ANNUAL REPORT 2019-2020

FRENCH-GERMAN RESEARCH INSTITUTE OF SAINT-LOUIS

CONTENTS

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RESEARCH INSTITUTE
OF SAINT-LOUIS

A FIRST-TIME HISTORICAL PERFORMANCE

On 14th July 2019, ISL's STAMINA-UGV Patrol, carrying the French and German flags, opened up the military parade on the Champs Elysées in front of Emmanuel Macron, Angela Merkel and numerous state representatives. Based on image processing and capable of following itineries without GPS, this smart, cost-effective robot took up a front-line position at this important event dedicated to demonstrating defence innovation capabilities.

EDITORIAL

Dear readers,

We are extremely pleased to present you the salient features of our 2019-2020 Annual Report which in many ways has become a very special issue.

On the one hand, because of the unprecedented impact of the 2020 Coronavirus crisis. This black swan has had enormous repercussions not only on the organisation of ISL's research activities but also on life in the local community, in the surrounding tri-national region Saint-Louis, Weil am Rhein, Lörrach and Basel as well as on human and business relations within the whole of Europe and world-wide.

On the other hand, because 2019 marked the 60th Anniversary of ISL. Our two-day special celebration event in June was a major step towards opening up the Institute further to the outside world. It also provided us with the unique opportunity of presenting ISL's front-line research activities within an innovative framework of five major scientific challenges fully matching the future capability requirements of the armed forces. This framework provides the basis for ISL's scientific strategy for the next ten years (Strategy 2020-2030).

Challenging times due to Coronavirus – health and safety first

As of mid-March 2020, during finalisation of the content of this Annual Report, we were suddenly confronted with unprecedented organizational, health security and safety challenges due to the Coronavirus crisis. This invisible enemy, which at the beginning of March badly hit the Grand Est region in France in particular, led to stringent confinement strategies being adopted by the surrounding government representatives of France, Germany and Switzerland. As a result of decisions, taken in particular by the French and German governments, ISL was forced to shut down all experimental research activities at both its sites in Saint-Louis and Baldersheim on 18th March 2020 and take up working from home.

Thanks to close collaboration with our company Doctor and the constructive support of the employees' representatives on ISL's Health and Safety Committee, we were able to elaborate and implement in record time a health and safety protocol in line with the toughest French and German standards.

The strict safety measures allowed us to return gradually to work as of Monday, 6th April and to resume all on-site research activities starting Monday, 4th May.

Our warmest thanks go to everyone who participated in these extensive, in-depth back-to-work preparations which clearly put the health and safety of all ISL employees first.

Our sincerest condolences go to all those whose relatives or friends have been affected by the virus. In particular, we would like to remember Jean-Marie Zoellé, Mayor of Saint-Louis. After suffering respiratory insufficiency caused by the Coronavirus, he was transferred from the hospital complex in Mulhouse to the St. Petrus Hospital in Bonn where he sadly died on Saturday, 4th April 2020. Jean-Marie Zoellé was a fervent supporter of ISL and intensive French-German collaboration.

A spirit of responsibility and commitment

Whether on site or working from home, especially within the crisis team, we were all determined to overcome adversity with enthusiasm. This shows yet again the keen spirit which motivates us all at ISL. Scientific teams used the time at home to exchange with partners and customers, work on the findings of recent trials and prepare the next series of tests. However, since the true assets of ISL's innovation work and expertise lie in the experimental activities and complex simulations which can only take place on site, returning to site was of vital necessity.

We are proud of all our employees who have shown responsible behaviour and the greatest of vigilance with regard to their own health safety and that of others around them.

By working together in unity and by respecting the necessary health and safety measures, we are resolved to continue to be of full service to our ministries, partners and clients in the fields of defence and security while protecting ourselves.

60th Anniversary celebrations

Governed by a binational agreement signed by France and Germany in 1959, ISL is one of the most powerful symbols of European reconciliation after the Second

World War. United in a common search for security, French and German scientists have been combining their defence research efforts in a relationship of mutual trust for more than half a century and have been joined by scientists from all over Europe.

The two-day anniversary event, which took place at ISL in June 2019, celebrated the transformation of the former Research Laboratory of Saint-Louis (RLSL) into the binational French-German Research Institute (ISL) when both parliaments ratified the first treaty concluded between France and Germany after the 2nd World War in June 1959, four years before the signature of the Elysée-Treaty.

ISL, front-line mover since 1959 and catalyser for future cooperation in Europe

In his opening speech at the anniversary event, the German State Secretary General Benedict Zimmer emphasised: "Fundamental and applicative research in the areas of security and defence are becoming increasingly important given the growing threat of terrorism and the rapid pace of technological development… German-French defence cooperation must therefore become the focal point and integral part of wider European efforts and needs to have a stronger influence on common security policy within the Western Alliance on both sides of the Atlantic. In order to meet this need, we have to overcome political stagnation and fragmentation in Europe… In this respect, ISL has been a front-line mover for the last 60 years."

Representing the Ministerial Delegate for Defence Procurement in France Joël Barre, General Thierry Angel underlined in his speech: "We all know that operational superiority depends on advanced technology which takes on different forms at ISL and is branded "ISL inside"... This technological superiority is acquired through innovation which is at the heart of ISL's activity and written in its DNA… ISL innovates through its in-depth knowledge of physical phenomena, by cooperating with other research institutes and through its capacity to adapt and develop an open culture based on cross-fertilisation of ideas fostering new inventions… Thanks to its binational status, ISL will certainly have its role to play as catalyser for future cooperation within the framework of the European Defence Fund."

Scientific strategy 2020-2030: five major challenges

A new feature of this 2019-2020 Annual Report is that the selected highlights of ISL's research results have been structured according to five major scientific challenges.

These five challenges, presented during the 60th Anniversary Celebrations, offer a preview of ISL's upcoming strategic scientific strategy 2020-2030, which replies to the future capability requirements of the armed forces.

The five main challenges are as follows:

1. Energetic materials and systems
2. Future gun systems and smart ammunition
3. Survivability of weapon systems
4. Protection and performance of dismounted soldiers
5. Advanced situational awareness

Meeting future capability requirements of the armed forces

In the period under review, ISL teams have made important advances on a number of highly successful multidisciplinary scientific research projects, all focused on meeting the future capability requirements of the armed forces.

Highlights include first steps towards a one-stage, low-cost, green and safe detonator, additive manufacturing of energetic materials, evaluation of long-range guided projectiles, real-time computing for navigation projectile applications, development of an eye-safe high-energy laser and non-explosive reactive armour against long-rod penetrators. A decisive step forward was also achieved in better sensitivity and range resolution of "see-around-the-corner" technology based on single photon-counting sensors.

Third-party contracts clearly on the upturn

ISL is dedicated to providing the best service to its third-party customers (public-sector entities or private industrial companies). In parallel, it makes sure that research work funded by third-party contracts contributes to the objectives jointly defined with the French and German Ministries of Defence, thus creating a win-win situation for all concerned.

Benefiting from its diversified innovation portfolio and its extended outreach towards a large community of customers and partners, ISL has registered a continuous increase in the overall number of third-party contracts over the last few years.

A number of important contracts awarded by public-sector customers in the period under review focus specifically on increasing the safety and protection of the armed forces and involve work on:

- designing a portable, short wave infrared active imaging system in accumulation mode for use in marine environments with moving targets,
- producing a bone conduction transducer for integration into soldiers' helmets, capable of reducing environment noise and thus optimising acoustic performance for the wearer while taking into account variations in human morphology,
- gaining more knowledge about the type of thorax injuries produced by blast effects in order to improve the effectiveness of clothing.

With regard to its contracts with private industrial companies, ISL has consolidated its partner base in France and is extending its collaboration with partner companies in Germany, essentially in the land domain but also for naval and aerial applications. At European level, the Institute is also enjoying more visibility thanks to its response to numerous calls for tender, a trend expected to increase in future. During the period under review, ISL has conducted numerous studies for private industrial partners encompassing the following areas of activity and many more:

- active imaging,
- guidance, navigation and control of projectiles and platforms,
- opto-pyro detonators,
- integration of GPS antennas, magnetometers and accelerometers,
- testing of electronic and mechanical components up to 25,000 g in the ISL soft in-bore recovery facility.

Events, academic excellence and warmest thanks

The final section of our Annual Report presents an overview of the important visits and events, workshops and conferences organised by ISL or at ISL during 2019-2020 as well as our participation at different trade fairs, exhibitions and conferences.

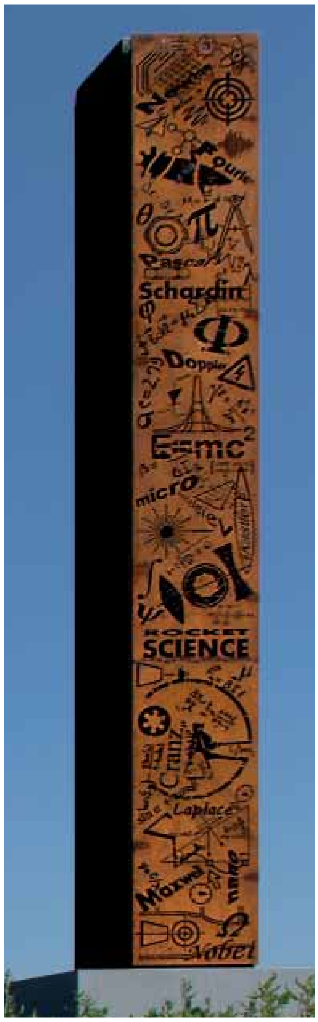
We are pleased to congratulate all the members of our staff who successfully finished their theses during the period under review. This high-quality work achieved in partnership with different European universities is of great importance to the Institute.

In conclusion, we would also like to thank the representatives of our ministries, our Research Advisory Board, the members of our Board of Directors, political actors in both countries, academic and industry partners for their continued support and trust in our capacity to innovate.

As in the past and in the face of all adversity, we are committed to continue our front-line research in the interests of defence and security for France and Germany, taking a leading role in Europe.

Dr.-Ing. Thomas CZIRWITZKY German Director	Christian de VILLEMAGNE French Director

