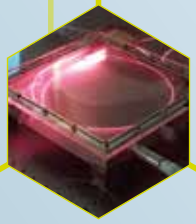
FRENCH-GERMAN RESEARCH INSTITUTE OF SAINT-LOUIS

FRONT-LINE RESEARCH

ANNUAL REPORT 2021|2022



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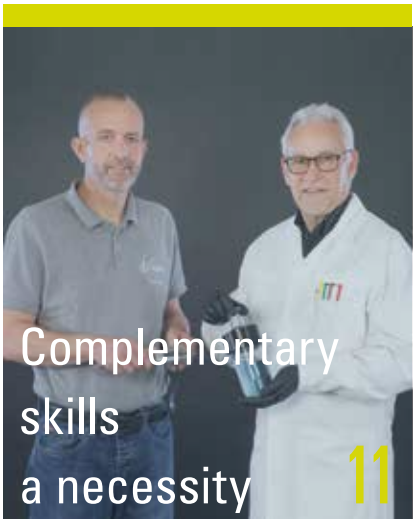
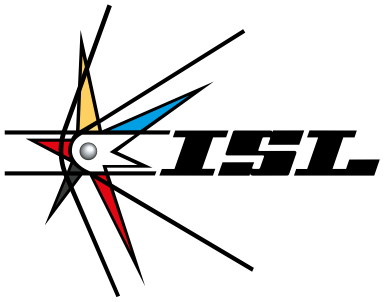




Annual Report 2021-2022

French-German Research Institute of Saint-Louis

Christian de VILLEMAGNE and Michael MEINL

EDITORIAL

Dear readers,

We are pleased to present you the salient features of our 2021–2022 Annual Report which focuses in particular on the results of ISL's research activities.

As the one and only binational research institute in the world dedicated entirely to the area of defence, our Institute is a unique hub providing front-line research. The term "front-line" relates both to cutting-edge research and its direct benefits for soldiers in the field.

In this Annual Report, we highlight the extraordinary diversity of ISL's research skills and the importance of fostering internal and external networking in order to fulfil our mission. This mission – to create cost-effective, innovative disruptive technologies for use by the armed forces in the toughest areas of military con-

frontation – is made possible by working in multi-disciplinary, cross-functional in-house teams and through regular in-depth exchanges and experimental work.

This Report presents highlights for each of our five major scientific challenges. In addition, it features six select interviews, illustrating multi-disciplinary inter-

Leading-edge research in defence and security in the heart of Europe

connectedness. These show how ISL can provide its stakeholders with one-stop-shop solutions by bringing together diverse skills under one roof.

The different workshops at ISL, significant events and trade fairs as well as important visits rounding off the Report underline the importance of the extensive networking we foster with government, military, industrial and academic partners.

Greater relevance of high-intensity warfare capabilities after 2022 Russian invasion of Ukraine

Although the return of high-intensity conflicts has been a plausible scenario at strategic level and has constantly guided the focus of ISL's research for many years, the Russian invasion of Ukraine on 24th February 2022 marked a new level of escalation.

At the time of writing this Annual Report, the war is on-going and land-force defence remains primordial. It showcases the increasing risk of high-intensity conflicts, giving renewed emphasis to NATO's Article 5 missions. ISL's focus on enabling the forces to deliver destructive energy with precision at long distance and to protect themselves by detecting adverse weapons before they impact the target or by reducing their effects is more relevant than ever.

ISL has a central role to play here. We thus commit ourselves anew to provide the best scientific output and the most efficient exploitation of our innovations. We offer inter-disciplinarity, unparalleled technical expertise, capacities in measurement techniques, modelling and simulation, some of which are unique in the world. Our ability to act as a hub, nurturing our links with many universities, leverages civilian scientific know-how. We steer disruptive solutions from basic research to technology maturity, facilitating the transfer of our innovations to the defence industry.

European projects on the increase and a record number of third-party contracts

In the period under review, ISL participated in a large number of calls for European projects and was awarded several contracts.

ISL is leader of the consortium "PILUM" (Projectiles for Increased Long-range effects Using Electro-Magnetic railgun) selected to conduct a research project on the electromagnetic railgun. The project brings together seven partners from four different European countries (France, Belgium, Germany and Poland) and

allows preparation of a second project phase aiming to develop an operational demonstrator on the ISL proving ground by 2028.

A Technology Maturation Phase for key subsystems shall start next year, possibly supported by the 2022 European Defence Fund (EDF) programme. It aims to federate European R&T efforts in this field, contributing to secure the strategic autonomy of the European Union.

ISL was also retained for its expert contribution to the FIRES (Future Indirect fiRes European Solution) project. The project brings together more than twenty different partners in Europe and aims to improve the performance, reach and survivability of two types of gun artillery – 155 mm projectiles and rockets.

In addition, ISL is a partner in the HYPOTENUSE (HYPersOnic Threat dEtection aNd coUntermeaSurEs) project, a study launched by a consortium of European research institutes and industry representatives to counter hypersonic threats. The objective is to explore potential new technologies and approaches for an early-warning space alarm system and an interceptor capable of reaching a speed of Mach 5.

During the past few months, ISL has replied to seven further calls for European projects in order to pursue studies in several of its specialist research areas including protection materials and the use of computational imagery for non-line-of-sight threat detection in military or civilian areas.

In 2021, the total amount of industry contracts and subventions awarded by research funding agencies other than by its supervisory authorities, the French and German ministries of defence, came to a record sum of 6.5 million euros in order intakes.

Strategic plan "Ambition 2030"

Securing the sustainable development of the Institute in a dynamic environment is a central task for management. With the implementation of the ISL 2020 plan, ISL has faced up to the challenges and achieved a lot in the last ten years.

This process must now be continued with a view to our future development. Together with our supervisory authorities, we are currently implementing the design of our new strategic plan "Ambition 2030". The objective is to provide "best value for money". This depends on the quality and relevance of our scientific and technical contributions and on being even better integrated with our binational DNA within the French and German Defence Industrial and Technological Bases (DTIBs).

"ISO 9001: 2015" certification

On 14th October 2021, ISL received the certificate confirming that its quality management system conforms to the requirements of the standard ISO 9001: version 2015. Following an initial audit in July 2021 and valid for all ISL's activities for a period of three years, this certification is an important milestone. It ratifies the long-term practice of a quality culture well installed at ISL and gives us further incentive to improve the quality of our processes on a continual basis.

Significant events, academic excellence and warmest thanks

The final section of our Annual Report provides an overview of the significant events and visits, workshops and conferences organised by ISL or at ISL dur-

ing 2021–2022 as well as our participation at important trade fairs and exhibitions.

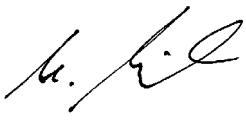
ISL is especially proud of the growing number of PhD students who successfully defended their thesis in the period under review. The excellent results achieved were obtained in partnership with our wide network of universities. These reinforce the scientific reputation of ISL and constitute a major contribution to ISL's success.

In conclusion, we would like to thank all our staff, the representatives of our ministries, our Research Advisory Board, the members of our Board of Directors, politicians in both countries as well as our academic, military and industrial partners for their commitment, trust and support in our capacity to innovate.

As in the past and in the face of new emerging threats, we will continue to fulfil our mission, performing front-line research of excellent quality for the improved protection of our forces in France and Germany, taking a leading role at European level.

We wish you all an interesting and stimulating read of this Report.

Christian de VILLEMAGNE
French Director



Michael MEINL
German Director

Energetic materials and systems

Increasing performance and safety

ISL designs new energetic materials in order to meet the challenging defence requirements in terms of reduced sensitivity, enhanced performance and improved life cycle. Coupling its capacity in process engineering and characterisation of materials with its skills in interior ballistics and detonics, ISL develops advanced energetic systems such as ignition devices, pyrotechnic actuators, propellant charges as well as high explosive small calibre projectiles.

Synthesis and shaping of energetic materials

For the first time, ISL has successfully printed complex geometric samples of energetic materials, using the so-called extrusion 3D-printing method (photos page 9). For 3D-filament printing, it realised a system for the production and spooling of energetic filament. ISL will now be able to characterise the combustion behaviour of its printed samples and identify suitable geometries to improve weapon performance.

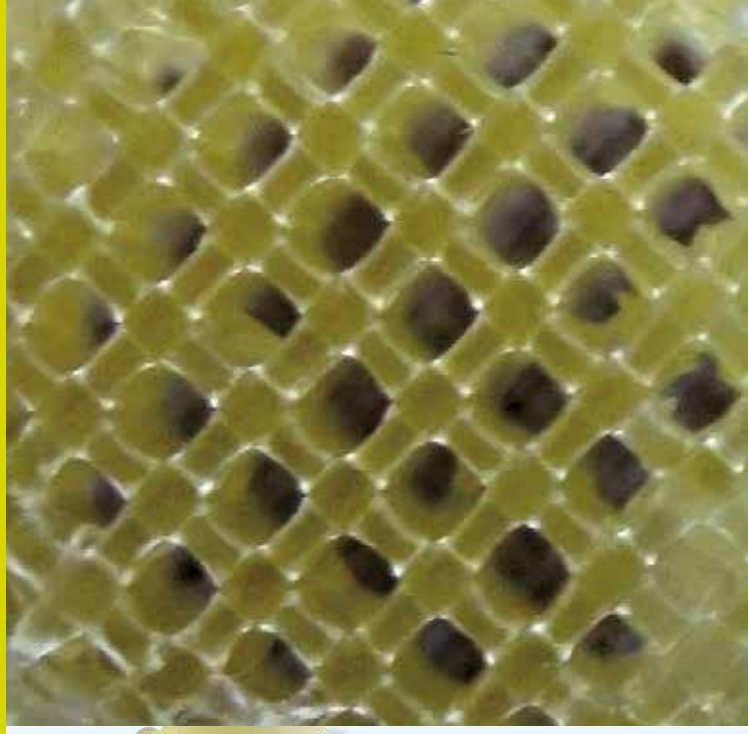
In its efforts to reduce explosive sensitivity, ISL has considerably improved the yield and productivity of its patented crystallisation process. Thus the production of VI-RDX (Very Insensitive RDX) and VI-HMX (Very Insensitive HMX) can now be achieved with yields of 80% (instead of 30 to 40% previously) and with a productivity of 400 g/l (instead of 10 to 30 g/l previously). These results are very important in terms of process profitability and open up prospects for transfer to industry.

Finally, ISL has achieved a major improvement in its patented continuous Spray Flash Evaporation (SFE) nano-crystallisation process by integrating in the atomisation chamber an Infra-Red oven which allows precise control of the evaporation of solvent and thus better management of the shapes and sizes of the explosive particles produced. In 2021, ISL also realised a new pilot process derived from SFE which it patented, called Spray Flash Synthesis (SFS). The first application will be to produce primary explosive particles (silver azide) with reduced sensitivity.

Reactive behaviour characterisation

In the field of explosives and detonics, ISL, in cooperation with the CEA and the École des Mines de Paris, carried out an experimental and theoretical study to determine the microstructural characteristics of an explosive formulation that control its sensitivity. The characterisation of real microstructures by micro-tomography (photo bottom right page 9) has allowed the creation of a database of representative numerical

challenge 01



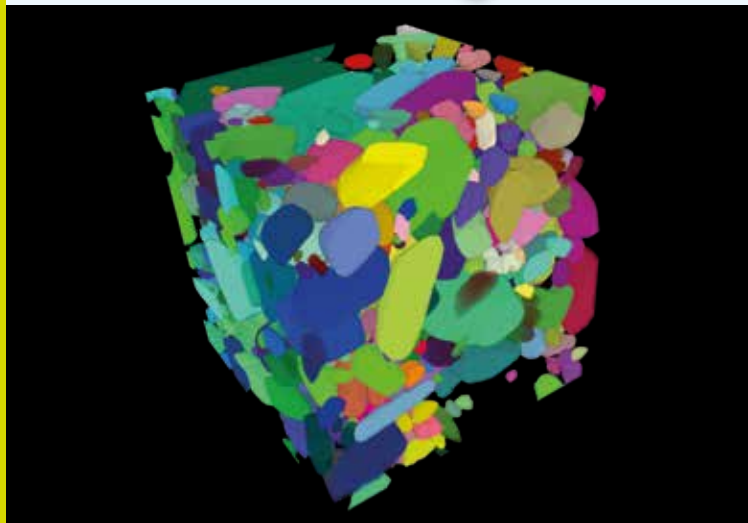
microstructures. The modeling study of the detonation initiation of these microstructures has confirmed the major role played by the solvent inclusions, but it also showed the important role played by the contact zones between particles on the sensitivity. These aspects (interface and surface properties) will be the subject of increased research efforts in the future.

