 7
 38108 Braunschweig
 phone: +49 (0) 531 / 295 - 25 00
 fax: +49 (0) 531 / 295 - 25 50
 email: info-pks@dlr.de
 Internet: www.dlr.de/fl



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Flugsystemtechnik DLR FT
 Lilienthalplatz 7
 38108 Braunschweig
 phone: +49 (0) 531 / 295 - 26 00
 fax: +49 (0) 531 / 295 - 28 64
 email: info-pks@dlr.de
 Internet: www.dlr.de/ft



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Hochfrequenztechnik und
 Radarsysteme DLR HR
 Oberpfaffenhofen
 82234 Weßling
 phone: +49 (0) 81 53 / 28 23 05
 fax: +49 (0) 81 53 / 28 11 35
 email: info-pks@dlr.de
 Internet: www.dlr.de/hr



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Luft- und Raumfahrtmedizin
 DLR ME
 Linder Höhe
 51147 Köln
 phone: +49 (0) 22 03 / 601 - 35 24
 fax: +49 (0) 22 03 / 69 62 12
 email: info-pks@dlr.de
 Internet: www.dlr.de/me



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Methodik der Fernerkundung
 DLR MF
 Oberpfaffenhofen
 82234 Weßling
 phone: +49 (0) 81 53 / 28 26 68
 fax: +49 (0) 81 53 / 28 13 37
 email: info-pks@dlr.de
 Internet: www.dlr.de/imf



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Robotik und Mechatronik
 DLR RM
 Oberpfaffenhofen
 Münchner Straße 20
 82234 Weßling
 phone: +49 (0) 81 53 / 28 39 76
 fax: +49 (0) 81 53 / 28 11 34
 email: info-pks@dlr.de
 Internet: www.dlr.de/rm



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Technische Physik DLR TP
 Pfaffenwaldring 38-40
 70569 Stuttgart
 phone: +49 (0) 711 / 68 62 - 773
 fax: +49 (0) 711 / 68 62 - 788
 email: info-pks@dlr.de
 Internet: www.dlr.de/tp



Deutsches Zentrum für Luft- und Raumfahrt
 Institut für Raumfahrtantriebe DLR RA
 Langer Grund
 74239 Hardthausen
 phone: +49 (0) 62 98 / 28 - 203
 fax: +49 (0) 62 98 / 28 - 190
 email: info-pks@dlr.de
 Internet: www.dlr.de/ra

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Bundesministerium der Verteidigung
Unterabteilung A II
Fontainengraben 150
53123 Bonn

DESIGN AND REALISATION

Konzeptbüro Schneider, Erfstadt

CONTENT SUPPORT

Fraunhofer INT, Euskirchen

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Bundesamt für Ausrüstung, Informationstechnik und Nutzung der Bundeswehr,
Koblenz
Bundesministerium der Verteidigung, Bonn
Deutsch-Französisches Forschungsinstitut, Saint-Louis
DLR, Institut für Aerodynamik und Strömungstechnik, Köln
DLR, Institut für Hochfrequenztechnik und Radarsysteme, Weßling
DLR, Institut für Technische Physik, Stuttgart
Fraunhofer EMI, Freiburg i. Br.
Fraunhofer FHR, Wachtberg
Fraunhofer FKIE, Wachtberg
Fraunhofer IAF, Freiburg i. Br.
Fraunhofer ICT, Pfinztal
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Fraunhofer IOSB, Karlsruhe, Ettlingen
Institut für Mikrobiologie der Bundeswehr, München
Institut für Pharmakologie und Toxikologie der Bundeswehr, München
Institut für Radiobiologie der Bundeswehr, München
Psychotraumazentrum der Bundeswehr, Berlin
Schiffahrtsmedizinisches Institut der Marine, Kronshagen
Universität der Bundeswehr München
WIS, Munster
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WTD 41, Trier
WTD 52, Oberjettenberg
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WTD 91, Meppen
Zentrum für Geoinformationswesen der Bundeswehr, Euskirchen / Offenbach
Zentrum für Luft- und Raumfahrtmedizin der Luftwaffe, Fürstenfeldbruck
Zentrum für Militärgeschichte und Sozialwissenschaften der Bundeswehr,
Potsdam