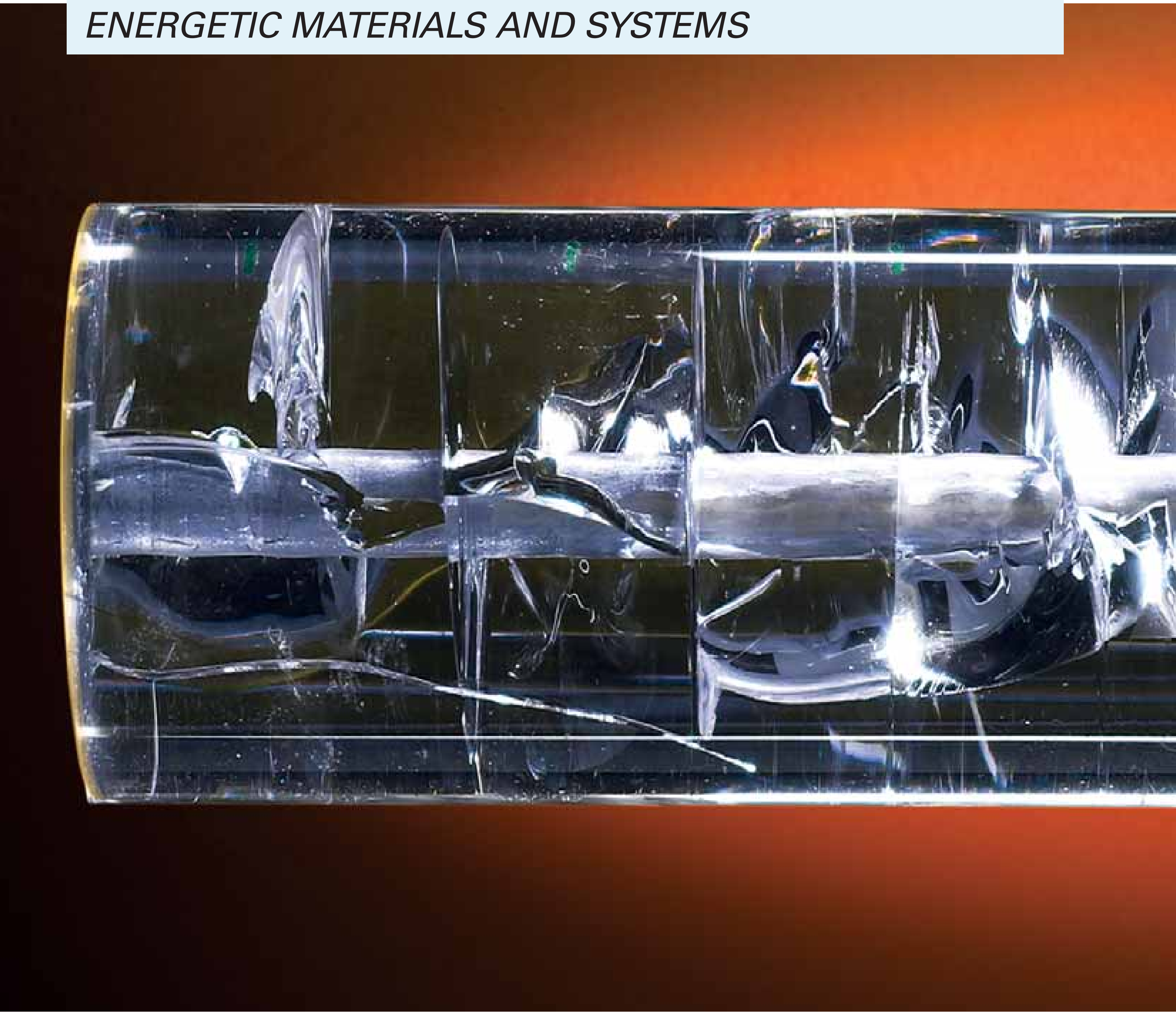
60TH ANNIVERSARY IMPRESSIONS




Elektromagnetische Kanone

1 ENERGETIC MATERIALS AND SYSTEMS

IMPROVING THE PERFORMANCE AND THE SAFETY OF ENERGETIC MATERIALS AND SYSTEMS



Art and science: the effect of a solvent on a tube used for pyrotechnic tests

Energetic materials can be enhanced using modern and accurately controlled processing techniques, such as finely tuned crystallisation, nano-engineering or 3D printing. ISL designs materials and system microstructures from micro-scale down to nano-scale in order to control their reactive behaviour. In order to increase the performance and safety of energetic systems, ISL pursues a number of important objectives. These include adjusting the pressure time curve with novel propellant grains, tuning the shock sensitivity of explosive particles, miniaturising reactive systems, developing new nano- or submicro-structured materials to replace primary explosives and improving the life cycle management.

To **increase weapon performance**, ISL develops new propellants, charge configurations and ignition technologies. This activity includes developing improved igniters for low vulnerability ammunition (LOVA) gun propellants (e.g. thermites based on nanomaterials or electrothermal-chemical technology), the advanced modelling of interior ballistics mechanisms (e.g. chemical kinetics models), the synthesis of new energy carriers such as azole-based salts and the use of 3D-printing technology to design and manufacture tailored propellant grains with enhanced properties based on complex grain geometry or multi-material grain.

By mastering the sensitivity and the performance of energetic materials, ISL is able to meet the stringent defence requirements concerning reduced sensitivity (safety, vulnerability), enhanced ballistic performance, improved life-cycle and ageing behaviour as well as compliance with REACH regulations. ISL research teams address this challenge by developing engineering techniques for energetic materials that provide accurate control of the physical and chemical properties of the materials from micro-scale down to nano-scale. Characterising the influence of materials features on their reactive behaviour, i.e. combustion, deflagration, detonation or transitions from one mode to another, is also of prime importance. Both activities require developing cutting-edge metrology techniques and numerical tools, from quantum chemistry to detonics simulations.

ISL combines its skills in energetic materials engineering, interior ballistics and detonics to **develop advanced energetic systems** such as ignition devices, pyrotechnical actuators for projectile course control, miniaturised reactive systems (e.g. shaped charges) or explosive reactive armour (ERA) systems with highly reduced sensitivity based on nanostructured energetic composites.

1.1

ADDITIVE MANUFACTURING OF PROPELLANT GRAINS

In the field of energetic materials, 3D-printing technology, which refers to all manufacturing processes in which material is applied layer by layer to create three-dimensional objects, is of significant added value and improves weapon performance in particular. Thanks to 3D printing, access to particular shapes, difficult to reach with conventional methods as well as manufacturing of multi-material propellant grains, is today possible.

Patented in the mid-1980s, additive manufacturing or 3D-printing technologies are currently experiencing considerable growth. Thanks to the versatility of this production technique, it is now possible to print an important number of various materials ranging from metal alloys, polymers and ceramics to concrete or reactive and energetic materials. Consequently, the defence industry is increasingly interested in additive manufacturing which offers many different possible applications. Printing energetic materials such as high explosives or solid propellants remains, however, a challenge.

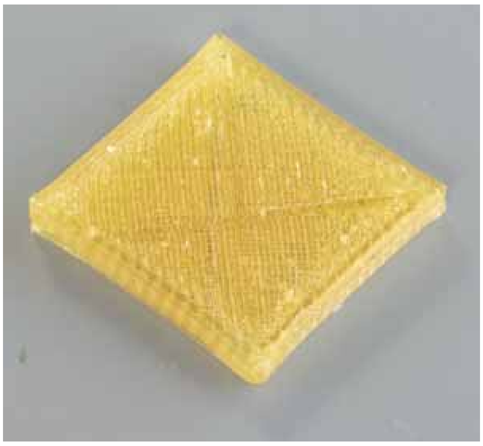
For this reason, in December 2018, the European Defence Agency (EDA) launched an R&T project on the 3D printing of energetic materials. The project is coordinated by the French-German Research Institute of Saint-Louis (ISL) and involves fifteen European organisations from a total of seven different countries.

The main objective of this four-year research programme, called Additive Manufacturing Techniques for Energetic Materials (AMTEM), is to identify appropriate 3D-printing materials and production techniques for novel warheads and propellants with enhanced performance, in order to enable a faster and cheaper production of prototypes and short series.

ISL is deeply involved in this project thanks to its interior ballistics skills. The main current issue within this field consists in enhancing weapon performance by increasing the muzzle energy of the projectile. The adjustment and control of the gas flow rate of the propellant during the ballistic cycle is one of the most ingenious ways of achieving this goal. This can be accomplished by using specific propellant grains such as co-layered propellants consisting of two or more layers of different compositions as shown in the figure on the right. This kind of layered propellant allows optimisation of the energy transfer between the energetic material and the projectile, resulting in increased muzzle velocity.

Co-layered propellant charge

A former study conducted at ISL highlighted an increase of 15% in muzzle kinetic energy at equivalent maximum pressures with this type of propellant. However, the manufacturing of the propelling charges was quite complex. The difficulties in producing co-layered propellants can now be overcome thanks to 3D-printing technologies.



Images of 3D-printed flakes

After having carried out a literature review on 3D-printing techniques and associated materials, ISL decided to focus on a material extrusion technique, replacing the original heated filament extruder, used to print thermoplastic such as polylactic acid (PLA) or acrylonitrile butadiene styrene (ABS), with a syringe-based system. This allows printing of viscous materials such as loaded pastes. ISL researchers proposed an operating procedure to print simple shapes of gun propellant. The first step of the work consisted in selecting the compositions to be printed and performing extrusion tests and viscosity measurements.

Using a nitrocellulose-based energetic composition, the formulation is fully soluble in acetone (Ac) giving a viscous paste whose viscosity can be adjusted by the charge rate of the mixture energetic material (EM) / Ac. A simulant of the energetic paste, made of cellulose acetate particles dissolved in acetone, was also used while the pyrotechnic safety issues for the 3D printer were tackled.

Inert materials with simple shapes (e.g. 20x20x3 mm^3 flakes as displayed in the figures at the bottom of page 12) were first printed by using the simulant. Important parameters for the optimisation of the final quality of the produced part were identified. The viscosity of the material must be controlled, and it was shown that it was easier to print highly viscous materials than fluid ones with the system. Furthermore, printing parameters such as layer height, print speed or extrusion flow play a huge role.

Finally, the energetic paste was successfully used to 3D-print propellant grains. Around 100 energetic grains were printed and there was excellent reproducibility in terms of size and density. The printed grains were then dried to remove residual solvent and are currently being characterised.

At the time of printing this Annual Report, ISL researchers will be studying the burning performances of the 3D-printed propellant grains (see figure on this page) and comparing the results to the combustion of traditionally manufactured grains. Work will continue on optimisation of the printing process aimed at enhancing the final quality of the flakes. This should allow printing of co-layered gun propellant grains of more complex geometry.

Additive manufacturing techniques are enormously promising and work at ISL highlights the possibility of reliably producing energetic gun propellants with a slightly modified 3D printer. In order to produce a new generation of gun propellants, freedom of shape brought by these techniques as well as multi-material approaches will be topics of particular concern in the coming months.

Combustion of propellant grains

1.2

ENHANCING MICROSTRUCTURE OF ENERGETIC MATERIALS

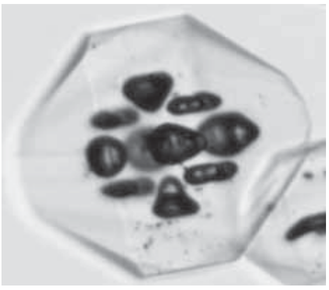
The performance and safety of energetic materials can be enhanced by tuning their microstructure. Fine crystallisation processing allows control of the solvent inclusions in RDX particles to vary their shock sensitivity. The energetic system architecture is important to manage their reactive behaviour. The combustion – deflagration – detonation transition (CoDDT) of a set of HMX particles is strongly affected by the particle size distribution, its processing and its confinement.

Solvent inclusions are natural parts of crystals resulting from the crystallisation processes. For pharmaceuticals, the presence of inclusions is tied to problems such as increased impurity content and caking.

In energetic materials, commercial RDX grades contain inclusions leading to high shock sensitivities. By ridding crystals of fluid inclusions, ISL has developed its own patented VI-RDX, a very insensitive RDX particle grade.

ISL researchers are now exploring RDX sensitivity control by engineering fluid inclusion using finely tuned crystallisation processes. In addition, attempts have been made to modify inclusion number and size, aiming at the production of RDX batches with adjusted shock sensitivities.

Crystallisation processes and regimes have been pointed out where the position of inclusions was far from random and seemed directly tied to the external crystal shape, resulting in regular patterns of inclusions as shown in the two figures at bottom left of this page. These patterns and the associated particular symmetries seem to be closely associated with the crystal morphology and its growth faces. Changing the solvent modifies the crystal habitus and the inclusion pattern. Changing the crystal growth condition impacts the inclusion sizes. Both resulted in various shock sensitivity levels.

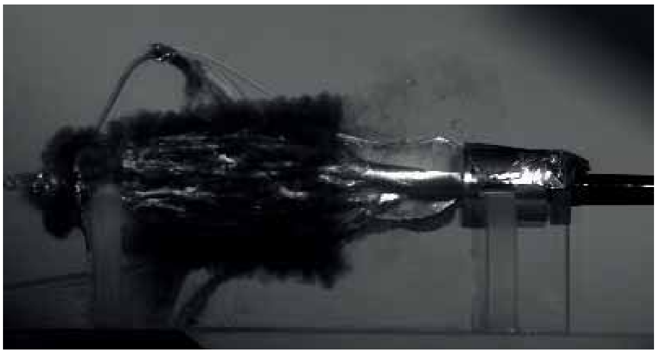


RDX crystal shape and pattern of solvent inclusion

New pyrotechnical devices (detonator, cutter, etc.) based on the thermal initiation of heavily confined secondary explosives are currently developed to offer better ageing and higher safety. This presupposes the ability to control precisely the decomposition regimes either to favour or avoid the possible evolution from a controlled combustion to deflagration/detonation depending on the final effects expected.

Transitions between the different decomposition modes are highly dependent on the explosive microstructure and are driven by parameters like granulometry, compaction pressure/porosity and the confinement strength. The objective was to better predict the transition point both experimentally and numerically with the development of a specific model.

By performing numerous deflagration tests on three different HMX lots compressed in hard strength tubes whose granulometry had been previously characterised (BET measurements, mercury porosimetries, LASER granulometries, SEM observation), ISL has shown that the detonation is achievable on relative short explosive length in the case of large initial grain size and high porosities (see figure at bottom right). First simulations show similar tendencies, but model improvements are still needed to reproduce all the observed behaviours.