In addition, ISL has designed and built an experimental device to characterise the chemical species produced over time during the ignition of propellant powders. This device consists of a flash pyrolysis system, a chamber in which the sample is placed (Brill cell) and a Fourier-transform infrared (FTIR) spectrometer for gas analysis. This method is fast and accurate and requires only very small quantities of material. The first results have already been obtained on a low-vulnerability ammunition (LOVA) propellant and show a good correlation between modeling and experimental results. This device will be invaluable for future studies on the ignition of propellants.

Opto-pyrotechnic detonators (OPD)

The year 2021 saw the successful transfer of the OPD technology developed at ISL to a German industrial company for active protection applications. This transfer follows the excellent performance (response time and jitter) demonstrated by the ISL OPDs, in particular at low temperature. The following interview shows how energetic materials and systems combine in the realisation of the OPD prototypes.

Complex 3D-printed shapes



Numerical extraction of particles of an explosive formulation
(E. Kaeshammer PhD work, Cooperation ISL – CEA Gramat – École des Mines de Paris)

Sébastien P.

- Mechanical and pyrotechnical specialist
- Shock physics and detonics
- At ISL since 2001

My motto:
“To achieve results, you need precision”

Dominique S.

- Pyrotechnician
- Shock physics and detonics
- At ISL since 1985

My motto:
“Meticulous work is the result of concentration”

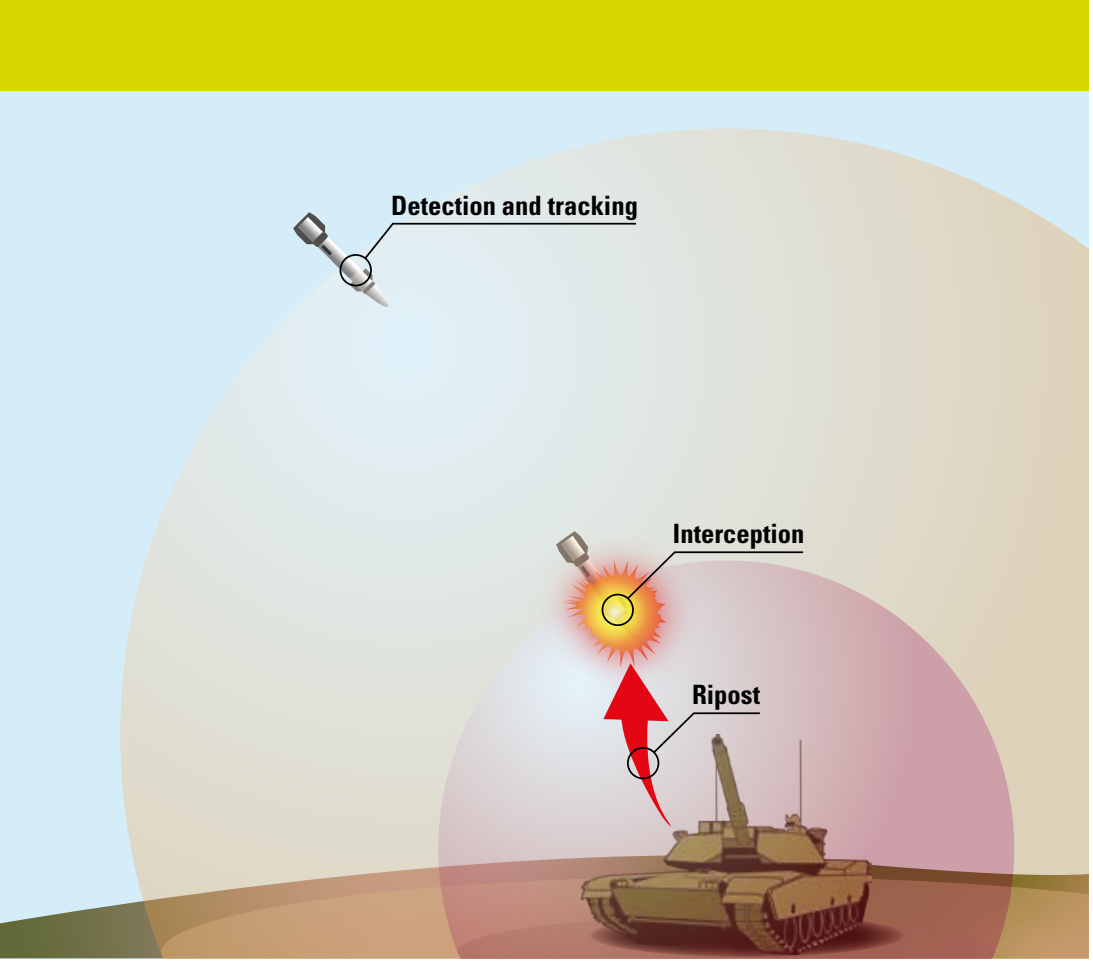
Developing OPD prototypes at ISL – complementary skills are a necessity

In this interview, two specialists, one in energetic material processing and one in mechanics, describe how they best combine their skills to produce more efficient, safer initiation systems for greater protection in the military field and more reliable civilian applications which can be used, for example, in space projects. Dominique S. and Sébastien P. work closely together to realise OPD (opto-pyrotechnic detonator) prototypes based on tailor-made energetic materials and matching mechanical systems. To do this, sharing know-how and skills is primordial. Work is meticulous based on pyrotechnic safety rules and careful risk management. A wide range of skills is needed for concept design, testing and prototype fabrication. Pyrotechnic tools are all made in-house. There is also a need to anticipate on the transfer to industry.

What is an OPD and what are its advantages?

Dominique S.: ISL has been developing opto-pyrotechnic fusing systems since the 1990s. The selected device designed by ISL is a two-stage OPD based on a shock-to-detonation transition (SDT). In the first stage, laser energy triggers a rapid combustion of a secondary explosive which generates high-pressure gases that accelerate a small projectile at high velocity. In the second stage, this projectile impacts a compressed secondary explosive and triggers a SDT provided that the velocity and pressure are high enough.

Sébastien P.: The ISL OPD offers many different advantages. In terms of risk reduction, the sole use of secondary explosives simplifies the safety of the firing system, which is compliant with REACH, the European Union regulation adopted to improve the protection of human health and the environment from the risks of chemicals. It is also immune to electric interference, insensitive to electrostatic discharge and thanks to its design, can withstand thermal cook-off and fuel fire tests without detonating. In addition, the ISL OPD is compatible with multi-way initiating architecture and can be controlled over long distances due to the low power losses of optical fibres. The functioning time of the ISL OPD is finely controlled allowing a high reproducibility. Last but not least, ISL OPDs operate with commercially available, low-cost diodes delivering just a few watts.



Defence application – active protection

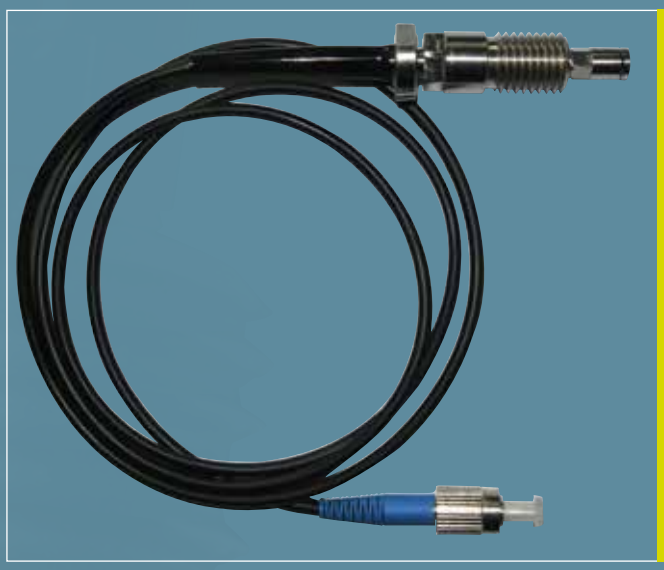
What is important in the work you do?

Dominique S.: I work in laboratory pyrotechnics. Upstream, my job involves identifying the pyrotechnic batch which corresponds to the needs defined by the researcher. We carry out preliminary tests on the selected explosive to determine various parameters including, for example, its sensitivity and its strength. Once we decide which material could be appropriate to use, we look at whether the manipulation is reproducible in order to obtain the most accurate results. We exchange with several operators, both with the ISL researchers who had the initial idea as well as with different engineers and technicians. We also control the microscopic aspects of the material mixtures. For this, we have continuous traceability and fill in work sheets from A to Z. This helps us to look back on the past. Our work is extremely rigorous and the result is a precise manufacturing protocol.

Sébastien P.: First, I work on the concept, the mechanical manufacturing design which I imagine will best match the researcher's specifications. The mechanical design needs to be simple since at this stage we also take into account how the system will be industrialised in future. Since I have a lot of experience with industry, I know that the system needs to be feasible, capable of being easily produced by industry and micromechanically precise. At ISL, we produce miniaturised systems, just a few centimetres in size. These need to be reproducible to a hundredth of a millimetre.

Space application
https://www.thalesgroup.com

After the first design, tests and firings, we have to make modifications to the materials and the systems. We also design specific compression tools for the explosive materials. Quality is always important. Then we make a mould on the remote press, compressing two milligrammes of explosive. Finally, we assemble the opto-pyrotechnical detonator prototype integrating the various stages before proceeding to test fire.



Opto-pyrotechnic detonator with its harness

What are OPDs used for?

Sébastien P.: OPDs can be used in both civilian and military applications. Civilian applications include, for example, replacing hot-wire firing devices on space launchers by the safer ISL OPD alternative. In the field of defence, ISL OPDs allow the functioning time of active protection systems on military vehicles and of initiation systems to be precisely controlled, which is an absolute necessity (illustration page 12).

What are the key words that summarise the development process for OPD prototypes for you?

Dominique S. and Sébastien P.: Fine-tuning and control of all components and the final system architecture, pyrotechnic safety, traceability, precision, in-house specific tools and continual exchange of information with different colleagues. That's the ISL recipe for success.

Future gun systems and smart ammunition

From pinpoint accuracy and high agility to hypervelocity and stand-off capabilities

Next-generation defence systems must be "smarter" as well as "harder, further, faster, stronger". Main challenges include shortening the sensor-to-shooter chain, reducing firing times for high-tempo joined fires, embarking intelligence for precision guidance and robust connectivity to support net-centric operations up to swarming. The future battlefield requires re-imagining lethality, range, precision, connectivity, mobility and survivability.

From launch to impact – the trajectory

ISL remains unrivalled in Europe for developing and maturing the concept of the electromagnetic railgun to achieve hypersonic speeds for launchers. In the period under review, ISL technology was used to accelerate projectiles in the kilogramme range up to hypersonic speeds of more than 2,500 metres per second using the 10 MJ energy supply system. Obtaining over 65% efficiency in electrical to kinetic energy conversion, ISL has set a new benchmark. The laboratory demonstrator at ISL enables fire bursts of up to five shots in a calibre of 25 x 25 mm^2 with accelerations of more than 100,000 g and muzzle velocities of 2,400 m/s, with extremely high firing cadences of more than 75 Hz (illustration top right page 15).

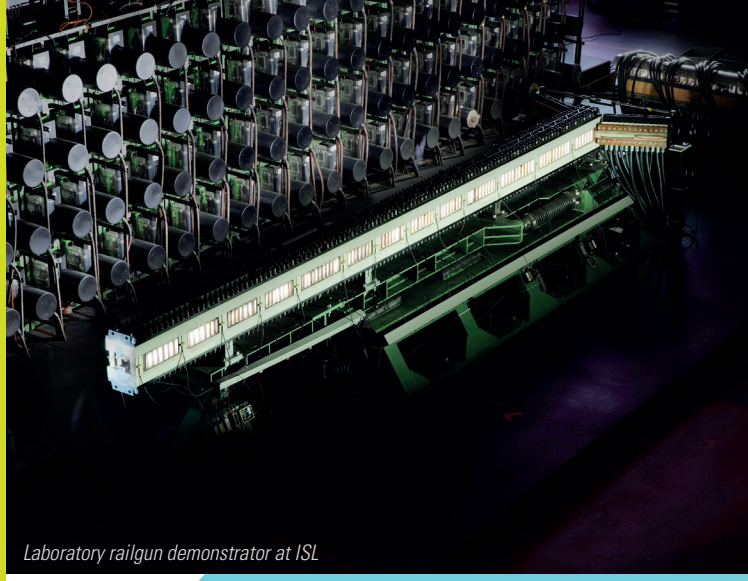
Alongside the development of the railgun technology, ISL progressed in the design of its hypervelocity effector from an aerodynamic, mechanical and electronic point of view. A radio data link embedded in the railgun projectile was fired in November 2021, proving the resistance of the electronics against acceleration and electromagnetic pulses. In addition to this work on future hypervelocity effectors, ISL carried out research on the detection of threats such as hypersonic glide vehicles. As an ISL first, the impact of plasma flow at hypersonic speeds on the target radar cross section could be simulated and measured in the shock tunnel (illustrations page 15).

Advancing from laboratory technology to demonstrator level, the period 2021–2022 also saw ISL performing full flight tests with top-quality munition which requires precision hits under impact angle constraints. Currently under development is an end-to-end navigation and guidance solution, to combine a global navigation satellite system-independent mid-course navigation with a terminal guidance module. Leveraging on signals of opportunity like from Low-Earth-Orbit satellite constellations, first simulations and tests look promising.

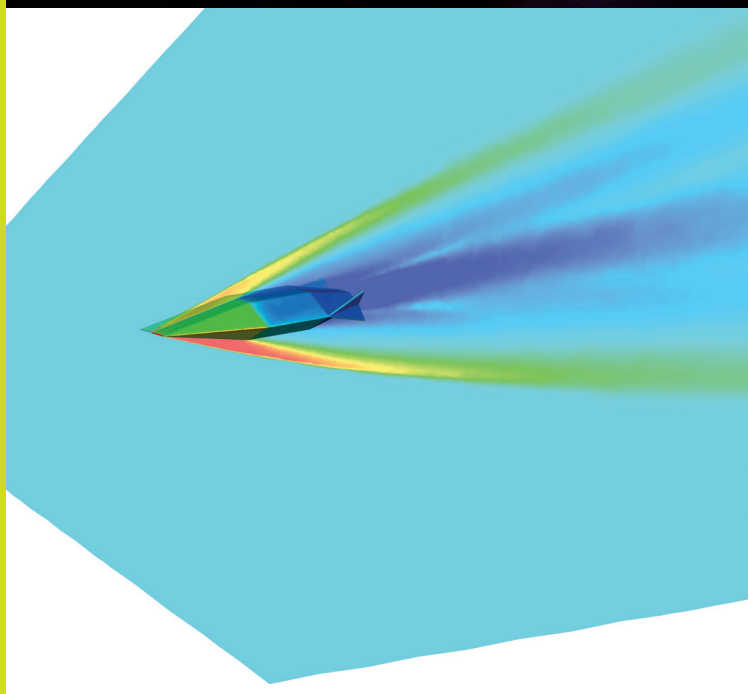
The future mission of going beyond the lines

To gain a decisive advantage in any future military engagement, the contribution of science needs to provide

Challenge 02



Laboratory railgun demonstrator at ISL



Hypersonic flow computation of ISL-designed, short-range projectile for rapid-fire railgun showing superior low drag performance and directional stability

thought leadership, exploring the more risky ideas, concepts and potentially less mature technologies and methods. Paving the way ahead are, amongst others, revived research activities on hypersonic technology, vulnerabilities caused by electronic warfare on navigation and communication performance, hybrid concepts of projectile-missile-drone crossovers and collateral damage mitigation by precision strike and target selectivity.

ISL – a European centre of excellence for future gun systems and smart ammunition

Succeeding in technology transfer from ISL's research activities to fielded next-generation deep precision strike systems depends on building alliances with industry. ISL's activities in this area include growing and deepening industrial partnerships as well as making key contributions to European collaborative research programmes.

In the period under review, ISL consulted the European Defence Agency (EDA) on its Key Strategic Action for Precision Strike Capabilities on Land Platforms and Related Skills, consolidated its position as leader of the project PILUM (Projectiles for Increased Long-range effects Using electroMagnetic railgun) of the European Union Preparatory Action on Defence Research (PADR) managed by EDA, and co-authored the roadmap for the Future Indirect fiRes European Solution (FIRES project) within the European Defence Industrial Development Programme.

Hypersonic flow field around sphere body in ISL shock tunnel showing influence of generated plasma on radar signature quantified

Michael P.

- Engineer
- Guidance, navigation and control
- At ISL since 2015

My motto:
"To fly further, you need a better pilot"

Michel L.

- Scientist
- Aerodynamics, measurements and simulations
- At ISL since 2012

My motto:
"To fly further, you need to be in proper shape"

Combining form with intelligence, an interactive process

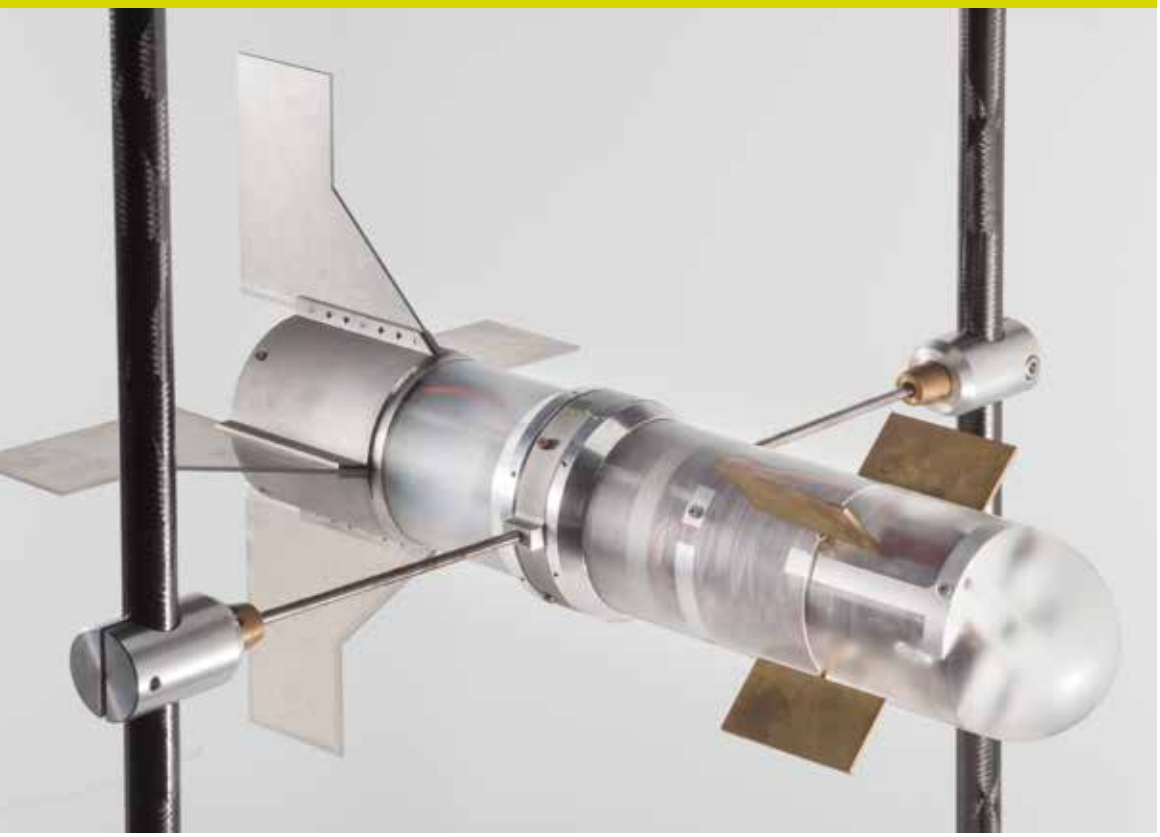
In the event of any future military confrontation, it will be essential for the armed forces to be equipped with innovative technologies capable of providing maximum protection against adverse attacks to ensure operational and strategic superiority. In the face of newer, harsher adverse threats, such as hypersonic missiles, the next-generation gun and ammunition systems will need to have improved flight performance. The main goal here is to fly further and hit the target with high precision using more advanced guidance and control laws, keeping costs at an affordable price.

At ISL, scientists and engineers from different research groups work hand in hand, sharing diverse perspectives. They interact with each other on a daily basis to achieve the best inter-disciplinary solutions possible.

The following interview is a good illustration of the cross-fertilisation that takes place at ISL between a German engineer and a French scientist combining artificial intelligence with aerodynamic measurements and simulations. Michael P. and Michel L. pool their specialist knowledge to take projectile technology to the next level required to meet the future needs of the armed forces in France and Germany and at European level.

Can you both describe your work at ISL?

Michel L.: My work at ISL involves dimensioning the shape of projectiles to improve their aerodynamic performance. Here the aim is to reduce drag, in other words resistance to air penetration, while at the same time increasing lift to enable the projectile to fly further. Dimensioning the projectile also involves integrating on-board ancillary devices such as electronic components, actuators and the payload. The challenge is to fit all these elements into the projectile while reducing



Hardware In-the-Loop (HIL) Wind Tunnel model

volume and mass so that the maximum payload reaches its target. Existing guided ammunition has a range of up to 40 kilometres without added propulsion or base bleed. Research work at ISL aims to extend this range to over 100 kilometres. This will ensure greater protection of the armed forces.

Michael P.: My job focuses on optimising the guidance and control of the projectile. Here there are two objectives. First, we need to make the best possible use of the advantages of aerodynamic geometry in order to increase the range. Second and in parallel, it is important to guarantee high precision at the target. Guidance is composed of two phases. In the first phase, we aim for maximal range, making the projectile behave like a glider in free flight. In the second phase, called terminal guidance, precision is key as the projectile must avoid creating collateral damage while increasing the effectiveness of the warhead. The guidance specifications are executed via the control function which is responsible for reaching the target while keeping the ammunition stable.

Plasma-actuated arrow projectile

Why are form, guidance and control complementary?

Michel L.: When we talk about form, we mean the size and geometry not only of the projectile but of the wings (length, width, sweep angle, aerofoil…) and the tail fins. The entire form has to fit the constraints and functionalities of the ancillary devices which need to be embarked. It is important that the performance of the projectile allows the guidance and control laws to extend the range of the projectile.

The decoupled fuse demonstrator for use in wind tunnel at subsonic speeds
E. Roussel, Roll control of a decoupled fuse in low-speed wind tunnel, R-02/19/01/000/0/00-04/RE-139/2021

Michael P.: The guidance and control functions have an effect on the wings and rudders. Both these functions interact with the projectile to achieve the stability necessary to reach the target. For projectiles to fly further, we need better geometry. Increasing the aerodynamic performance beyond that of conventional ammunition may render the projectile unstable. The role of the control function is to keep the projectile stable. In other words, the geometry, guidance and control of the projectile are interlinked and cannot be dissociated.

Michel L.: If, for example, Michael applies a more complex control law allowing active stabilisation of the projectile, then I might have the opportunity to suppress stabilising tail-fins in order to increase even further its aerodynamic performance. In other words, you can't have an innovative and effective shape without a corresponding brain.