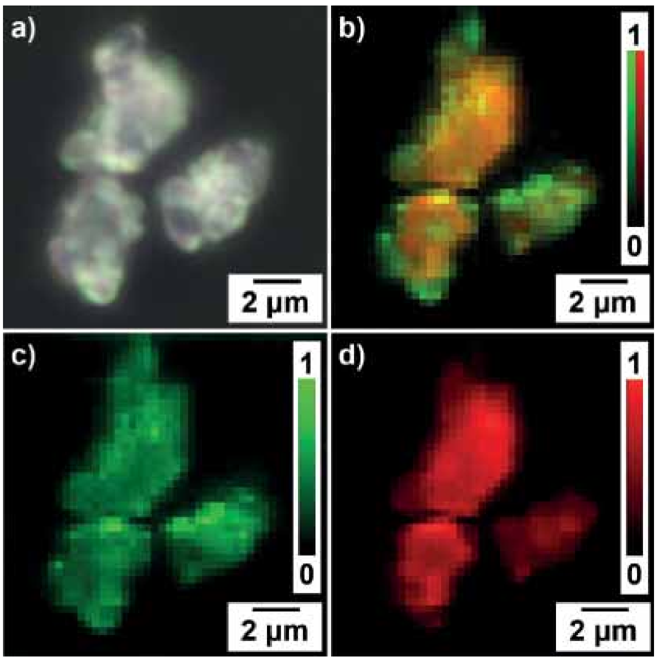
Study of the combustion to deflagration to detonation transition

1.3

ADVANCED UNDERSTANDING OF SFE EXPLOSIVE AND PROPELLANT ENGINEERING

Spray flash evaporation (SFE) is a multi-patented ISL technology used for the continuous production of submicron-sized energetic and non-energetic materials. This highly versatile technology produces explosives and propellants based on ultrafine pure, core-shell, nanocomposites or cocrystal entities. It requires complementary on-line metrologies and off-line cutting-edge characterisation methods to understand how it works in order to extend further its applications in the field of energetic materials.

Spray flash evaporation (SFE), which received the "Grand Prix Lazare Carnot" award from the French Academy of Science in 2015, is a continuous one-step process to formulate energetic and non-energetic materials. The process allows formulation of nano- and sub-micron-sized RDX and HMX explosives with reduced critical detonation diameter for high penetrating miniaturised projectiles. Nanostructured hexolites were prepared to synthetise the worldwide smallest detonation nanodiamonds. The CL-20/HMX 2/1 nanococrystal was formulated by SFE and was successfully used in "green" detonator prototypes to replace heavy-metal-based primary explosives. Thanks to its scale-up and formulation capacity, SFE changes industrial practices since it is able to produce high-performance LOVA propellants in large quantities. As it is a one-step process, it is more economical than multi-batch step processes, such as mixing and laminating processes currently used. SFE is also safer than the traditional preparation methods of propellants, as mixing of components is done in a very small quantity at all times.



Hexolite nanoparticles

In order to optimise the SFE process, research steps are conducted in two phases. The first permits measurement of the droplet size and velocity in order to understand evaporation kinetics prior to particle crystallisation off-line particle characterisation. The second involves off-line particle characterisation by tip enhanced raman spectroscopy (TERS) on single nanoparticles. TERS was acquired two years ago at ISL and jointly funded by ISL and CPER. Here, ISL achieved two breakthrough results core-shell and cocrystal particles respectively.

The figure on this page represents hexolite nanoparticles. Evidencing hexolite nanoparticles as core-shell particles, with a RDX core and a TNT shell, allows understanding of the formation mechanism of nanodiamonds obtained by detonation of the explosives.

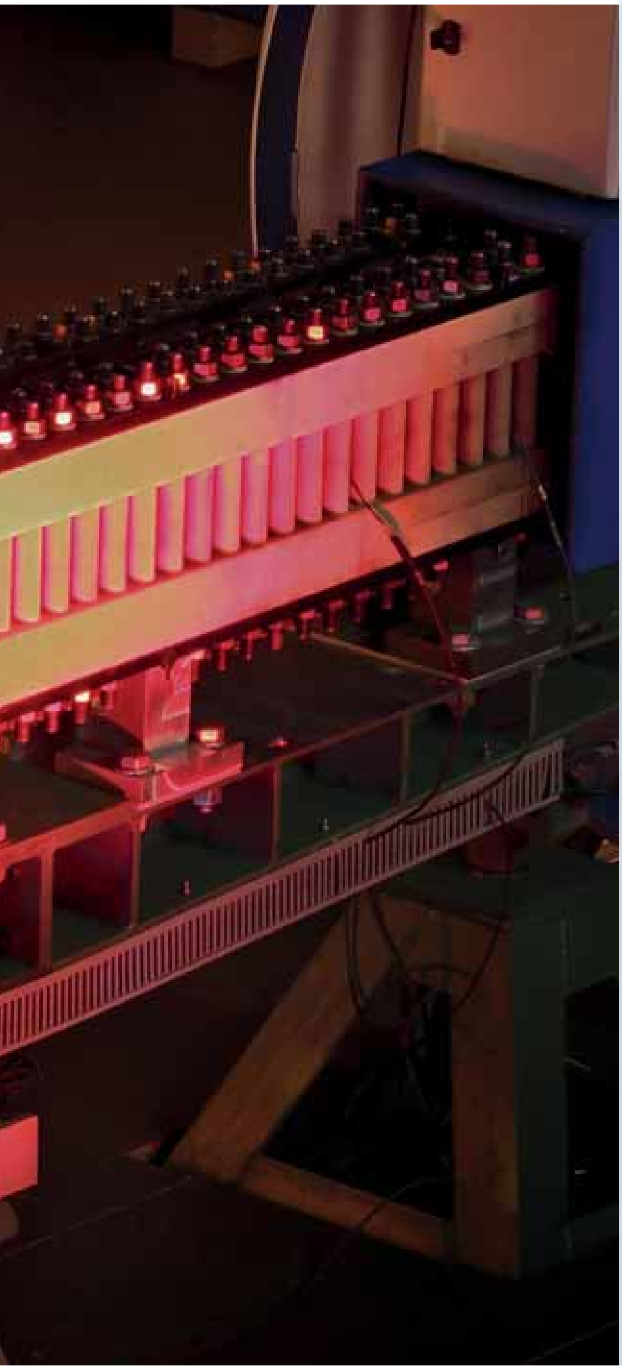
After having shown five years ago that smaller nanodiamonds come from smaller hexolite particles, the NS3E laboratory at ISL has made a new major breakthough with regard to understanding building of nanodiamonds. Concerning TERS investigation of CL-20/HMX 2/1 nanococrystal, mappings are able to show cocrystal nature on a single nanoparticle, a result never obtained before on such a small amount of organic material! These off-line metrologies, combined with their material characterisation power, are essential for understanding and pushing further the extension of SFE, making it a key player in the safe and efficient processing of energetic materials.

2 FUTURE GUN SYSTEMS AND SMART AMMUNITION

HYPERVELOCITY, LONG RANGE, HIGH ACCURACY AND PRECISION AT LOW COST

New-generation railgun

The next generation of guns and ammunition will have to provide long range precision strikes and effective air and missile defence capabilities to land and naval forces. Meeting this challenge requires a cross-domain approach: increasing the muzzle velocity and the rate of fire of guns using electrical energy, designing gun-hardened aerodynamic architectures for extended-range vectors, miniaturising sensors and actuators to implement on-board low-cost navigation and control capabilities and shaping up swarms of projectiles.



Future guns using electrical energy will be game-changers for land and naval forces. They will provide drastic superiority over conventional guns due to very high muzzle velocities (currently up to 3 km/s), insensitivity to ambient temperature changes and higher rates of fire. All these factors will contribute to increasing the probability of hitting targets. Two promising technologies are under investigation: electromagnetic (EM) railguns and electro-thermal-chemical (ETC) guns. The former uses electrical energy only to launch projectiles, the latter generates a plasma to optimise the ignition of high-density gun propellants. Both guns require the development of efficient and compact pulsed power sources, including the development of electronic components required for the fast switching of high-intensity current pulses.

Together with these new launchers, ISL is exploring **disruptive solutions for future guided ammunition**. These will provide higher effectiveness to artillery and tank fires thanks to higher velocity, extended range (more than 200 km with EM railgun artillery) and higher accuracy and precision (less than one metre circular error for anti-air warfare). To meet these goals, ISL researchers need first of all to design innovative gun-launched aerodynamic architectures in all flight modes, from subsonic to hypersonic regime, including studies related to actuators, aerodynamic heating and ablation as well as high-angle of attack aerodynamics. They also need to develop low-cost, ITAR-free gun-hardened projectile components such as inertial measurement units, communication devices and antennas. Last but not least, there is a need to develop specific algorithms for guidance, navigation and control, enabling in particular the use of precision munitions in any hostile environment out of the reach of global navigation satellite systems (GNSS), e.g. GPS and Galileo. In the longer term, ISL aims to investigate swarm concepts of highly manoeuvrable and interconnected projectiles.

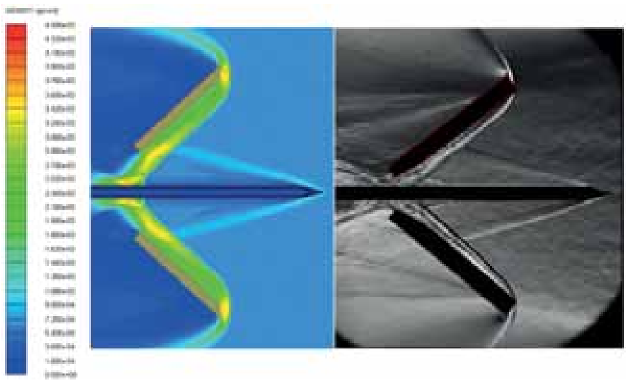
2.1

ELECTROMAGNETIC LAUNCHER AND ITS POWER SUPPLY

Electromagnetic launch is a disruptive technology that offers increased projectile velocity, repetition-rate and efficiency. For operational scenarios such as large area coverage or air defence, railguns offer new capabilities. For mobile applications, new compact electric power supplies are required in order to provide electrical power in the gigawatt range. Projectiles with masses in the range of 0.1-100 kg are to be accelerated within a few milliseconds to velocities above 2000 m/s.

Electromagnetic railguns offer a disruptive potential compared to traditional guns because they can realise projectile speeds in the hypervelocity range (i.e. > 3000 m/s). This allows either drastic extension of the weapon range or considerable increase in the performance of a defence system. Recently, ISL has made significant progress in both scenarios. NGL60, a novel, 6 m long, 6 mm square caliber railgun has been connected to ISL's 10 MJ (megajoule) power supply and put successfully into service. NGL60 will be used to study the optimisation of launch packages, in particular with respect to their payload-to-total mass ratio. The rapid fire railgun RAFIRA has been also connected to the 10 MJ capacitor bank, enabling RAFIRA to perform intelligent bursts of five shots at Mach 2 with a fire rate of almost 70 Hz. Furthermore, muzzle velocities of Mach 5 could be obtained for a two-shot salvo.

With regard to military applications, ISL is also studying further aspects of electromagnetic launch. Recently, research has focused on bore life. Investigations concentrate on wear mechanisms at the rail-armature interface with the end goal of increasing the lifetime of the rails. In parallel, studies are looking into the transitional ballistics of railguns. In this context, the aerodynamic behaviour of a sabot after exiting the railgun is investigated both experimentally and theoretically. The figure below shows the separation of a railgun sabot at Mach 4.5. Furthermore, with regard to system integration, electromagnetic compatibility (EMC) is an on-going topic. ISL is carrying out investigations on potential EMC issues in the vicinity of the launcher and its power supply or even inside the barrel using in-situ measurements and numerical simulations.



Sabot separation at muzzle exit: simulation (left) and experiment (right)

Electromagnetic launchers require several MJ of energy and operate in power ranges of gigawatts. The development of compact and efficient electrical sources is a key point for system integration on mobile platforms. Available pulsed power supplies (PPS) need to shrink in size and weight in order to fit military requirements. Instead of incremental improvements of existing capacitor bank technology, a PPS based on inductive storage is under development at ISL. An XRAM topology is used to realise an inductive PPS with semiconductor-based opening switches. A proof of concept has been realised by connecting a 1 megajoule, 10-stage XRAM generator to the RAFIRA railgun (see figure below right). The amplitude of the charging current of 40 kA was tenfold multiplied to propel an 80 g projectile to 1120 m/s.

ISL's XRAM inductive pulsed power supply

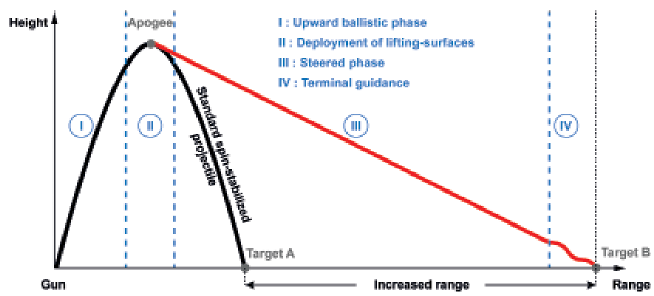
2.2

LONG-RANGE GUIDED PROJECTILE PROJECT

The extension of the sphere of action for artillery systems aims at improving the fire capability of combat platforms. It also aims at increasing their survivability and that of the soldiers by keeping them out of the reach of enemies. The extension of the projectile range is then mandatory and is strongly linked to the flight strategy, the aerodynamic architecture and the navigation, at least. This section summarises ISL's recent research work done on a dedicated project of a long-range guided projectile.

The long-range guided projectile (LRGP) project is dedicated to the range increase of low-cost, ITAR-free (i.e. not submitted to US regulations restricting export of defence technology), full calibre 155 mm artillery projectiles. While conventional ammunitions can reach ranges of about 35 km, the goal of this project is to develop a concept that can reach at least 70 km without propulsion systems or base-bleed units.

ISL proposes a specific flight strategy summarised in the graph below. The range-increasing function is fulfilled by a phase where the projectile behaves like a glider (phase III, also called gliding phase). Therefore, wings are unfolded in the vicinity of the apogee (phase II) of a classical spin- or fin-stabilised ballistic phase (phase I). The impact precision is guaranteed by the terminal phase (phase IV), which only starts when the projectile is close enough to the target. Although this last phase has not yet been investigated, it will be considered.

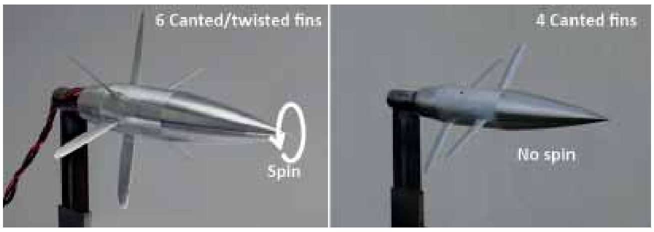


Flight phases of the long-range guided projectile

For range increase purposes, the slope of the gliding phase has to be minimised. At constant flight velocity, a well-known result consists in maximising the lift-to-drag ratio. But as the conditions change during the flight, it was already shown that this property is not suitable for the LRGP concept. At the current state of the investigation, a first flight strategy has already been found. Research is under way for designing a novel guidance law increasing the range still further.

The good news here is that such control laws require a one-off increased effort in design but do not result in additional recurring costs.

As the range is the most important criteria for performance evaluation, ISL performed trajectory simulations with a dedicated in-house code. Two lifting wings based on spinning (left) and non-spinning (right) aerodynamic architectures were proposed as shown in the following figure.



Possible aerodynamic architectures

With perfect navigation, a 70-km range can be reached for both concepts in spite of more or less restrictive hypotheses. The computed values of the distances thus need to be considered with care, but the relative performances can clearly be assessed.

This investigation shows that the most promising architecture is the non-rotating configuration. However, secondary criteria like the manoeuvrability, the flight duration, the cost, etc. shall also be considered. For example, the main drawback of both solutions is that the range increase is obtained to the detriment of the velocity. Thus, the flight can reach durations up to 10 minutes. An additional aerodynamic investigation will therefore be performed in 2021 in order to evaluate the range increase capability of a supersonic glider, by accepting a range sacrifice to promote the velocity, and thereby, to reduce the flight duration.

2.3

DECOUPLED FUZE FOR GUIDED PROJECTILES PROJECT

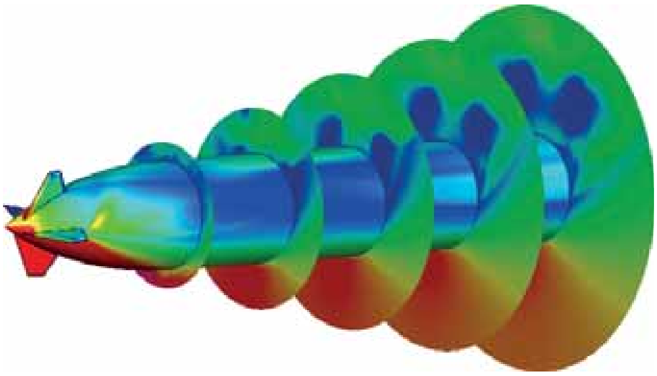
Equipping existing rounds, such as the 155 mm for example, with a decoupled fuze integrating controlled mobile canards transforms a ballistic ammunition into a guided projectile. This is a way of enhancing the accuracy of projectiles on targets. This section summarises the research work done in mechatronics, aerodynamics, flight dynamics, guidance and control to converge to a demonstrator which should be fired in 2022.

Spin-stabilised ballistic projectiles exist in large quantities in most nation armies worldwide. Although relatively cheap, they suffer from relatively low target accuracy due to the absence of active, closed loop guidance, navigation and control (GNC). ISL proposes an original solution to remedy this issue, converting ballistic projectiles into guided ones by integrating a roll-decoupled guidance module onto their nose as displayed in the figure below. Some commercial solutions have already been fielded. These are, however, subject to ITAR regulations and show severe limitations with regard to integration in existing rounds and performance. ISL's decoupled fuze is ITAR-free and shows a high performance.

ISL's roll-decoupled guidance module

This module incorporates mechatronic components such as sensors, aerodynamic control fins as well as motor actuators and electronics. Most importantly, guidance, navigation and control algorithms render the projectile accurate and autonomous. To this end, ISL is working on several critical technologies and know-how.

In the field of aerodynamics, ISL provides in-depth understanding of the flow interactions between the control fins and the main body, both through wind tunnel experiments and computational fluid dynamics (CFD) simulations. The following figure shows the pressure distribution on the model and the density distribution in the flow field computed by CFD around the projectile. The projectile with rotating canards flies at a supersonic speed at a high angle of attack.



Simulation of the flow around the decoupled fuze guided projectile

For flight dynamics, state-of-the-art non-linear simulators were perfected to yield accurate and split-second simulations of the projectile flight behaviour exploiting parallel computing. Design-oriented, linear parameter-varying models were obtained throughout the projectile's whole flight domain, embedding aerodynamic and mechanical uncertainties.

The reduced control authority of spin-stabilised projectiles is a limitation since it may lead to control fin saturation and instability. To remedy this critical effect, bespoke anti-windup flight control algorithms were developed, helping to reduce the projectile-to-target miss distance in simulation. Finally, guidance laws based on the so-called zero-effort-miss principle, were extensively tested and tweaked in order to not overly deviate the projectile from its nominal ballistic trajectory, while also providing achievable load factor tracking commands.

The next milestone of this project is the testing of the guidance module inside ISL wind tunnel facilities. All of its primary hardware and software components will be characterised, verified and validated for roll manoeuvres. Future work will focus on free flight guided tests, gradually advancing from direct to indirect fire scenarios, supported by full system simulations of the GNC loops.

2.4

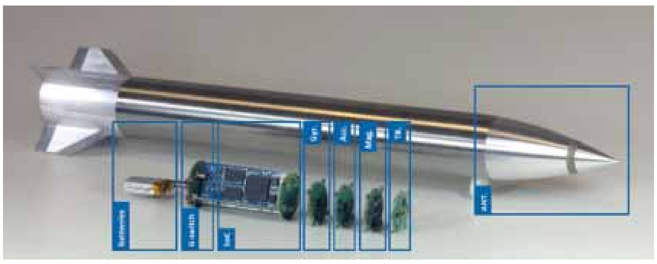
COMMUNICATION AND REAL-TIME NAVIGATION FOR GUIDED PROJECTILES

ISL is currently developing a navigation building block based on low-cost ITAR-free components to be embedded in guided projectiles. This involves research on an inertial measurement unit, on real-time on-board computing, on secure communications between the projectile and the ground station, all in harsh conditions of projectile firing and in an environment not covered by GNSS (global navigation satellite systems). This section presents a number of on-going developments in this area.

The development of guided ammunitions is a trade-off between performance and cost. In order to improve the range and accuracy of guided projectiles, there is a growing need to study innovative embedded navigation systems able to communicate with the projectile while reducing the size, weight, power and cost of the projectile.

ISL is currently developing a gun-hardened magneto-inertial navigation unit based on ITAR-free consumer grade sensors. The poor performance of these sensors is mitigated by using magnetometer measurements which provide a direct external reference (the Earth's magnetic field) as well as integrating a simplified 6-DoF (degree of freedom) ballistic model of the projectile in the navigation filters.

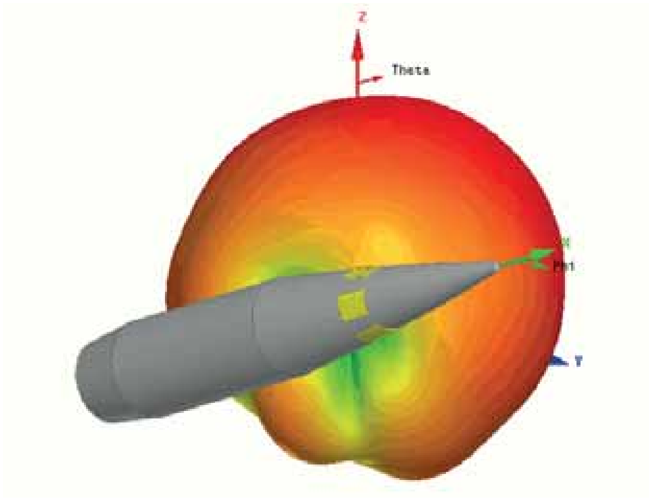
In order to be computed in real time on board a projectile, ISL researchers are implementing these navigation algorithms into a SoC (system on chip) – a specific computing unit which combines a FPGA (field-programmable gate array) and a multi-core ARM (advanced RISC machines) processor. The figure below shows a fin-stabilised 48-mm caliber projectile equipped with the complete embedded navigation unit: from the left to the right, LiPo batteries, a G-switch, a SoC and its associated power supply electronics, rate gyros, accelerometers, magnetometers, an S-band transceiver and an antenna.



Components of an embedded navigation unit

In addition, thanks to the computing performance of these SoC, ISL is able to use embedded SDR (software defined radio) based transceivers. SDRs offer higher flexibility and re-configurability. In addition SDRs allow the implementation of more complex digital modulations and encodings, which enable higher data rates and more robust radio links.

These on-board bi-directional telecommunication systems allow the transmission of in-flight data, mission abort or re-targeting messages, as well as alternative localisation information. ISL uniquely uses conformal printed phased array antennas in order to improve the data link security. These antennas are used to steer the radiation pattern dynamically towards a defined direction. The figure below depicts a spin-stabilised projectile having a controlled GNSS antenna array with its 3D radiation pattern despite the continuous roll of the projectile. The gain is always maximum towards the satellites and minimum towards the ground station, improving the robustness to jammers or spoofers.