Advanced situational awareness

Designing innovative sensor systems for enhanced overall detection capabilities

The successful completion of any mission depends on having a detailed knowledge of the enemy's position, identifying and localising potential threats, including, for example, continuous surveillance of strategic zones for intrusion detection. All these methods provide not only the necessary information to select the best appropriate protection measures, but also to help optimise decision-making. With its wide range of detection and sensing technologies, ISL contributes to the overall goal of securing comprehensive situational awareness.

New multi-sensor threat detection systems

The acoustic detection and localisation of different threats, including artillery, gun shots or drones, is particularly challenging in an urban environment. Combining acoustic sensors with other types of sensors, such as optical detection technologies, improves the overall detection capability. This is clearly demonstrated in the results obtained with the project DEEPLOMATICS, a new intrusion detection system for sites and infrastructures in open spaces and urban areas. While new sensors based on differential antennas using MEMS microphones and exploiting artificial intelligence (AI) offer an affordable possibility to detect intrusions even in a large area, these concepts can also be integrated into the personal hearing protection devices described in Challenge 5 (see page 37).

Future imaging applications

Driven by new functionalities now available for illumination components, ISL successfully continues to extend the detection range of its active imaging systems in order to improve the detection effectiveness through highly scattering and/or turbulent media using short-wave infrared laser sources. New 3D simulations allow the production of 3D tomographic sequences by varying the angle of incidence on realistic targets. This permits future 3D active imaging applications such as active imaging on board a self-steering missile.

Computational imaging allows for fundamentally new ground-breaking possibilities in imaging and optical sensing. A good example is ISL's edge-cutting work on non-line-of-sight (NLOS) imaging, also known as "seeing around the corner". These new technologies require the development of novel computational concepts and the capability of using two powerful reconstruction algorithms: the back projection of complex phasor amplitudes and the signal migration in the Fourier domain. The phasor back projection can be adapted to a wide range of application scenarios

challenge 03

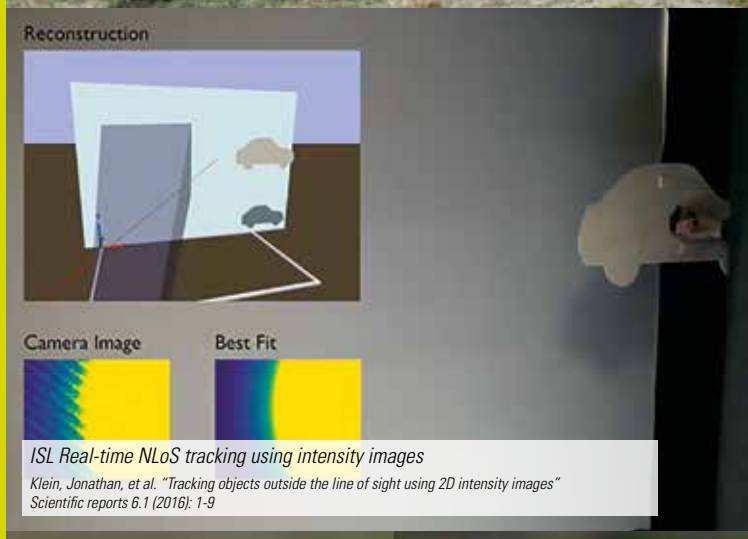
and can be used to reconstruct hidden scenes with centimetric resolution. The signal migration approach delivers fast reconstruction but resolution and reconstruction volume are strongly linked to sensing conditions. Furthermore, NLOS imaging benefits considerably from novel cameras such as single-photon-counting (SPAD) cameras. Recently, ISL has carried out detailed investigations to explore SPAD-camera functionalities by studying, for example, the interaction between a picosecond SPAD camera and a very short pulse laser illumination (80 ps) in different types of integrating spheres (from 15 cm diameter to 50 cm). These experiments can be applied to cavity or room reconstruction.

Better detection of explosives, sensor miniaturisation

Detection and identification of explosives remain important challenges in order to provide the best possible protection. ISL's activities in broadband terahertz (THz) spectroscopy within the respective national networks contribute to the evaluation and improvement of the detection capacity of this technology.

Cost-efficient small sensors with an on-chip capability to pre-process big data and perform classifications complement the different types of sensors and technologies used in order to obtain complete and comprehensive situational awareness. ISL's research work in this scientific challenge includes the integration of such smart functionalities in all the different sensor systems, exploiting AI concepts and algorithms including deep-learning convolutional neural networks.

Image-based navigation system on Aurochs platform



ISL Real-time NLoS tracking using intensity images

Klein, Jonathan, et al. "Tracking objects outside the line of sight using 2D intensity images" Scientific reports 6.1 (2016): 1-9

New intrusion detection system

Contact-free THz detection of hazardous substances

Dr. Richard A.

- Scientist
- Flight techniques for projectiles
- At ISL since 2021

My motto:
“Joined and deep fires need joined and deep research”

Dr. Pierre N.

- Scientist
- Acoustics and soldier protection
- At ISL since 1984

My motto:
“Keep listening to stay one step ahead of the threat”

ISL, THE END USER AND INDUSTRY – A TRIANGULAR RELATIONSHIP FOR A VIRTUOUS CIRCLE

While fundamental research produces ground-breaking inventions, necessary for scientific progress, ISL's research, funded by both the French and German Ministries of Defence, is destined to be implemented by the armed forces.
To fulfil this mission, for the benefit of the French and German Defence Procurement Agencies (DGA and BAAINBw), ISL is in a triangular relationship with the end user and industry. Regular contacts with the forces and industrial R & D teams help ISL provide target-specific innovative experience upstream. This co-development leads to tailored ISL technologies for advanced situational awareness which improves soldier and vehicle protection and leads to effective defence systems for deep fires and precision strikes.

Why is this triangular relationship important?
Richard A.: Because it is only in the triangle that we can succeed and achieve "ISL-inside". Technology transfer goes from research via the industry to the end user. It's a classical process chain. In this triangle, all three parties have equal importance but their functions are different. All are driven by the client's needs. Through interactions with each other, everyone is both a customer and a supplier with regard to a particular need. This creates a virtuous circle.

The process actually starts with the end users and discussion about future needs. Dialogue can be both top-down (they explain their needs and we think about a solution) or bottom-up (we discover a new technology and discuss how it can enable new missions and capabilities).

Pierre N.: Talking to the end user is the only way to understand how they function and what they need to do their job. Since technology is not a part of their function, we need to adapt our innovations to their occupational needs and help them integrate the new technology into their work processes.

A good example of this is the research work we are doing with an industrial partner on new-generation, custom-moulded ear plugs for the land forces giving greater protection while allowing efficient cross-communication and situational awareness within a group of

Setting up the shot noise measuring device in a helicopter cabin

dismounted soldiers (BANG). While the distribution of earplugs of the right size for each soldier is a recurrent challenge, ISL has proposed an efficient "fit check" function to solve the problem. This also guarantees better acceptance of the new technology by the end users.

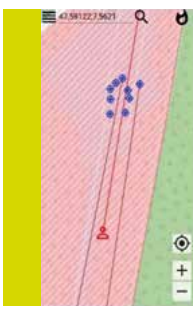
In the same way, our industrial partners need to integrate ISL innovations into their manufacturing processes, maintenance and future development programmes. For a win-win situation, we need to understand how the innovation will fit into their production chain in the long-term even though our research is at a much lower maturity level.

Richard A.: Research and industry converge in that industry helps us identify which innovations are necessary and need to be prioritised in terms of maturity level. End users help us to keep track of fieldability issues and their needs strategically guide our technology foresight.

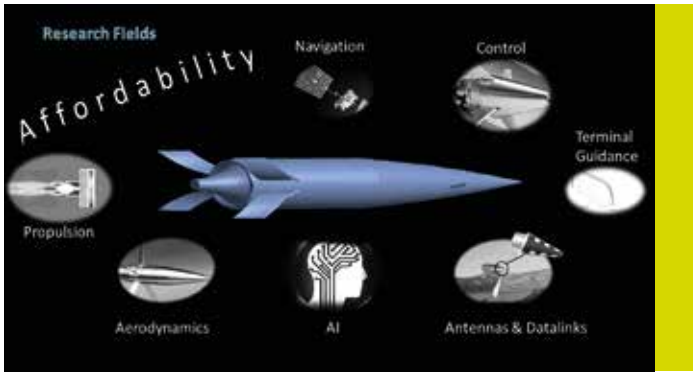
Can you be more specific about ISL's contribution and added value?

Pierre N.: If we take the example of sniper detection, this innovation work began in response to the expressed needs of soldiers returning from the front. They reported hearing gun shots but could not localise them. This led ISL to imagine and create the electronic association of Mach and muzzle waves coming from a sniper shot, something the human brain is not trained to do. ISL was solicited for its expertise in acoustics and ballistics based on its multi-disciplinary approach. Today, ISL's research work contributes to improving situational awareness, threat detection and threat localisation for groups of soldiers on the ground in difficult urban environments.

Richard A.: As a European excellence centre for smart munition, ISL pools skills from all the scientific domains necessary to design an entire munition architecture comprising aerodynamics, autopilot, communications, structure, mechanics, etc. Applying multiple technologies to a single application for a single client differentiates ISL from other research and technology organisations (RTOs). Typically, an RTO is built around a single technology field which is applied to many markets. The fact that ISL covers all aspects of the innovation allows us to create a system solution for the client. This provides the client with a one-stop shop.



PACOPAC, a new-generation system combining auditive protection, communication technology and advanced threat detection



ISL research teams design comprehensive munition architectures creating system solutions

Pierre N.: Another example of cross-fertilisation is the project DEEPLOMATICS in which acoustic detection, localisation and tracking phases combine to steer passive and active imaging cameras in the right direction to identify drone intrusion in a sensitive zone. This project brings together four different disciplines – mechatronics, acoustics, optronics and signal processing – all of which are interrelated in one system. ISL is one of the few research centres to implement expertise in all these areas of physics. This provides added value all under one roof.

New generation hearing protection device used in the PACOPAC project

What about other complementarities?

Pierre N.: ISL is equipped with high-quality state-of-the-art equipment which can be used by industrial partners. Everything contributes to the end result, whether it be the wind tunnel, Computational Fluid Dynamics (CFD) models or tests on the proving ground.

Richard A.: Very often, colleagues from the end user side come to work at ISL. On an academic level, we integrate, for example, up to 25 students per year from the Bundeswehr procurement agency in Germany or master students from the "École de guerre" in France. A number of government institutions such as AID, Battle Lab Terre (BLT), the STAT or the special forces on the French side and the Planungsamt or Bundespolizei from Germany exchange with us on a regular basis and provide us with useful tactical knowledge which allows us to adjust or fine-tune our technical research as appropriate.

Dr. Bernd F.

- Scientist
- Protection technologies, security, situational awareness
- At ISL since 2009

My motto:
"I'm always curious about new things"

Dr. Denis S.

- Scientist
- Protection against explosives and ballistic threats
- At ISL since 2000

My motto:
"Research is my passion, not my work"

Fostering relations with academic networks in France, Germany and beyond is key to innovation

Composed of 60% researchers and engineers including 40 PhD students, ISL fosters intensive relations with many renowned universities in France, Germany, within Europe and internationally. This crucial network provides direct access to incipient research trends and increases the notoriety of the Institute at academic level.
In addition, Master or PhD students from a wide range of universities join ISL's research programmes, benefitting from ISL's know-how and high-tech equipment. This secures long-term contacts for ISL since the qualified students take up work at universities, other research institutes or with industry.
Dr. Bernd F. and Dr. Denis S. describe why academic relations are essential for ISL.

Why is it important to foster relations with the academic world?

Bernd F.: Academic relations are indispensable because universities are the birth place for new ideas. ISL can thus access first-hand knowledge and participate in the newest developments.

Since ISL has only a very small number of employees pro subject area, collaborating with universities provides us with a wider knowledge base and exchange of information.