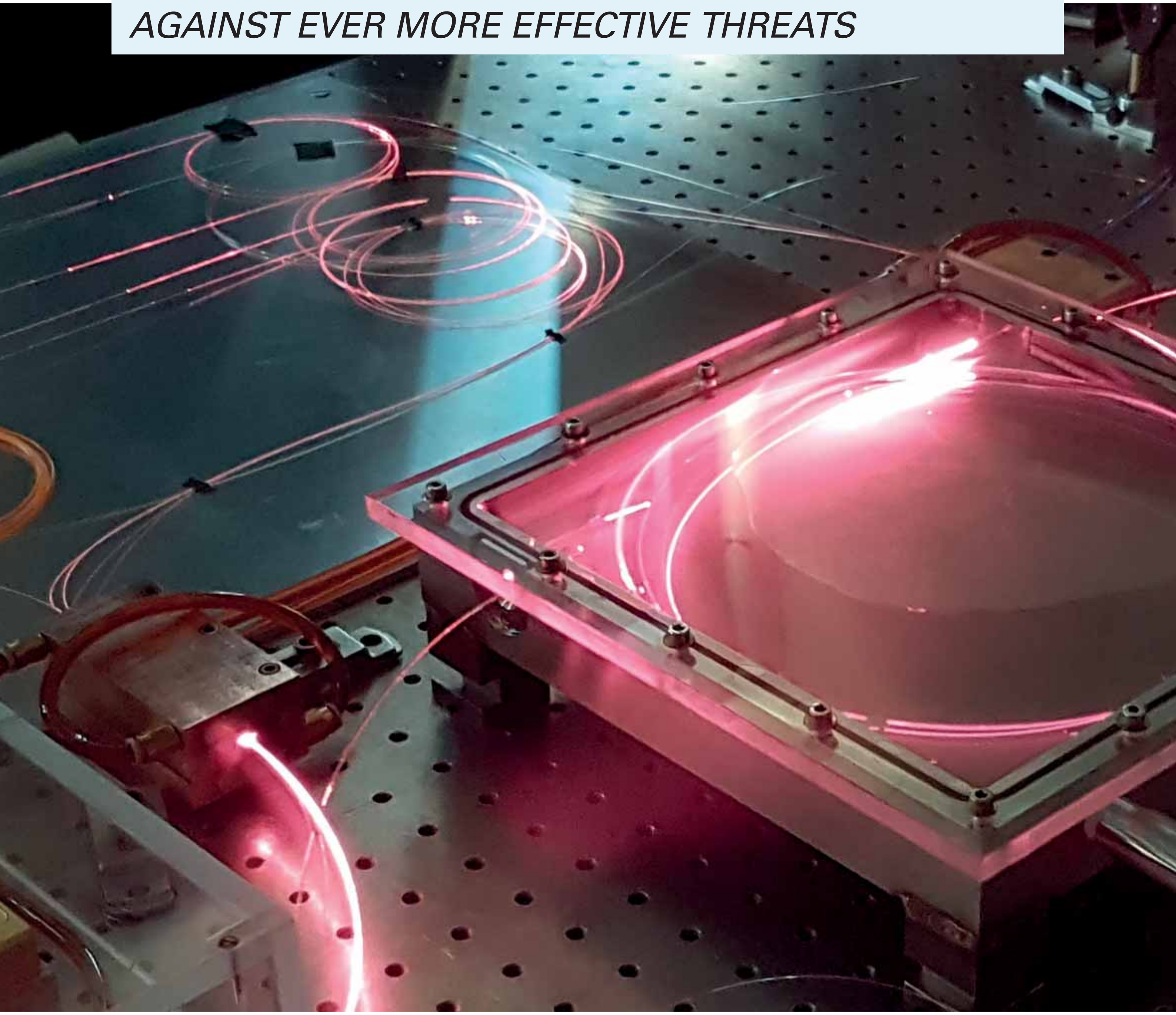


Roll-decoupled 3D radiation pattern associated to a GNSS antenna array

In order to reduce the dimensions as well as enhance the bandwidth, ISL is working on meta-material-inspired antennas. The objective is to develop a gun-hardened conformal multi-band GNSS antenna array which can be used for all civilian GNSS signals (GPS L1 and L5, Galileo E1 and E5).

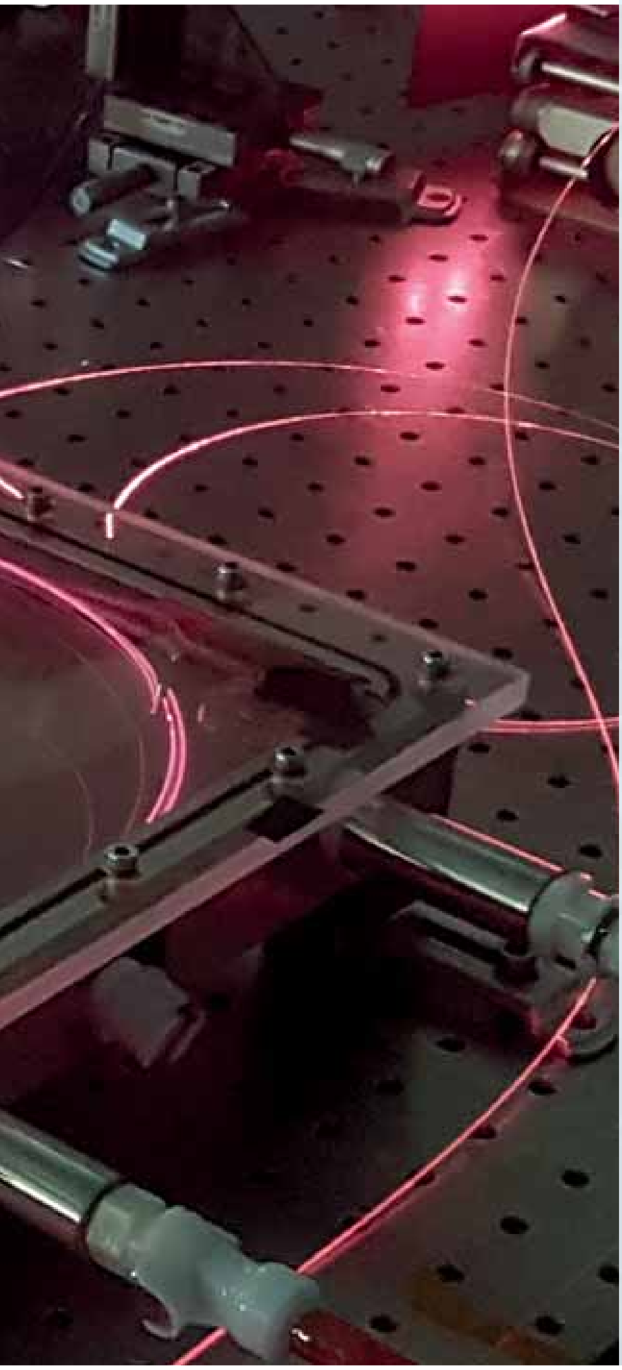
3 SURVIVABILITY OF WEAPONS SYSTEMS

INCREASING PROTECTION OF WEAPONS SYSTEMS AGAINST EVER MORE EFFECTIVE THREATS



Alignment-free all-fibred laser set-up

Surviving exposure to high threat environments is critical to the mission success of land, naval and air systems. Increasing the survivability of military platforms and crews is based on three main activities: threat characterisation to understand lethal effects, threat engagement to avoid hit and platform protection to reduce vulnerability to hit. Different threats are considered – namely ballistic, explosive and high-energy laser threats – and addressed with active soft- and hard-kill countermeasures, advanced materials and protection systems.



The objective of **threat characterisation** is to investigate, model and assess the interaction of current and emerging threats with representative targets based on theoretical analyses, computer simulations and experimental testing of the lethality mechanisms. Regarding ballistic and explosive threats, ISL's main objective is to consolidate and increase its expertise about the effects of threats such as explosive shells, fragments, kinetic penetrators, mines and improvised explosive devices. Regarding high-energy lasers, ISL studies focus on understanding the interaction of laser beams with materials, which necessitates the development of specific simulation models and metrology tools.

Active soft- and hard-kill countermeasures are designed to deflect and/or to intercept incoming threats – including hypersonic projectiles and missiles – to avoid being hit or to reduce effects on impact. Soft-kill is based on directed infrared countermeasures (DIRCM) fiber and solid-state laser systems that can jam, dazzle or damage on-board IR-seekers of guided weapons. Optimising the size, weight and power parameters of DIRCM systems to meet military requirements is a major concern. New concepts of damage or supercontinuum laser are also under consideration. Hard-kill systems are investigated to defeat explosive warheads and long rod penetrators using kinetic or enhanced blast effectors or to scatter laser beams with mitigation systems based on aerosols.

Improving the platforms' last line of defence is achieved with **advanced passive or reactive protection** systems embedding advanced materials and energy dissipation mechanisms. High-strength materials with low specific weight based on metals, ceramics or polymers as well as multiphase crushable materials or lattice structures will improve the protection against ballistic and blast threats while nonlinear optical limiting materials will reduce the transmission of incoming laser light. Last but not least, investigating the effects of ageing to guarantee the protection level of materials over time is also of prime importance.

3.1

DESIGNING ACTIVE-REACTIVE ARMOUR SYSTEMS

Explosive reactive armour (ERA) consists of a layer of high explosive sandwiched between two plates of inert material. Upon impact of a threat, the explosive is initiated and accelerates the inert plates against the threat, disturbing and eroding it, resulting in reduced penetration of the main armour. Although ERA is known to be effective against shaped charge jets and long rod penetrators, active ERA systems, which are triggered on threat detection, provide greater protection.

The initiability of ERA depends on different parameters, including the features of the incoming threat such as shape, material and velocity, the sensitivity of the explosive used as well as the material and the thickness of the moving armour plates.

Modern ERA uses explosives so insensitive that they would not usually initiate upon impact of a kinetic energy (KE) projectile, such as STANAG Level 6 projectiles, especially in the case of medium calibre protection. This is because this type of projectile threat has a relatively low impact velocity (~1400 m/s) and a rather small diametre (9 mm). In this case, the efficiency of the ERA component against this threat is not activated and the threat is only defeated by the inert behaviour of the armour.

In order to use the effectiveness of ERA against KE penetrators with low sensitivity explosives, a relevant solution permits detection of the incoming threat and artificial detonation of the ERA component using a detonator.

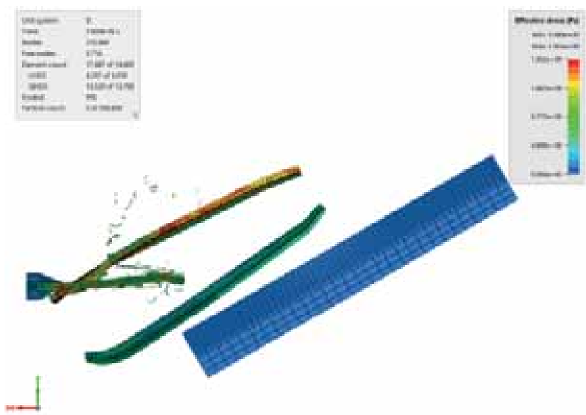
ISL research teams designed a reference projectile in order to investigate and develop an efficient active-ERA system against STANAG Level 6 threats. When tested and compared with the STANAG Level 6 threat, the ISL reference projectile was found to have the same ballistic performance as the original projectile.

Active-ERA interacting with a long rod penetrator

An active-ERA system was designed and tested experimentally. This involved equipping the ERA with a system to detect the impacting projectile and using a detonator to initiate the explosive of the ERA upon impact of the projectile. A flash X-ray of an active-ERA interacting with the projectile is shown in the photo at bottom left of this page. The photo was taken 75 µs after the impact of the penetrator on the target. It shows the ERA plate moving against the direction of the projectile to disturb and bend the penetrator, resulting in a reduced depth of penetration (DOP) in the witness blocks.

Compared to an equivalent mass of RHA (rolled homogenous armour) steel, the first tested configuration had an efficiency factor of about 2. In order to optimise the interaction between the ERA plates and the projectile, numerical simulations were performed with a finite element (FE) code. A result of such a numerical simulation is shown in the figure at bottom right of this page.

This code allows different configurations to be tested and evaluated quickly and reliably. ISL found that the most efficient defeat mechanism against the long rod projectile is to fragment the rod. In order to simulate this, research teams investigated the dynamic failure mechanism of the tungsten heavy metal alloy.



Numerical simulation to optimise the effectiveness of ERA plates

3.2

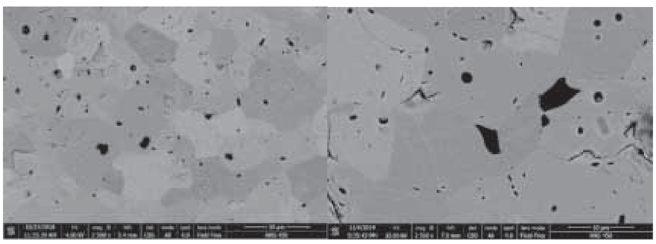
DEVELOPING TiB_2 CERAMICS BY SPARK PLASMA SINTERING

ISL decided to consider titanium diboride (TiB_2), a material with an outstanding hardness (HK1 > 20 GPa), good mechanical properties and low specific weight (4.52 g/cm³), as a potential candidate for front face tiles used in ballistic protection systems. Ceramics were developed using the spark plasma sintering (SPS) technique in order to achieve high densities while controlling both the microstructure and chemical compositions. Ballistic tests show promising results.

ISL researchers developed two TiB_2-based ceramic composites for ballistic protection applications, choosing the SPS process since TiB is refractory material. In addition, they used sintering aids like B_4C, Al_2O_3 and SiC (silicone carbide) to favour the densification.

Among all the compositions tested, the TiB_2 + 5 wt% SiC and TiB_2 + 1 wt% B_4C ones were found to be the most promising after first evaluation of their sintering behaviour. In comparison to the expected theoretical densities, relative densities of 96.1 and 95.2% were respectively reached for SiC and B_4C doped composites while their microstructures were found to be very homogeneous and composed of fine grains. After optimisation of sintering conditions, densities of 97.4 and 98.1 were respectively reached while maintaining high homogeneity and fine microstructure. Investigations were then performed based on a scale up from 30 mm to 60 mm diametre (at a constant thickness of 6 mm) in order to carry out the ballistic evaluation with a 24 kg/m² areal density (A.D.). It was necessary to optimise the sintering cycle and more particularly reduce the maximum sintering temperature in order to maintain a high density level and an average grain size close to the ones observed on the smaller scale.

The figure below left shows SEM images of the 30 and 60 mm diameter samples of the SiC-doped TiB_2. Even if larger size average grains can be noticed after scale up, the shape of the grains and the number of the porosities remain approximately the same.

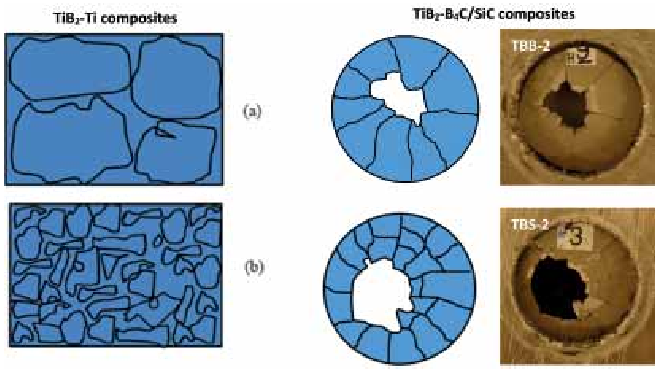


30-mm diameter (left) and 60-mm diameter (right) samples of SiC-doped TiB_2

ISL evaluated the ballistic efficiencies of the two TiB_2-based composites using the energy method and found ballistic efficiencies reaching 17.4 and 11.8 kJ.m²/kg respectively for the B_4C and SiC-doped composites. In parallel, examination of the visual aspect after impact revealed that the B_4C-based composite exhibits more cracks as well as more and smaller fragments than the SiC-based one, indicating absorption of higher energy during the impact.

These results are consistent with the ones reported by the literature and are schematically represented in the illustration below right. In parallel, X-ray images recorded during ballistic experiments revealed that in both cases projectile tips have been eroded by the ceramic tile, proving that the function of the ceramic was successful.

Although only one condition of A.D. and one evaluation method were considered, the TiB_2-based composites have already shown strong ability to erode the projectile tips. Given this aspect and the small amount of fragments created on impact, this ceramic is of interest in a multilayer or functionally graded ceramic system.



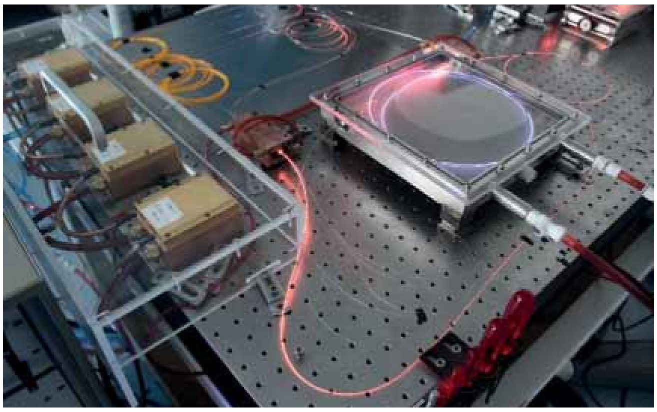
Cracks observed after impact for various samples

LASER SYSTEMS TO PROTECT MOBILE PLATFORMS

Infrared-guided missiles are one of the most significant threats for mobile platforms on battlefields. In order to counteract this type of threat, ISL is working on laser sources for directed infrared countermeasures (DIRCM) systems. These advanced active protection systems integrate a laser source and emit an infrared beam (between 2 and 5 µm wavelength) directed at the missile to defeat the on-board IR-seeker.

ISL research and development work on DIRCM laser sources at ISL covers different kinds of threats depending on IR-seeker technologies, from the most proliferating current generation of reticle-based seekers to the future generation based on multispectral imagers. The research on short-to-mid-wave infrared laser sources addresses two main goals: achievement of beyond-state-of-the-art highly versatile sources, which is of specific military importance, and providing high-level expertise for the national electronic warfare communities, including knowledge on sources and components as well as participation in field trials and measurement campaigns with current state-of-the-art ruggedised lasers.

In 2019, for the first time at ISL, a completely alignment-free all-fibred laser setup has been developed thanks to new combiners allowing direct fibre-injection of the pump light into the active fibre (see figure below left). More than 150 W of continuous wave (CW) output power has been extracted from this fibre laser at a wavelength of 2.09 µm, which constitutes a power record for a Tm-Ho co-doped monolithic fibre laser based on a single oscillator architecture. All-fibred laser setups are of particular interest for military applications, since they allow realisation of more robust and compact laser systems.



Alignment-free all-fibred laser set-up

In addition to this, significant progress was made on the already existing mid-infrared laser solid state sources. The implementation of an amplifier stage in a home-made Ho:LiLuF laser allowed further increase in the average output power at 2 µm. More importantly, it more than doubled the power level in band II, paving the way for the realisation of a real-scale DIRCM demonstrator.

ISL performed measurement campaigns in close cooperation with the German Ministry of Defence, field-testing the effectiveness of ISL high-pulse-energy mid infrared laser sources. This allowed further analysis of the behaviour of the propagating laser beam on real distances and preliminary tests on damaging optical components.

2019 was marked by the successful realisation of an up-scaled heat capacity laser emitting at 1.6 µm i.e. in the eye-safe region, as displayed in the figure at bottom right. After several years of research, an output power of 23 kW was measured for the Er^{3+}-YAG system. The optical-to-optical efficiency of the laser was determined to be 52%, which is clearly superior to former realisations of the same type of laser at lower power levels. The power and efficiency obtained rank the laser among the most powerful solid-state lasers ever built.

ISL's eye-safe heat capacity laser

3.4

COMPOSITE MATERIALS SUBMITTED TO HIGH-ENERGY LASER IRRADIATION

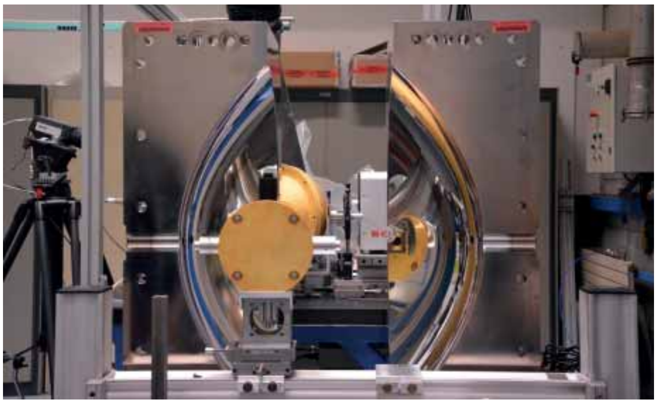
High-energy laser weapons are now a short-term challenging threat to structural materials. Due to their complex nature and their many different components, composite materials such as fibre-reinforced polymer show a wide range of reactions resulting from the fast absorption of the intense radiation. To provide relevant simulation models in line with industry and prospective needs, ISL is developing key instrumentation capabilities to assess the parameters of main materials.

The interactions between a continuous wave high-energy laser beam and composite materials concern optical, thermo-dynamical, chemical and mechanical issues. The fine understanding of all these processes is mandatory for the design of relevant simulation tools. While the tools need to be fed by the material parameters of interest, some of the key parameters are not accessible by commercial devices due to the high dynamical temperature ranges or are too specific.

Industry high-power solid-state lasers feature wavelengths of around 1000 nm whereas eye-safe legal issues for free space propagation require wavelengths above 1500 nm. Unfortunately, high-power sources operating at eye-safe wavelength are not yet available on the market. On the other hand, addressing the 1550 nm absorption and back-reflected properties is of prime importance for prospective studies. ISL has therefore developed a specific test bench allowing simultaneous measurement of diffuse transmission and reflection of two beams at 1070 nm and 1550 nm (see figure at bottom right). The objective is to compare the optical properties at both wavelengths with respect to the degradation cycle. These beams will be first used on carbon and glass-fibre reinforced epoxy samples, typical of aeronautical structures. They are also easily expandable to 2 µm wavelength.

In contrast to small calibre ammunitions, whose typical terminal effect is to perforate the target, the absorption of a laser beam first leads to heating of the irradiated area. The heating of polymer-based materials strongly affects their mechanical properties before reaching the chemical decomposition threshold. This property could be used to induce a weakness within the structure leading to the loss of operational capability. In cooperation with the German company WIWeB, ISL developed a test bench to allow measurement of the Young modulus' weakening of samples under tensile stress. This system has been successfully used to assess the loss of mechanical properties of carbon-reinforced epoxy samples up to 100 kN loads.

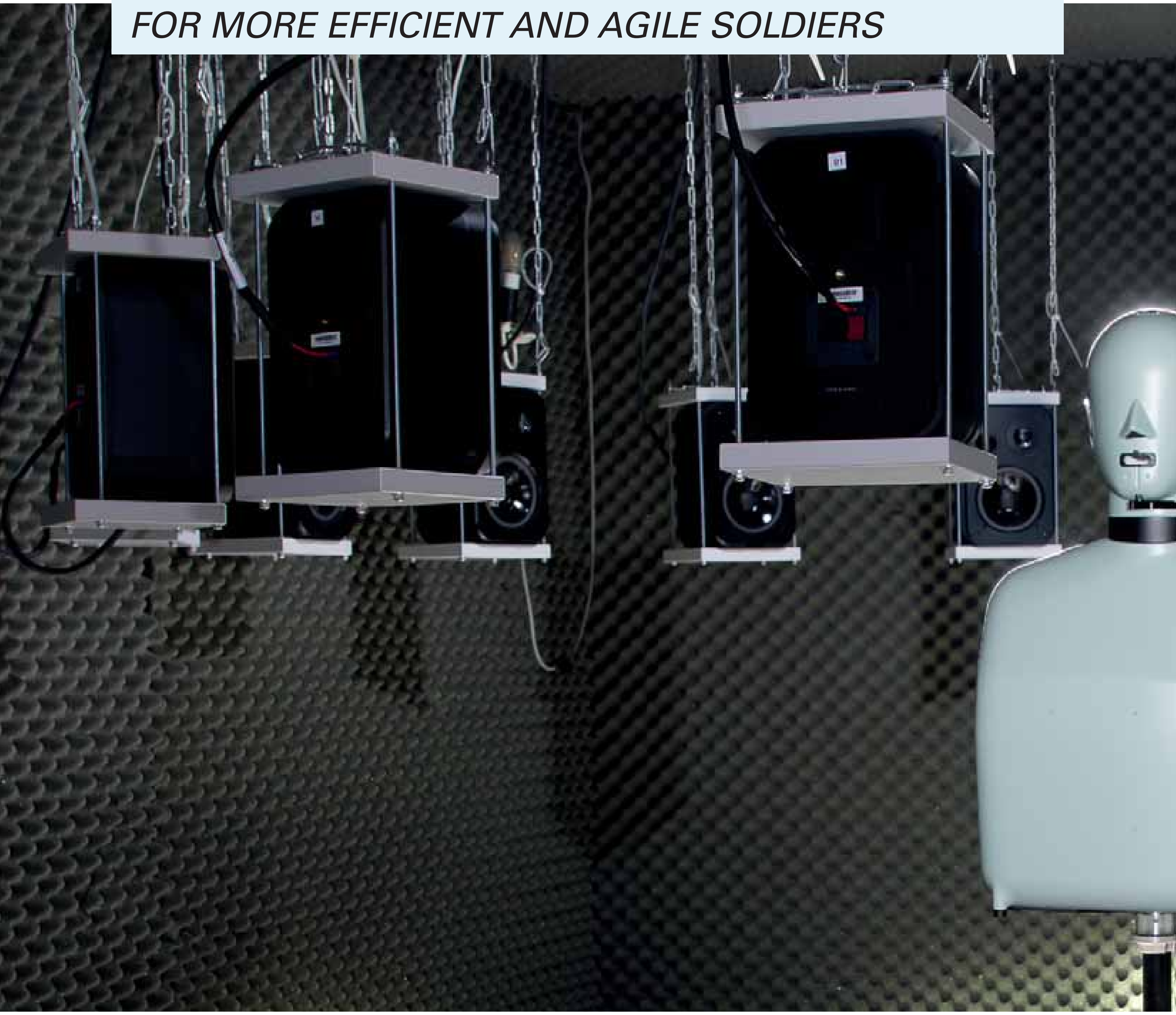
The beam propagation within semi-transparent materials leads to a volume absorption and hence to an internal heat source. This propagation can be modeled by the Radiative Transfer Equation in which the material is characterised by volumetric radiative properties (extinction coefficient, albedo and phase function) and boundary scattering properties. A numerical solver was developed to determine these properties measured by means of bidirectional reflectance and transmittance. The experimental data are obtained using a spectrophotometer equipped with a goniometric system enabling measurements in different directions. The collision-based Monte Carlo method is employed to solve the radiative transfer equation (RTE) with boundary conditions designed for semi-transparent samples with rough surfaces and to obtain the theoretical values. ISL has demonstrated that the phase function can be modeled by the Henyey and Greenstein approximation and the surface scattering properties with Gaussian and cosine distribution functions. This technique shows promising results with fibre-reinforced epoxy supplied by the French Ministry of Defence Procurement Agency (DGA, Direction Générale de l'Armement).