A good example of the timely recognition of trends and advantages of academic cooperation is our non-line-of-sight imaging project. Recognising from the outset the potential military benefits of this innovation, ISL worked with academic partners to accelerate work on the subject. While the universities focussed on civil applications, such as autonomous driving or planet exploration, ISL concentrated on increasing soldier protection by enabling them to "see around the corner" in order to detect threats outside their field of vision.

Today, ISL is a highly experienced, recognised pioneer in this area. It has received funding from the Defence Advanced Research Projects Agency (DARPA) in the USA. More recently, we joined a consortium and have submitted a European project on the subject to the European Defence Fund (EDF).

From left to right: Dr. Denis S. (Research Director ISL, Director NS3E Laboratory), Pierre Braunstein (CNRS, UNISTRA Professor), Jean-Pierre Sauvage (CNRS, UNISTRA Professor, 2016 Nobel prize in chemistry), Dr. Marc C. (Research Director ISL)

Denis S.: Before taking up my current position, I was a doctoral student at ISL from the University of Strasbourg. At the time, I was inspired by Philippe Klein who defined research as "what we do not understand". Understanding the unknown is what motivated me to deepen ISL's collaboration with other academic research centres such as the Centre national de recherche scientifique (CNRS).

Working with both local and international universities as well as with other research institutes allows us to test new ideas which can then be transferred to ISL. Building bridges is essential. As researchers, we need to combat one-track thinking and acquire new competencies. Working with others leads to a confrontation of ideas and we learn how to do things differently. This is the fire that keeps research going.

ISL collaborates with which universities?

Bernd F.: On the German side, our priority partners are the Universities of the Armed Forces ("Bundeswehr") in Munich with a special partnership existing since 2019 and in Hamburg (Helmut Schmidt University, HSU), where I have been lecturing for many years on protection technologies. The lively exchange with students there has led to up to ten students from this university carrying out their Master or Bachelor thesis at ISL each year.

The synergistic effects are obvious. On the one hand, students have access to experimental possibilities they do not have on the Hamburg city campus, such as the ISL proving ground for ballistic testing. On the other hand, ISL becomes known among future leaders, which could facilitate innovation transfer to military equipment at a later stage.

Cooperation with other German universities also exists, often within the framework of doctoral theses. At international level, we have frequent contacts with other European universities and with all NATO member states and associated partners. We also collaborate with other German research institutes like Fraunhofer and the German Aerospace Centre (DLR, Deutsches Zentrum für Luft- und Raumfahrt) or relevant departments of the German Ministry of Defence.

Denis S.: If we take the CNRS, for example, this is a network of 32,000 people including 11,000 researchers working in 1,200 laboratories located all over France. Most of the researchers work on university premises.

At ISL, I direct the NS3E laboratory which is composed of CNRS personnel, doctoral students from Strasbourg University and my own ISL research team. We achieve more together than alone. The well-known CNRS brand is a mark of credibility and gives our communication greater resonance. Another example is the MICA

ISL German Army students visiting WTD 91 in Meppen

network founded by the Carnot Institute of which ISL is a member.

How does ISL foster its relations with the academic world?

Bernd F.: We organise workshops and symposia in which our academic partners participate. They also join common research projects and programmes supported by the European Defence Fund (EDF).

In addition, we edit shared publications which confer international recognition of scientific excellence. I benefit, for example, from the title of Associate Professor at the University of Adelaide, which is one of the top 100 universities world-wide.

Academic recognition is a key asset for ISL. While the Institute has no home university, it can transform this into an opportunity if it is able to attract the best academic partners world-wide on each of its topics.

Denis S.: We foster academic relations through joint ventures such as the NS3E laboratory which was created in September 2006 by ISL and the CNRS to work on a common topic. In 2012, with the development of the Spray Flash Synthesis (SFS) process, the President of Strasburg University (UNISTRA) asked to join the laboratory. This enabled ISL to supervise doctoral students directly. The support given to SFS by the CNRS, particularly with regard to pharmaceutical applications, has subsequently led to the creation of a spin-off called SPINOFRIN, which has just moved its Headquarters from ISL to Aesch in Switzerland.

I also received the Lazare Carnot science prize for the dual application of the SFS process. This has increased ISL's credibility, in particular, with regard to our relations with industry.

Atomisation chamber of the spray flash synthesis (SFS) process warmed by infrared heaters

Survivability of weapon systems

Threat characterisation and designing innovative counter-measures for improved weapon protection systems

Providing the best possible protection is a key requirement for all military operations. Weapon systems must be constantly adapted to counter evolving and emerging threats. Detailed knowledge about the threats is crucial in order to limit their impact or to counter-attack effectively. At ISL, researchers investigate both classical explosive and ballistic threats as well as different types of emerging laser threats and laser counter-measures.

Protection against explosives and ballistic threats

ISL's research work focuses on military threats, such as anti-tank Tungsten-Heavy-Alloy long rod penetrators, enhanced blast thermobaric explosives, tandem anti-tank shaped charges and reactive fragments. These threats are borne by gun-launched projectiles, mines, missiles and increasingly by Unmanned Aerial Vehicles (UAVs). With regard to asymmetric warfare (fight against terrorism), the focus is on Improvised Explosive Devices (IED) and home-made explosives.

Threat characterisation is essential for better knowledge of the threat architectures, describing the underlying physical lethal mechanisms, designing laboratory surrogates and for numerical and experimental assessment of the effects.

Designing appropriate counter-measures

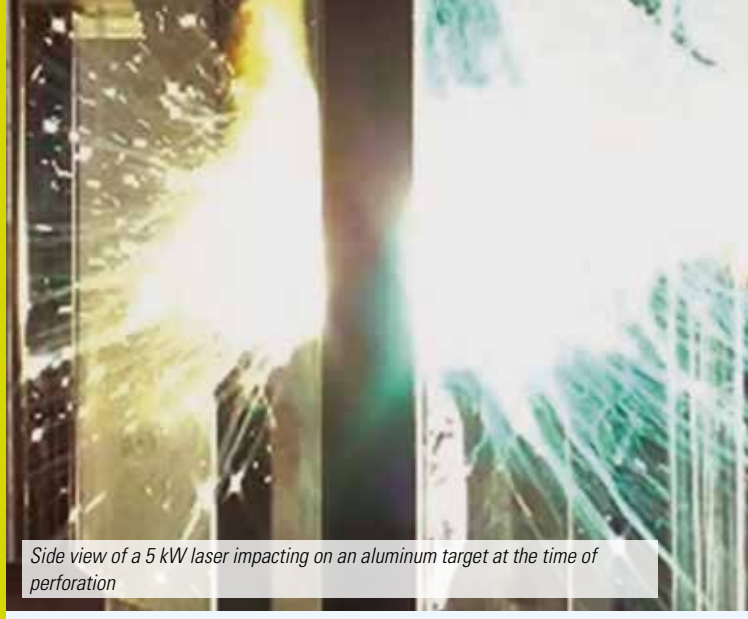
To develop effective counter-measures, ISL conducts investigations in two main areas:

1. Stand-off interception of threats with either blast or kinetic energy as found in hard-kill active protection systems, in particular against Tungsten heavy alloy long-rod penetrators.
2. Mitigation systems for use in the vicinity of the explosive threat device in order to destroy or at least reduce both blast and kinetic effects on the surrounding environment should the device detonate. ISL has proven that techniques based on aqueous foam, water mist or multi-phase materials can effectively counter both blast and fragmentation threat devices.

Blast protection against buried mines

ISL is investigating a concept of blast protection for armoured vehicles against buried mines based on sacrificial cladding with a 3D auxetic crushable core. It uses additive manufacturing to produce a wide range of 3D candidate lattices. It then assesses both numerically and experimentally the characterisation of the

challenge 04



Side view of a 5 kW laser impacting on an aluminum target at the time of perforation

material properties and the dynamic response of the lattice when submitted to blast loads.

Directed infrared countermeasure (DIRCM) systems and use of fibre technology for optimised laser systems

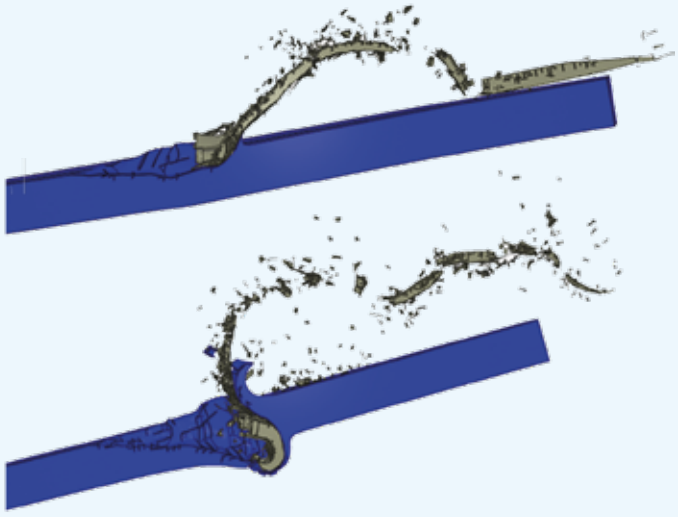
To protect mobile platforms from infrared-guided missiles, ISL is developing new laser sources for DIRCM systems. The operating principle of these systems is based on jamming, dazzling or damaging the infrared seeker missile head and requires powerful, robust, and compact laser sources with a good beam quality and a specific spectral range, capable of impacting seeker heads over several kilometres.

In 2021, ISL recorded up to 200 W of continuous wave optical power emitted at 2.1 µm under laboratory conditions, with a 45% efficiency and a near diffraction limited output beam. This is one of the most powerful, efficient laser sources based on a Tm^{3+}, Ho^{3+}-codoped active fibre reported in the literature. In the 3–5 µm spectral region, ISL has achieved a new record of 38 W using a ZGP (zinc germanium phosphide, $ZnGeP_2$) crystal. With the novel miniaturized FIRE cavity, it has also obtained the best beam quality at high output power reported in literature.

Optimal optical limitation

To protect imaging sensors against pulsed-laser radiations, ISL has developed optical limiting filtres based on in-house synthesised nano-diamonds. The filtres have a very low activation threshold (10 µJ) and an impressive attenuation factor of 100 times.

Samples of AlSi10Mg aluminum alloy crushable lattice additively manufactured by Direct Metal Laser Sintering



Numerical and experimental investigations on ricochet at impact velocity of 1400m/s against homogeneous armour

Dr. Teresa F.

- Scientist
- Explosive and ballistic protection
- At ISL since 2013

My motto:
“Affordable protection at the right time and place”

Dr. Sébastien L.

- Scientist
- Advanced materials and testing
- At ISL since 2010

My motto:
“Innovative ceramics for safer soldiers”

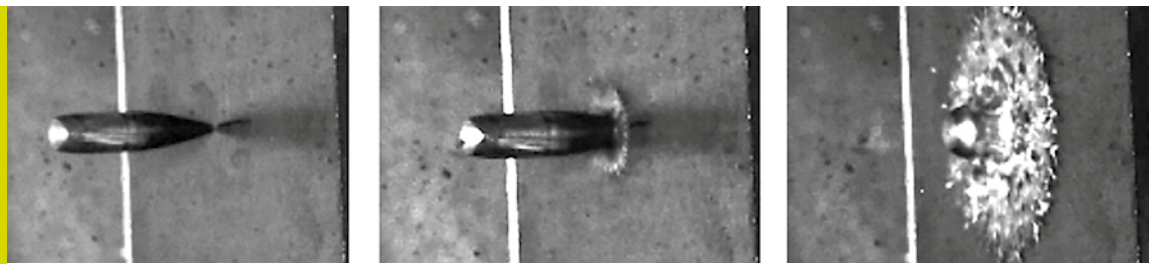
From chemistry through ballistic testing to material optimisation – interrelated skills for lighter, more efficient soldier protection

Developing lighter, higher-performance protection systems involves doing research at different levels. At the material level, new chemical formulations are created and innovative processing routes developed. At the system level, the design needs to take into account the material properties in order to optimise the protection performance and ballistic testing is done in real conditions to validate hypotheses and implement a continuous improvement process.
At ISL, two research groups with different skills complement each other to cover the entire innovation chain, from chemical synthesis through ballistic testing to subsequent material optimisation.