Test-bench to measure transmission and reflection of laser beams

4 PROTECTION AND PERFORMANCE OF DISMOUNTED SOLDIERS

ENHANCED PROTECTION AND PERCEPTION SYSTEMS FOR MORE EFFICIENT AND AGILE SOLDIERS



Testing acoustic protection

Front-line soldiers need to be more efficient and agile in order to counter new threats such as improvised explosive devices (IEDs) and snipers and in order to operate in hostile environments. In future, soldiers will be equipped with a protection system composed of three interconnected layers: personal armour to limit the risks of fatal injuries due to blast and ballistic threats, protection of perception and communication skills (vision and hearing) and augmented perceptive and cognitive capabilities to detect threats at greater distances.

In order to improve soldiers' survivability, ISL is designing **new protective solutions which also reduce the weight of personal armour.** Using threat characterisation for a better understanding of how armour interacts with ballistic impacts and blast waves and by improving knowledge about injury criteria, research teams at ISL aim to meet two objectives. Firstly, to develop more efficient materials with low specific weight and high mechanical strength. Secondly, to design optimised protection systems based on different ways of combining materials such as fabrics and crushable materials arranged in lattices. Future armour will also include integrity control, physiological monitoring and self-repair capabilities.

Soldiers also need enhanced protection of their perception and communication skills. This is why ISL is working on the development of new-generation acoustic protection systems such as auricular earplugs, which provide both passive protection and active noise reduction, increased communication capabilities and better perception of the sound environment. ISL technology also protects the eyes of the soldier against laser dazzling thanks to new non-linear transparent polymer or ceramic windows. In addition, ISL researchers are investigating techniques to deceive the enemy's perception using passive or active camouflage and to ensure the indoor and outdoor continuity of services.

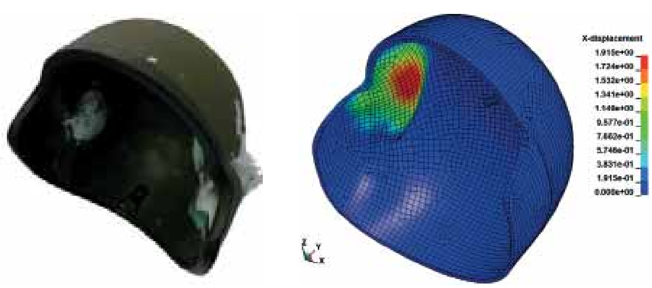
Last but not least, **augmented perceptive and cognitive capabilities** are key to success on future battlefields. ISL is designing portable equipment to improve the audio perceptive and communication skills of soldiers based on 3D-audio, augmented and virtual reality or to extend their visual range in all-weather and day/night conditions using both passive and active range-gated imaging, including the capability of detecting hidden targets. Developing advanced information sharing and processing as well as cooperation between soldiers and drones will also play a major role in better understanding the tactical situation.

4.1

RICOCHET OF A SMALL CALIBRE BULLET ON A BALLISTIC HELMET

Ricochets occur when a projectile is deflected by an object under certain conditions such as high impact velocity and a sufficiently large incidence angle. Enhancing the likelihood of ricochets can improve the ballistic protection level of combat helmets without increasing their weight. To meet this objective, ISL undertakes a full analysis of the dynamics of the impact of small calibre bullets on helmets using both numerical simulations and experimental investigations.

The ballistic impact response of a combat helmet causes head injuries to the wearer. At close to ballistic limit velocities, complete perforation of the helmet might be prevented, but the kinetic energy of the projectile is sufficient to cause severe helmet shell deformation. The back face deformation (BFD) of the helmet shell in contact with the human head causes serious trauma. Modern combat helmets are categorised according to regulations, such as the German norm VPAM and there are limit values on BFD upon impact of fragments and 9 mm hand gun projectiles. Nevertheless, soldiers and the armed forces are more likely to face a 7.62 x 39 mm threat during missions. In order to design a helmet to withstand such a direct hit it would be necessary to increase the mass of the helmet significantly which renders daily use improbable. A better protection method is to increase the likelihood of projectile ricochet by using sandwich structures for example. On the other hand, even a deflected or ricocheting projectile causes BFD in the helmet shell which may seriously harm the wearer. The figure below shows the BFD - located on the right side of the helmet - obtained by experimental testing (left) and finite-element simulation (right).



Experiment (left) and numerical simulation (right) to characterise a back face deformation

For ISL, two main aspects are of interest - the projectile trajectory and the helmet BFD. Research teams visualise the trajectory using X-ray cinematography resulting in definition of the projectile path inside the material and the remaining projectile energy upon exit. The data are used for numerical model validations.

Digital image correlation (DIC) captures the helmet shell BFD. It is an optical, non-contact measurement system. For optical access to the interior surface of the helmet additional helmet interior needs to be removed. Although the helmet constitution influences the BFD, ISL has obtained repeatable results on aramid helmet BFD with 9 mm projectile. Teams measured BFD of 7.62 x 39 mm upon ricochet off aramid combat helmets as well as in aramid plane plates of the same high density-woven composites. They also used ricochet off aramid plates at different velocities for further numerical model development.

The numerical model is set-up using a code based on the finite element method to calculate displacement and stresses explicitly. Projectile and helmet are imported from technical drawings to have as accurate results on deformations as possible. Available material models can describe isotropic and anisotropic behaviour during impact. More specifically, the well-developed human models in the programme will give a deeper insight into the material behaviour to decrease BFD and, ultimately to protect soldiers from potential injuries.

4.2

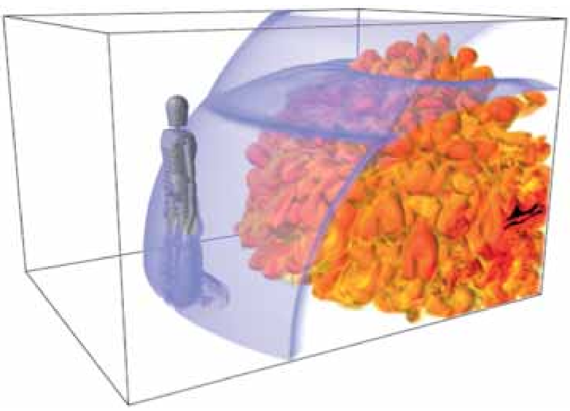
PROTECTION OF DISMOUNTED SOLDIERS AGAINST BLAST THREAT

Recent conflicts have shown an increasing use of improvised explosive devices (IEDs) in attacks against soldiers in western armed forces, resulting in specific clinical patterns of blast injuries. To reduce these casualties, detailed understanding about blast-related vulnerability of the human body is of the utmost importance. At ISL, researchers investigate connections between the physics of various phenomena regarding the threat, the injury mechanisms and future body armour.

In a first step, ISL scientists gain understanding of the mechanisms involved during all the stages of the generation of the shockwave due to the detonation of a high explosive charge, its propagation and interaction with the human body and the internal organs of the soldier. This involves performing new experimental and numerical approaches and allows detailed knowledge to be obtained concerning the pressure field for explosive weights varying from 500 g to 2 kg and distances to the centre of the charge between 2 and 10 metres.

The second, more technical step concerns the elaboration and the validation under "blast conditions" of new tools based on outdoor experimentation with instrumented manikins and numerical 3D models (see illustrations below). Free-field trials with the ISL manikin BOPMAN (blast overpressure manikin) standing 3 metres in front of the charge have allowed a relatively accurate value of the force to be obtained while the dummy is exposed to a 400-500 kPa side-on pressure. The manikin and the 3D model are used to evaluate the load of the shock wave on the surface of the body. The link between the physical mechanisms, the response of the chest and the injury risk criteria is studied with the medical units of the French and German armed forces (IRBA, BwZK). The injury risk criteria available for the blast threat, such as the Bowen curve and the Axelsson model, can only predict a percentage of lethality when the manikin does not wear personal protective equipment. In order to gain insight into thoracic protective system efficiency against the blast threat, new lung injury tolerance limits have been defined for short duration blast waves. It has been noticed that the chest wall velocity and the intra-thoracic pressure impulse are related to the risk level of lung injury.

In a third step, ISL seeks to improve thoracic protection resulting from the efficiency of the protective solution for both ballistic and blast threats taking into account operational constraints such as weight or human factors, in particular, the interaction between the shock wave, the textiles or fabrics making up the combatant's clothing and the air layer between the fabric and the skin of the soldier. ISL has developed a 3D numerical model to refine its understanding of the interaction of a shock wave with the fabrics of the soldier's outfit (in terms of reflected and transmitted wave) and the resulting effect on the condition of the combatant. Fabrics are modelled with a geometry defined at the stitch level as two perpendicular sets of parallel threads (warp and weft). ISL has validated the numerical model by performing measurements in its shock tube facility.



Investigating the human body vulnerability to blast waves using numerical simulation (left) and experiment (right)

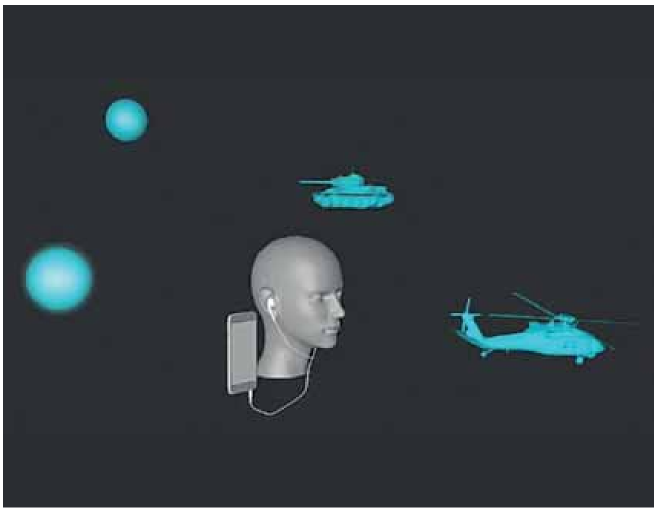
4.3 NEW GENERATION AURICULAR EARPLUGS – MORE THAN JUST ACOUSTIC PROTECTION

Acoustical waves generated by machine guns, artillery or shock waves due to explosive charges may induce temporal or permanent injuries. Despite the wearing of classical hearing protection, the number of acute acoustic trauma cases remains important in many western armed forces. The main objectives here are to increase the hearing protection performance, provide an ergonomic and "acoustically transparent" device with a greater personalisation of the equipment and of its functions and to obtain real-time efficiency control of the hearing protection.

The armed forces need to decrease the vulnerability of the individual soldier caused by physiological effects, while improving his or her operational performances (audio communication, safety, mobility, etc.). The high sound levels of continuous and impulse noise generated by military weaponry impede the operational capacities of the combatants (difficulties in communication, detection, localisation and identification of sound sources, etc.), and may be a limiting factor.

For a group of soldiers, ISL aims to enhance further the global perception and the analysis of the sound environment of the battlefield by using innovative signal processing.

Alongside increasing the protective capacity of acoustic head equipment, it is also necessary to improve the intelligibility of communications in noisy environments (de-noising, talk-through capabilities, communication using bone conduction) and to provide an enhanced auditory reconstruction of the battlefield sounds and voices (3D-audio displays for audio-communication and for the audible representation of threats, as illustrated in the figure below).



3D-audible representation of threats

In the context of future dismounted soldier systems, ISL has succeeded in inserting within one electronic protection device a large number of different functionalities. The basic ones include the following:
- High-quality passive protection using high-quality custom-moulded earplugs,
- Active noise reduction algorithm,
- Reproduction under the earplugs of the sound environment at a controlled level (pass-through system). This allows a better direct speech communication between two soldiers and a greater acoustic situational awareness by using the capability to amplify low surrounding sounds.
- Fit-check procedure to verify the correct insertion of the protection when the system is switched on,
- Recording of the speech directly within the ear canal underneath the earplug.

Based on funding provided by the French Defence Procurement Agency (DGA) and a partnership with the company Cotral Laboratory, ISL has produced 30 prototypes of an intelligent earplug named "BANG" to demonstrate these new possibilities.