What type of background do you have?
Sébastien L.: I have a background in materials chemistry. In my work, I need to know and understand how the different atoms will arrange themselves when we slightly change the composition of the materials, submitting them to temperature and pressure treatment. I also need to determine the influence of such changes on the final properties. Working with completely new types of materials requires a scientific approach. You need to generate hypotheses and verify these in specially designed experiments, because there is very little scientific literature available. Taking an iterative approach, we perform a very large number of experiments. Because of its multi-disciplinary nature, my activity involves many rich discussions with my colleagues.

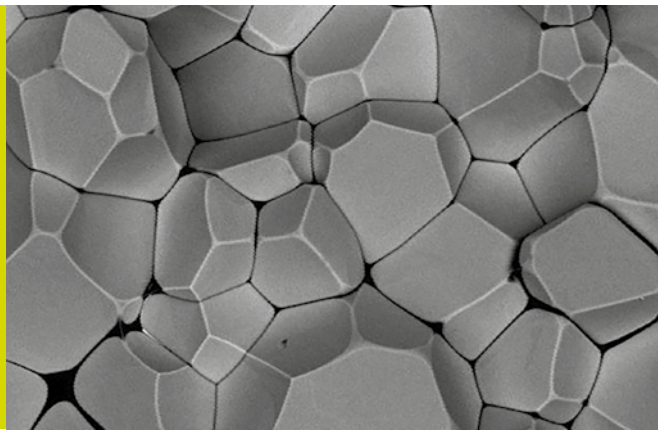
Teresa F.: I am qualified in mechanical and material engineering. This forms a good basis for my work at ISL. Thanks to dynamic testing, which I have been doing every day over these last few years, I have also gained experience in many different subjects, such as chemistry, material processing, dynamics and last but not least, terminal ballistics. Our work is inter-disciplinary and requires expertise in more than just one specific domain.

How does your work help improve soldier protection?
Sébastien L.: Generally speaking, the front face of the soldier protection is composed of ceramic material because its properties, in particular its hardness,



Ceramic plate stops a hard-core bullet calibre 7.62 (frames taken by high-speed camera)

allows erosion of the projectile and limitation of its penetration capacity. Nowadays, mainly three ceramics – aluminum oxide (Al_2O_3), silicon carbide (SiC) and boron carbide (B_4C) – are used because they have proved their potential. Based on this state of the art, there are two ways of improving the efficiency of the protection systems. The first is to work on existing materials enhancing their performance. The second is to search for completely new materials with unexplored properties, developing and evaluating them. At ISL, we pursue both approaches in parallel because this is a good balance.



Dense ceramic microstructure

Research work on the three well-known ceramics is of primary importance since it provides us with knowledge and understanding of the systems of reference.

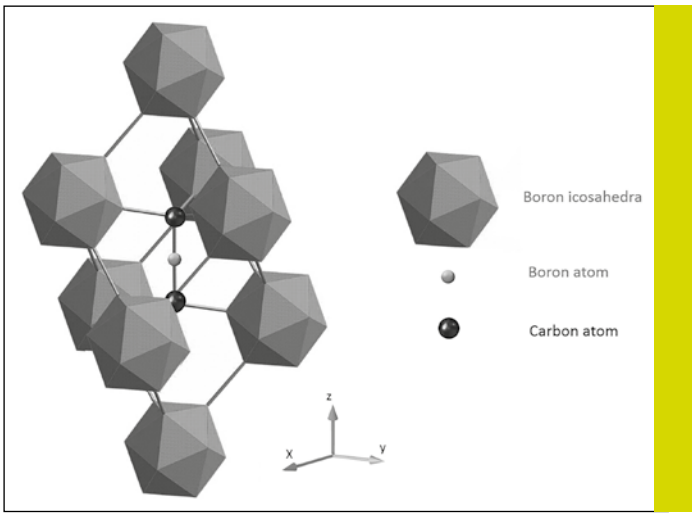
Research into new materials is fascinating but generally complicated, raising uncommon issues. Here, the investment is long-term. Our work focuses on lightweight materials exhibiting high hardness.

Teresa F.: We perform instrumented impact and blast experiments in the laboratory. These experiments are very fast, lasting only a few micro-seconds. Thanks to cutting-edge techniques, we are able to see what is happening during this fleeting moment and to measure certain effects. We analyse, describe and model the observed mechanisms. When our model simulations faithfully replicate our experiments, we can understand impact physics. This allows us to improve, optimise and develop solider protection systems.

In parallel to our core research activities, we engage in direct cooperation with a large number of industrial partners and manufacturers of personal, land and marine structural and protection systems. They often turn to us with very specific questions which helps us keep pace with industrial requirements.

How is your work complementary?

Sébastien L.: While material characterisation and its mechanical (both intrinsic and microstructure-related) properties can be considered a guideline, evaluation of the material's performance in real conditions is the only way we can obtain an objective assessment of our work. In the case of ceramics for ballistic protection, it is necessary to take advantage of complementary competencies in ballistic evaluation, including scientific set-up, the determination of threats to consider and the experimental conditions as well as metrology. In addition, a deep analysis of the ceramic behaviour during and after impact – post-mortem analysis – is carried out. This indicates the direction our research



Schematic view of the crystallographic structure of Boron Carbide (B_4C)

should take and permits identification of materials that could be of interest.

Teresa F.: Our aim is to propose structures for better protection of persons and assets against the effects of explosives and ballistics. To do this, the right material – chosen because of its specific structural and material properties – should be in the right position in a protective shield. The materials and their composition, which may provide a better performance – in the sense of efficiency in mitigating threats, their spectrum or their weight – are worth scientific investigation.

Ballistic evaluation with regard to different threats

Regarding materials and their properties, we rely on the knowledge and experience of our colleagues from Advanced materials and mechanical testing. Material science is upstream, whereas protection systems are downstream from to the end-user perspective. Thanks to this collaboration, we obtain material characterisation of properties which helps us model the protection systems and achieve virtual prototyping of new solutions. We also work together to specify custom-made materials for dedicated reasons. We optimise existing solutions and develop innovative protective systems based on the improvement of physical mechanisms or on new dual-use, military/civilian, innovative materials. ISL is one of the few places where all experts are co-located. This is an invaluable asset for creativity and reactivity.

Protection and performance of dismounted soldiers

Enhanced protection and perception systems for more efficient, agile soldiers

Front-line soldiers need to be more efficient and agile to protect themselves against new threats such as Improvised Explosive Devices (IEDs), snipers and small Unmanned Aerial Vehicles (UAVs). Future individual protection systems will probably be composed of three interconnected layers: personal armour limiting the risk of fatal injury caused by blast and ballistic threats, protection of vision and hearing as well as augmented perceptive and cognitive capabilities to detect threats at greater distances.

Reducing the weight of armour

One important objective is to improve soldiers' survivability while reducing the weight of their armour. ISL is thus investigating the mechanical behaviour of fibre-reinforced composite laminates under impact loading and associated modelling. It has also studied a new architecture of protection plates in order to avoid or reduce the penetration of small calibre projectiles (7.62 x 39 mm ammunition) under oblique incidence of impact (65° NATO). Here, ceramic layers were applied to woven fabric composite plates using spray coating. The ricochet characteristics and the dynamic back-face deformation of these plates were determined using digital image correlation. They also developed dynamic mechanical characterisations and numerical models of 9 mm and 7.62 mm lead core bullets impacting composite materials. The goal was to study and evaluate threat-target interactions as well as damage mechanisms.

Improving blast protection

Another objective is to improve the survivability against blast threat. In this context, ISL has developed new physical and numerical tools to evaluate Thoracic Protective Equipment against blast threat. It has also proposed practical relationships between the measurements done using the ISL anthropomorphic BOPMAN dummy and the observed lung injury severity.

Investigating the effects of ageing

By combining material characterisation, ballistic testing and the development of novel materials in a multi-disciplinary approach, ISL is investigating the effects of ageing on the performance of protective structures. The goal of this study is to propose and develop protection systems which are less prone to ageing and to provide better and more individualised prediction of the respective life-cycles.

challenge 05

ISL's anthropomorphic BOPMAN dummy specifically developed for lung injury investigation

Developing smart hearing protection devices

Hearing capabilities have to be protected in order to guarantee effective communication and audio situational awareness. Here, ISL is performing studies to improve existing devices and to increase its knowledge in order to develop future smart hearing protection devices.

In the context of the third-party subsidies contract BIONEAR, ISL has enhanced the quality of the audio signal. In comparison with previous versions, it has significantly reduced the background noise by combining new microphones with improved signal processing algorithms (reduction of 6 dB(A), dividing the noise amplitude by a factor of 2).

In addition, ISL has developed a more user-friendly two-dimensional transient numerical model using COMSOL Multiphysics. This shows the propagation pathways of the acoustic waves in soft tissues, skin, cartilage, bones and through the earplug. Based on this knowledge, ISL researchers expect to develop a solution that goes beyond classical earplugs.

Working to improve head protection

Another focus of ISL's work is to understand better how to protect the human head against blast and to integrate this protection in combat gear. ISL is developing a dummy head that exhibits similar behaviour in terms of deformations of the human cranium when subjected to blast threat. The initial results obtained reveal new insights about the investigation of skull deflection injury.

Acoustic tests with specifically developed ISL measurement head on Charles de Gaulle aircraft carrier

BIONEAR, new smart hearing protection equipment, neck band version

Dr. Vincent P.

- Scientist
- Radiation interaction with matter
- At ISL since 2005

My motto:
“Ageing to predict the future”

Dr. Sebastian E.

- Scientist
- Radiation interaction with matter
- At ISL since 2014

My motto:
“Together, we go further”

Dr. Anthony B.

- Scientist
- Advanced materials and mechanical testing
- At ISL since 2019

My motto:
“Breaking materials today for better protection tomorrow”

Fast-forwarding ageing processes for better protection – the success of multi-disciplinary research

In the past, protection materials for soldiers were mainly steel-based. Reduced protection due to corrosion or rust was easily detectable because visible to the naked eye.

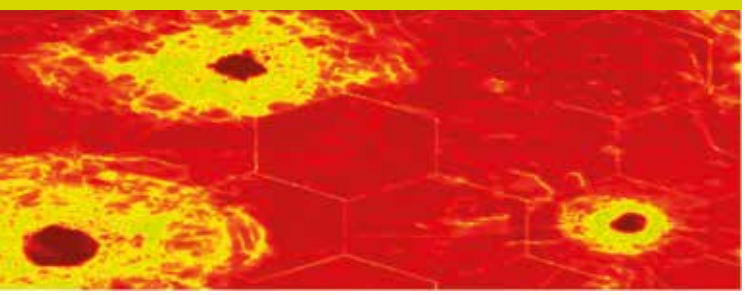
Today, battlefield dress is made of complex materials designed to be lighter in weight while providing greater protection. Little is, however, known about their ageing process. Changes in the performance of protective materials are likely to be invisible and their non-detection life-threatening.

Mandated by the French and German Ministries of Defence, ISL researchers from three different disciplines – material science, chemistry and physics – join forces to test, analyse and characterise ageing effects on various protection materials. The goal is to provide better protection while remaining cost-effective.

What skills are required in your different areas of expertise?

Anthony B.: I test, evaluate and study the behaviour of various materials in representative conditions within the context of defence. The results allow us to draw up guidelines for the choice of protective materials against a particular threat. With regard to the ageing project, this involves subjecting a wide variety of materials, for example, polymers, composites, metals and ceramics, to conditions which promote rapid material degradation. We then carry out mechanical and impact experiments on the aged materials and evaluate their performance. To address this research activity, a comprehensive understanding of material science, mechanics of materials and metrology is necessary.

Vincent P.: I am working on how the ageing process affects the chemical and physical properties of the materials. This involves research on polymer chain length, chemical bonds, water absorption and the adhesion between the different layers of the composite polymers. I use different analysis techniques, including spectroscopy, heat treatment and chemicals. Spectroscopy, for example, shows how the molecular bonds evolve in the material. By submitting the material to hundreds or thousands of hours of increased temperature, humidity and ultraviolet radiation, we reproduce the hot, wet conditions of the battlefield over time, accelerating



Non-destructive testing image of protective plate after ballistic testing

Composite visor sample after drop tower impact

the ageing process. Some materials change colour or become more opaque. For this type of research work, you need skills in material physics and chemistry.

Sebastian E.: I am the one pulling everything together which is the real challenge in an inter-disciplinary technology project which runs across the organisational structure. The positive aspect is that all the necessary experts work together. This is a typical project structure at ISL and is perfect for this type of project which cannot be done by one scientist alone.

How does a multi-disciplinary team work in practice?

Sebastian E.: I am an expert in Terahertz (THz) technology. But to obtain effective results in this project, we need to combine different research topics and perform a series of different tests – ballistic, thermal and mechanical – which requires complementary skills and scientists with detailed knowledge of their respective specialities.

To give you a concrete example: we might be asked to study ageing effects on eye shields. Here, we first need to know what the expected life span of the eye shield is, how we can characterise its material properties and how we are going to realise the ageing process.

The sample would go to Anthony for mechanical and impact tests and we would look at whether the molecular structure has changed and take measurements. Then, Vincent would provide spectroscopic data. The project is complex because it involves interactions between three or four different types of materials and

Comparison of aramid helmet composites before (left) and after ageing using different artificial ageing cycles (centre, right)

different testing methods. We also need to make a large number of measurements to identify the reasons behind the ageing process of the eye shields. ISL's advantage lies clearly in its multi-disciplinarity. We can provide an extensive report from a single source.

What about future developments?

Sebastian E.: The work we are doing on the effects of material ageing is also a European project, bringing together 25 partners from 14 different countries and ISL is leading the sub-project Ageing. By reproducing ageing effects on different types of material artificially, we can better understand how ageing impacts the degree of protection.

If we can define more accurate life-times for materials in the field, we can better plan their replacement and ensure adequate protection without generating unnecessary higher costs.

A: Visor in pristine state; B: Visor after ballistic impact

Workshops at ISL

3rd JANUARY 2021

First internal workshop on Sabots at ISL

This multi-disciplinary and cross-functional workshop provided an overview of ISL's current skills in the field of sabots. More than 30 staff members from different scientific groups specialising, for example, in aerodynamics, exterior ballistics, electric acceleration and protection against ballistic threats took part in the workshop.

Developing the new generation of tank guns (MGCS) and artillery (CIFS) opens up new opportunities to innovative sabot designs and this is an area where ISL has already excelled in the past.

17th FEBRUARY 2021

First ISL HACKATHON

Organised by Division II Flight techniques for projectiles, this event brought together four self-elected teams, built according to specific diversity rules. Each team of five members had just eight hours to solve the challenge "Design the next-generation anti-tank weapon system – Evolve company's rocket-propelled grenade (RPG) portfolio, filling the gap between RPGs and loitering ammunition"!

The winning team "CHRONOS" was awarded the first ISL Hackathon Trophy for their solution based on drone and munition cooperation using sensor-fused anti-tank warheads.

24th FEBRUARY AND 22nd MARCH 2021

Workshops on "Ambition 2030"

With a view to elaborating a sustainable development strategy for ISL over the next ten years, a series of workshops was launched by ISL management together with the supervisory authorities. Initial exchanges took place on site and by video-conference addressing a series of strategic topics including the positioning of ISL, future financing and French-German staff balance.

The initial findings will now be complemented by face-to-face work, essential to find consensus.

16th MARCH 2021

ISL Scientific Symposium

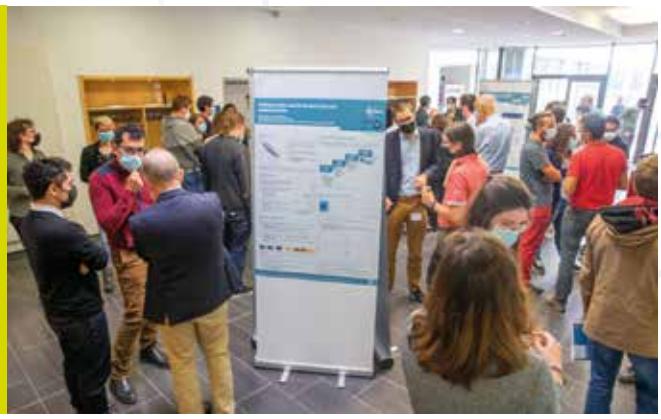
As a result of the COVID-19 crisis and for the first time, the traditional ISL Scientific Symposium took place in a new hybrid form with around 140 participants on-line

at a distance or in other rooms at ISL and just 20 people in the Schardin conference room. The chairmen – Frank Sabath and David Foricher, both members of the Research Advisory Board – also managed the sessions on-line from Munster and Paris.
During the symposium, researchers presented the highlights achieved over the last year within the five research topics: energetic materials and systems, flight techniques for projectiles, electromagnetic technologies, protection technologies, security and situational awareness and lasers.

28th–29th SEPTEMBER 2021

10th Budding Science Colloquium

Taking place every year, this colloquium is a forum for exchange and discussion where PhD students from different scientific fields have the opportunity to present their research according to the five scientific challenges of ISL.



17th–18th NOVEMBER 2021

"ISL KOMPAKT 2021", the first ISL-German Army Planning Office workshop

This two-day workshop brought together a delegation from the Planungsamt in Germany, headed by Major General Wolfgang Gäbelein, Director, and several ISL researchers.

The objective of the meeting was to have in-depth exchanges and to work together on relevant subjects, including the defence technologies of tomorrow and the precise steps that could be taken for collaboration in the future.

23rd–25th NOVEMBER 2021

The WTD 91 working group meets at ISL

During this workshop, ISL researchers came together with companies working on the study contracts for the 440 business area of WTD 91 to present their results. Participants included members of the ISL research group Protection against explosives and ballistic threats, protection manufacturers such as GEKE Engineering GmbH as well as a number of private consulting companies like Condat Projekt GmbH, Nordmetall

GmbH and IABG. Initial end-ballistic tests were carried out on the ISL test stand V3, which is equipped with the latest measuring technology.

14th DECEMBER 2021

ISL hosts the PILUM Security Advisory Board (SAB) meeting

ISL welcomed the nine members of the PILUM SAB composed of end users, the PILUM executive board members and representatives of the European Defence Agency (EDA). The meeting focussed on a progress report of the PILUM project activities and included a visit of the ISL railgun and wind tunnel facilities.

ISL is project leader of PILUM (Projectiles for Increased Long-range effects Using Electro-Magnetic railgun), a PADR (Preparatory Action on Defence Research) programme financed by the European Commission and managed by the EDA. The objective of the study project is to prepare the subsequent phases which aim to develop an operational railgun demonstrator on ISL's firing range by 2028.

3rd MARCH 2022

First ISL in-house workshop on hypervelocity

Hypersonic weapons, defined as flying faster than Mach 5 and being manoeuvrable unlike ballistic missiles, have become a hot topic in recent years. Most of these weapons are missiles. While ISL's portfolio does not include designing missiles, the Institute has expertise in this area and dedicated wind tunnels (up to Mach 20) of interest for both testing hypersonic vehicles and providing protection against them.

In this full-day workshop, ISL brought together all its experts from various disciplines to exchange on defence systems against hypersonic threats. The threats examined included hypersonic glide vehicles (HGV), cruise missiles, the railgun and lasers as well as Kinetic Energy (KE) projectiles which also achieve hypersonic speeds.

22nd MARCH 2022

ISL Scientific Symposium

Organised for the second time as a hybrid event, the 2022 ISL Scientific Symposium attracted more than 230 participants on the first day with 170 connected on-line.

Visitors from industry and government representatives engaged with ISL staff in lively exchanges, discussing ISL's five research areas.

SIGNIFICANT EVENTS AND TRADE FAIRS

7th JANUARY 2021

Inauguration of Battle Lab Terre (BLT), Satory

This event took place in the presence of the French Minister of the Armed Forces, Florence Parly.
The BLT is a newly created structure within the French Army destined to create links between the different innovation actors from, for example, industry, government bodies, start-ups, research centres, and universities, with the objective of accelerating the use of innovative technologies by the army.
During the event, ISL demonstrated the different capabilities of its image-based navigation technology embarked on the STAMINA-UGV Aurochs robotic platform.

10th JUNE 2021

First air-land Robotic Day and launch of the "VULCAIN" project, Satory

This event, organised by the French Army in collaboration with the GICAT (French Land Defence Manufacturers Association) and NEXTER Group, provided a first-time opportunity to present the army's objectives with regard to robotic technology as well as live demonstrations of the state-of-the-art technology within the French Defence Technological and Industrial Base (DTIB).
It also marked the launch of the VULCAIN project aimed to develop progressively the French Army's capabilities in robotics by 2040 by bringing together key players from the Ministry of Defence, industry, academia and research institutes.
Alongside sixteen industrial partners specialised in robots and air-land drones, ISL presented both a dynamic and static demonstration of its STAMINA intelligence building blocks embarked on the polyvalent tactical Aurochs robotic platform.

29th JUNE–1st JULY 2021

SOFINS (Special Operations Forces Innovation Network Seminar) at the Souges Camp, near Bordeaux

As member of the French "Cercle de l'Arbalète", ISL participated in the 5th edition of SOFINS, presenting ten different innovations in four different places: on its own stand, in a video providing a forward-looking vision of 2040 and in collaboration the French Defence Innovation Agency (AID) on the MoD stands inside and outside the exhibition hall.
The ISL exhibition stand focussed in particular on the next-generation hearing protection BANG/BIONEAR.
ISL also presented the concept of an observation projectile with an embedded camera for battle damage assessment (BDA) and a new high-tech ceramic/glass composite capable of reinforcing ballistic protection systems while reducing their mass by more than half.

14th JULY 2021

Special early morning live broadcast on France 2, Satory and public relations event at the Town Hall in Paris.

In the live broadcast on France 2 TV, ISL demonstrated the capacities of its high-tech STAMINA building blocks embarked on the robotic platforms UGV Aurochs and Patrol in two different military scenarios. In the first sequence "innovation at the service of the soldier", the STAMINA UGV Aurochs preceded a group of infantrymen in "push me" mode transporting their bags and a weapon. In the second sequence, the ISL STAMINA Patrol carried out a "reconnaissance exercise in enemy territory" using image navigation recovered by the Black Hornet drone.

At the townhall in Paris, ISL presented the two robotic platforms on its stand and exchanged views with members of the public.

6th–7th OCTOBER 2021

Presentation of the French Army capabilities (PCAT, "Présentation des capacités de l'Armée de Terre"), Satory

A total of 1,800 guests, including parliamentarians, elected representatives, generals, industry and media attended this second-time event where the French Army presented its operational capabilities under the motto: "Army of the future: new technologies for high-intensity operations."

ISL is proud to have been the only external player invited by the Army to participate in the demonstrations illustrating its future capabilities.

14th OCTOBER 2021

ISL obtains "ISO 9001: 2015" certification for its quality management system for all activities

At an official ceremony, ISL received the certificate confirming that its quality management system conforms to the requirements of the standard "ISO 9001: version

2015". Valid for all ISL's activities, the certificate was granted by the independent certifying body SOCOTEC Certification International after an initial audit started in July 2021 for a period of three years.

25th–27th NOVEMBER 2021

Innovation Defence Forum, Paris

A true showcase of defence innovation in France, this event brought together all government stakeholders and their partners around innovations supported by the Ministry of the Armed Forces.
During the forum, ISL presented two innovations – SURICATE and DEEPLOMATICS – in the exhibition space entitled "Securing superiority by winning the war in advance of the war".

28th–30th JANUARY 2022

The Defence Factory, Paris

With 19,900 registered visitors, the 2022 Defence Factory brought together a large number of stakeholders from the defence sector including politicians, military personnel and around 40 media, contributing to the development of a European strategic culture among young Europeans aged 15 to 30.

Present in three locations in two different areas, ISL exhibited its new naval model of the railgun (allowing shots to be fired) and presented its image-based navigation technology illustrated by film sequences showing the STAMINA UGV Aurochs and Patrol. It also promoted its job profiles and the different aspects of its European projects.

17th FEBRUARY 2022

5th Military recruitment and retraining fair (FER), Colmar

Organised by the Ad Honores section of the Gendarmerie reserve force, this fair targets military staff (gendarmerie or army) and their consort(s) planning on vocational integration in the civilian sector. On its stand, ISL presented its current job offers and the major assets of the Institute.

8th–10th MARCH 2022

DWT Congress – Applied Research for Defence and Security in Germany, Bonn

This conference and exhibition which took place for the fifth time attracted more than 500 visitors.
ISL made a significant contribution to the congress by giving presentations on energetic materials and systems, protection of the soldier's neck, laser technologies, sensor technology, hypersonic research and defence against hypersonic missiles. It also exhibited several innovations on its stand and moderated the closing debate of the congress on hypersonics.

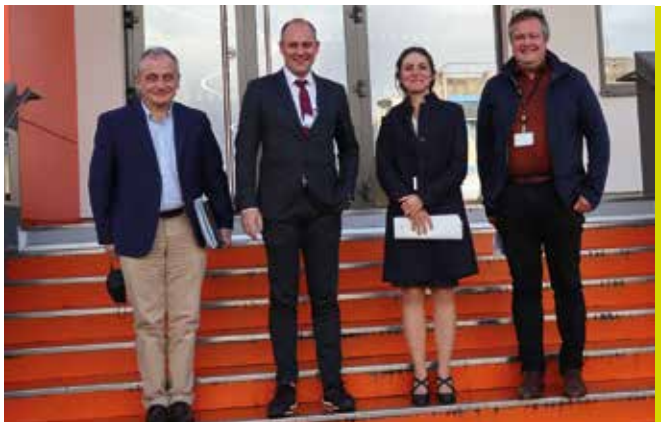
IMPORTANT VISITS (SELECTION)

20th–21st JANUARY 2021 &
20th–21st OCTOBER 2021
Visit from French Army officers in Training (EMSST)

7th SEPTEMBER 2021
Committee of medium-sized businesses, BDSV (Federal association of the German security and defence industry)

26th MARCH 2021
Emmanuel Chiva, Director of the Agence de l'Innovation de Défense (AID), right and Deputy Fabien Gouttefarde, left

2nd NOVEMBER 2021
Bernd Kögel, President of the DWT e.V. and SGW mbH, Germany



4th NOVEMBER 2021

Colonel Michel Lipski, Commander of the military base in Nancy and Valérie Cante, Regional Delegate of IHEDN Youth, Grand Est

8th FEBRUARY 2022

Aurélien Thiry, Deputy Director, Laboratoire central de la Préfecture de Police (LCPP), Paris

1st FEBRUARY 2022

SAFRAN Electronics & Defence, Paris

31st MARCH 2022

Group from the STAT, BLT and GICAT Defence sector, Paris

ACADEMIC EXCELLENCE

THESES DEFENDED IN 2021– 2022

Synthesis by flash spray of pure oxides, oxide mixtures and mixed oxides: photocatalytic and pyrotechnic applications
Denis PRÜSSING
Supervisors/Directors: Marc COMET (ISL, Unistra)
Defended on 28th January 2021

Numerical simulation of fracture in high-velocity impact
Marvin BECKER
Supervisors/Directors: Miriam MEHL (IPVS, University of Stuttgart), Marina SEIDL (ISL)
Defended on 23rd February 2021

Experimental and numerical study of the sensitivity of energetic materials: influence of the microstructure and role of the mechanical damage
Elodie KAESHAMMER
Supervisors/Directors: François WILLOT (MINES ParisTech (CMM)), Petr DOKLADAL (MINES ParisTech (CMM)), Lionel BORNE (ISL), Steve BELON (CEA Gramat)
Defended on 31st March 2021

Defeat solutions for electromagnetically launched multi-projectile threats
Philip GORES
Supervisors/Directors: John G. SPRAY (University of New Brunswick), Markus SCHNEIDER (ISL)
Defended on 31st March 2021

Transient non-line-of-sight imaging
Jonathan KLEIN
Supervisors/Directors: Matthias HULLIN (University of Bonn), Martin LAURENZIS (ISL)
Defended on 15th April 2021

Investigations on the behavior of normal/superconducting materials in strong pulsed magnetic fields
Vilius VERTELIS
Supervisors/Directors: Saulius BALEVIČIUS (Vilnius University), Markus SCHNEIDER (ISL)
Defended on 17th September 2021

Reconstruction of the audio environment with a hearing protection device: principle and concepts of solutions for an acoustically "transparent" hearing protection
Lorenz KRÖNER
Supervisors/Directors: Alexandre GARCIA (LMSSC, CNAM Paris), Véronique ZIMPFER (ISL)
Defended on 6th October 2021

Combustion-deflagration-detonation transition of a confined porous high explosive: influence of the microstructure
Thomas BOUCHET
Supervisors/Directors: Ashwin CHINNAYYA (CNRS-University of Poitiers-ISAE ENSMA, Pprime), Eric FOUSSON (ISL)
Defended on 19th October 2021

Phase change materials (PCM) for the reconfiguration of terahertz devices
Maxime PINAUD
Supervisors/Directors: Aurelian CRUNTEANU-STÀNESCU (Xlim), Georges HUMBERT (Xlim), Bernd FISCHER (ISL), Sebastian ENGELBRECHT (ISL)
Defended on 24th November 2021

Advanced anti-windup flight control algorithms for fast time-varying aerospace systems
Sovanna THAI
Supervisors/Directors: Clément ROOS (ONERA), Spilios THEODOULIS (ISL)
Defended on 25th November 2021

Neuromorphic computing for exploration and robust categorisation of visual and multimodal environments in embedded systems
Yann BERNARD
Supervisors/Directors: Bernard GIRAU (LORIA, University of Lorraine), Nicolas HUEBER (ISL), Pierre RAYMOND (ISL)
Defended on 7th December 2021

Study of radiative transfer in semi-transparent composite materials
Florent RETAILLEAU
Supervisors/Directors: Jaona Harifidy RANDRIANALISOA (ITheMM, University of Reims Champagne-Ardenne), Jean-François HENRY (ITheMM, University of Reims Champagne-Ardenne), Lionel MERLAT (ISL)
Defended on 17th December 2021

Preparation of desensitised reactive nanothermites
Virginie GOETZ
Supervisors/Directors: Pierre GIBOT (CNRS/NS3E, Unistra)
Defended on 7th January 022

Absorption of impact energy by rubber interlayers
Janis KARL
Supervisors/Directors: Matthias REHAHN (TU Darmstadt), Teresa FRAS (ISL), Leonhard PERKO (LBF), Roland KLEIN (LBF)
Defended on 24th January 2022

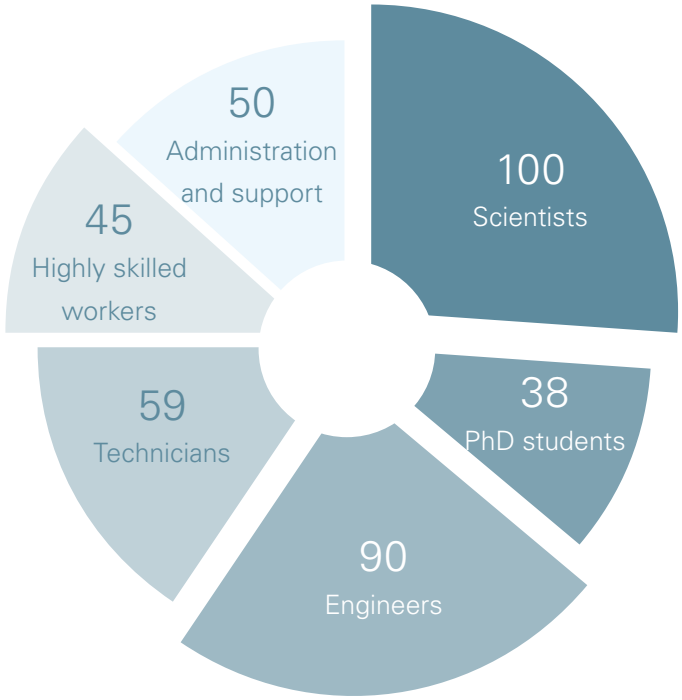
Study of the mechanical behaviour at the impact of a ductile core ammunition (small to medium calibre)
Yann COGET
Supervisors/Directors: Christophe CZARNOTA (LEM3, University of Lorraine), Yaël DEMARTY (ISL), Alexis RUSINEK (LEM3, University of Lorraine)
Defended on 25th February 2022

ENTITLEMENT TO SUPERVISE RESEARCH

Estimation and observation for navigation in defense applications
Sébastien CHANGEY
Defended on 6th April 2021

FACTS AND FIGURES (2021)

ISL STAFF

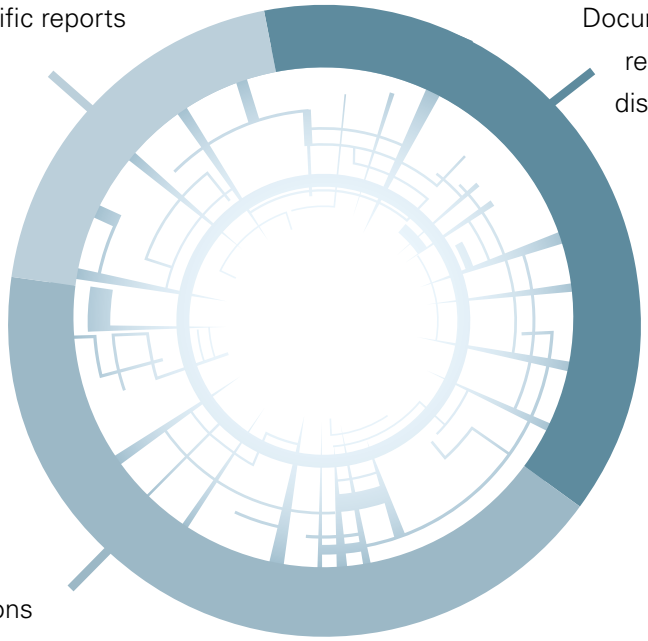


BUDGET

36.088 M€
Subsidies for fundamental research

15.262 M€
Governmental and third-party contracts (without value-added tax)

Scientific documents



66
Scientific reports

155
Documents with restricted distribution

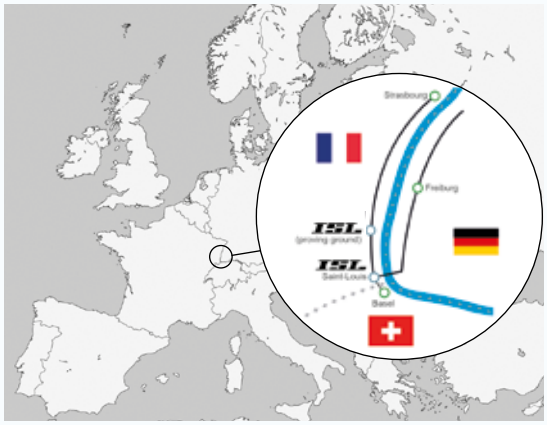
113
Publications (conferences, scientific journals, posters and proceedings)

Research focus: five major challenges

1. Energetic materials and systems
   13.13%
2. Future gun systems and smart ammunition
   36.90%
3. Advanced situational awareness
   29.44%
4. Survivability of weapons sytems
   11.15%
5. Protection and performance of dismounted soldiers
   9.38%

List of selected ISL publications on www.isl.eu

List of patents on www.isl.eu



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