In 2019, ISL achieved an important milestone. The BANG intelligent earplugs were evaluated in the laboratory and in real conditions by the technical section of the French army (STAT). The first operational users reported a real sensation of hearing protection while remaining connected to their environment as was exactly intended.

Other functionalities are also under development for future integration:
- Spatialisation of warning sounds and voices of different speakers,
- In-situ dosimetry of noise in real time that evaluates the daily auditory fatigue of the soldier,
- Full-duplex function that allows the user to listen and talk simultaneously.

4.4

INCREASING THE VISUAL PERCEPTION OF DISMOUNTED SOLDIERS WITH RETINIGHT

RETINight (range gated imaging goggle for night vision) is the first active time gated imaging system which is both portable and eye-safe. ISL has developed this demonstrator in order to increase the visual perceptive capabilities of the operators for defence and security applications in adverse conditions. This individual, portable imaging system is based on a bi-wavelength (1.064 µm/1.570 µm) pulsed laser associated with a short-wave infrared (SWIR) digital camera.

Laser gated viewing (LGV) is an advanced imaging technique using its own laser illumination. It was initially developed for long-range maritime and terrestrial applications. This technique permits day/night viewing capabilities and is particularly adapted to vision through obscurant media such as rain, fog, mist or smoke. Such systems can achieve a detection range greater than 20 km. It uses “range gating” or “time gating” techniques to eliminate the backscattering effects during the propagation of the illuminating light through diffuse environments. The elimination of these back-scattering effects leads to a range greater than twice the capability of the human eye.

In recent years, thanks to advances in laser sources and intensified cameras, ISL has developed several unique, ergonomic and easy-to-use active imaging systems for non-scientific users, such as the RETINight Goggle, displayed in the figures below. This portable device uses a discreet and eye-safe laser lighting. The nominal illumination wavelength is 1.57 µm (SWIR) in the so-called eye safety wavelength area. If legal evidence of facial recognition is needed, the system can acquire an image at the wavelength of 1.06 µm.

Using an actively Q-switched Nd-YAG laser, a part of the laser light is used to emit pulses of approximately 15 mJ at 1.064 µm and the remaining part is shifted using an optical parametric oscillator (OPO) to provide pulses of about 15 mJ at 1.570 µm. The sensor is a SWIR (short wave infrared) high dynamic range camera synchronised with the laser pulses. The system displays a real-time SWIR video of the scene and the user can take snapshots at both wavelengths for further facial recognition. In addition, the use of a dedicated and stealthy illumination source allows the detection of sniper’s pointed optics based on the so-called “cat’s eye effect” without the risk of being detected by the enemy. Finally, the synchronisation between the laser pulse emission and the gated receiver allows time-of-flight discrimination and 3D imaging.

The results obtained by ISL provide soldiers, from the Army as well as from the Special Forces, with a tactical advantage of improved vision during full night-time and with a capability to detect enemy positions through smog or when tactical obscurants are used on the battlefield. The operational range is 300 m with a weight smaller than 1.5 kg for the goggle head and an additional 4 to 5 kg for a backpack depending on the mission.

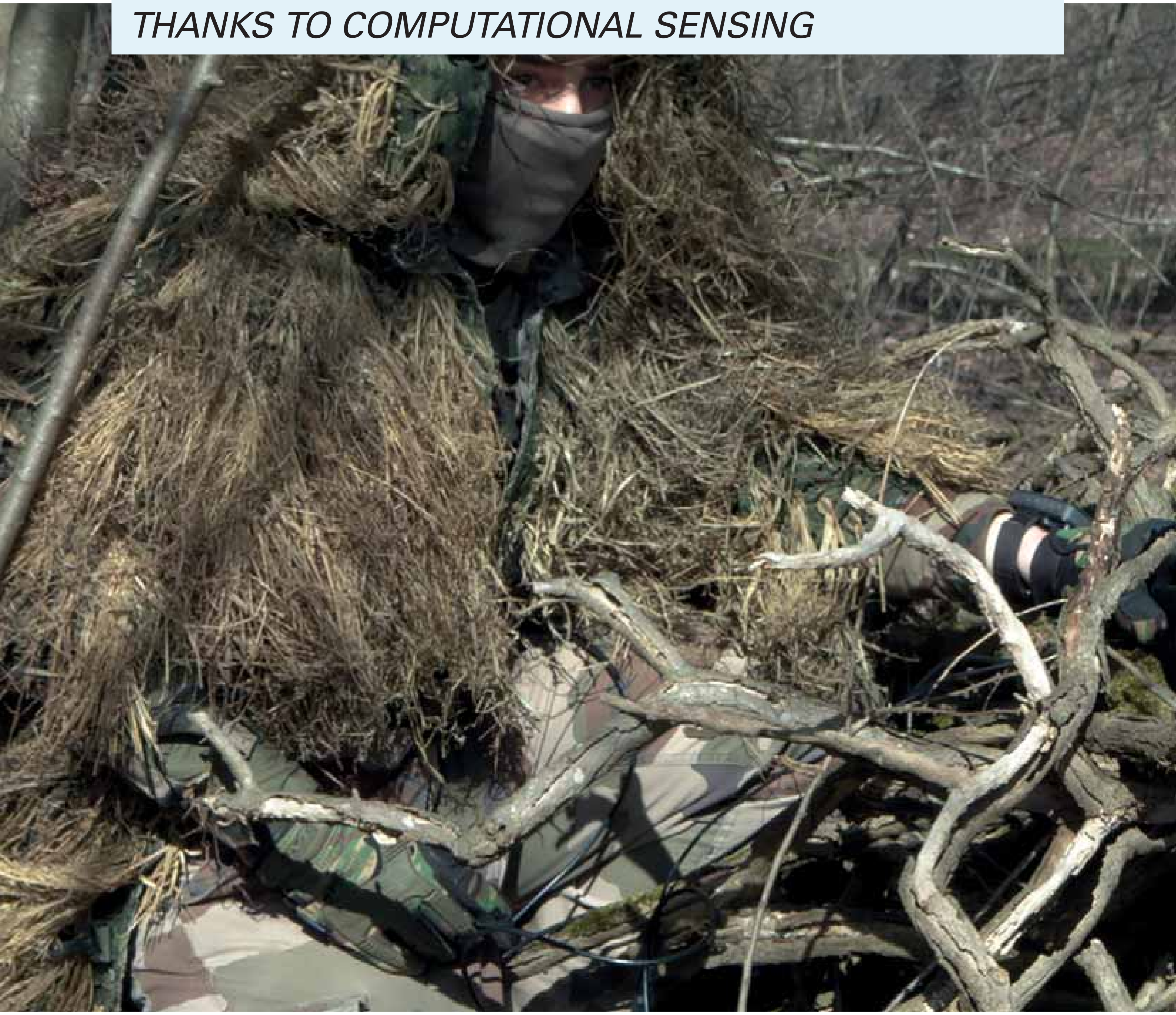
Future investigations focus on a further reduction of the size, weight and power (SWaP) of the system and on the transmission of selected images through a battlefield network.

ISL’s RETINight goggle

Using RETINight on the field

5 ADVANCED SITUATIONAL AWARENESS

NEW HORIZONS FOR SITUATIONAL AWARENESS THANKS TO COMPUTATIONAL SENSING



Camouflaged soldier on a surveillance mission

The perception of environmental elements, which is the basis of situational awareness, is on the verge of radical improvements thanks to computational sensing. In this field, ISL is currently designing very sensitive and accurate sensor systems closely combined with advanced data processing, including machine learning. This work will lead to a range of innovative applications such as 3D active imaging, non-line-of-sight imaging to detect hidden threats, automatic area surveillance or image-based navigation for autonomous vehicles.

The basic assumption of **computational sensing** is that the joint design of sensors and digital data processing can lead to systems that are superior to those created through sequential design.

The **design of innovative sensor systems** is aimed at increasing the performance of these systems in terms of sensitivity, resolution, range and/or time accuracy while keeping their size, weight and power (SWaP) parameters at a low level in order to meet military requirements. With regard to optical systems, single photon sensor systems based on single photon avalanche diodes (SPADs) are very promising. These provide a detection sensitivity (0.4 photon/pixel) at high speed (50 kHz) and a time resolution (picosecond) well beyond current systems and they pave the way to radically new applications such as non-line of sight imaging to detect hidden objects or threats.
ISL will also be improving active imaging systems with an extended detection range (tens of km) and better effectiveness through highly scattering and/or turbulent media. In addition, the focus is on the development of unattended ground sensors (UGS) based on visible/IR cameras and artificial intelligence (AI) chips to provide autonomous surveillance and intelligence capabilities. Regarding acoustic systems, ISL is currently developing a new generation of detectors based on differential antennas using MEMS microphones. The objective here is to detect, locate and identify threats such as small unmanned aerial vehicles (UAVs).

Advanced data processing is required to benefit from the sensor data in order to build a meaningful and tactically relevant picture of the observed scene or event. ISL is looking into a number of different techniques, including physics-based models, signal processing methods, AI algorithms based on deep learning or AI chips. Researchers are considering various applications such as automatic surveillance of hazardous areas, detection and localisation of UAVs, gun shots or artillery fires as well as image-based navigation for autonomous vehicles operating in GNSS-denied environment.

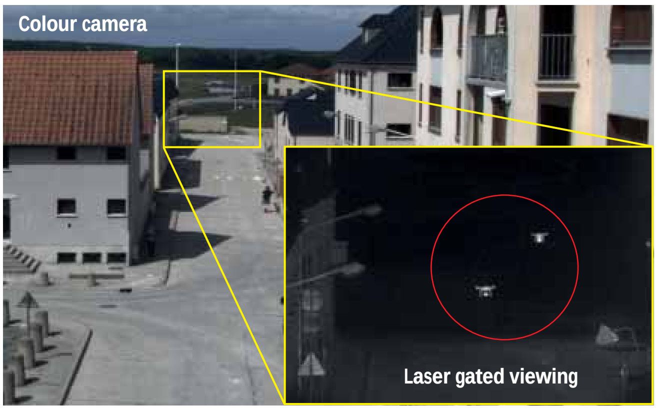
5.1

COMPUTER VISION INCREASES SITUATIONAL AWARENESS

Computer vision is facing a new revolution. In the next five years, the combination of image acquisition and computer processing will considerably increase the capacity of sensors to detect and locate threats on the battlefield. ISL is taking part in this revolution by developing hostile unmanned aerial vehicle (UAV) localisation and image-based navigation for autonomous platforms. In 2019, the value of these new technologies has been successfully demonstrated during two major events organised in France, in Sissonne and Paris.

HOSTILE UAV DETECTION IN URBAN ENVIRONMENT

The use of drones for terrorist purposes has increased over the last few years and there is an urgent need for reliable detection systems. This challenge is tackled by the NATO SET-260 working group entitled "assessment of EO/IR technologies for the detection of small UAVs in an urban environment". Within the framework of this group, ISL organised a major two-week testing campaign in June 2019 at the French army's training centre dedicated to urban warfare (CENZUB) located in Sissonne. Ten nations participated in this event. Many different sensors were used to build a large database of images displaying various types of UAVs and backgrounds. Several technologies such as colour, SWIR, infrared, Lidar, active or multispectral imaging were tested. The photo below shows how an eye-safe range-gated active imaging system can improve the detection and localisation of flying drones in an image by removing the fore- and the background of the scene with the objective of enhancing the signal to noise ratio of the drones.



Detection of UAVs using range-gated imaging

By applying new processing methods such as deep learning, ISL has obtained excellent results for UAV detection, localisation and tracking, without false alarms being caused by, for example, birds flying around the drones. After training on a selected dataset of images, the system is able to distinguish between a bird and a drone with a success rate of more than 95%.

DEMONSTRATION AT THE 14TH JULY BASTILLE DAY MILITARY PARADE

ISL is also using real-time image acquisition as a tool for autonomous navigation and has demonstrated that image-based navigation can be implemented on unmanned ground vehicles (UGVs) or unmanned aerial vehicles (UAVs) to give these platforms the capability to navigate in GNSS-denied environments. ISL's STAMINA-UGV Patrol was selected to open the military parade on Bastille Day on 14th July 2019 in Paris (see figure below and p. 4).

In front of the French President Emmanuel Macron and the German Chancellor Angela Merkel, the STAMINA-UGV Patrol successfully demonstrated its ability to perform an autonomous course, relying only on the images captured by its on-board camera. Using this method, ISL aims to increase the autonomy of different platforms allowing a group of soldiers to be followed autonomously by the vehicle on the battlefield. Such platforms can be used to transport heavy loads or as stretchers capable of autonomously taking wounded soldiers back to their base.

ISL's STAMINA-UGV Patrol at Bastille Day military parade

5.2

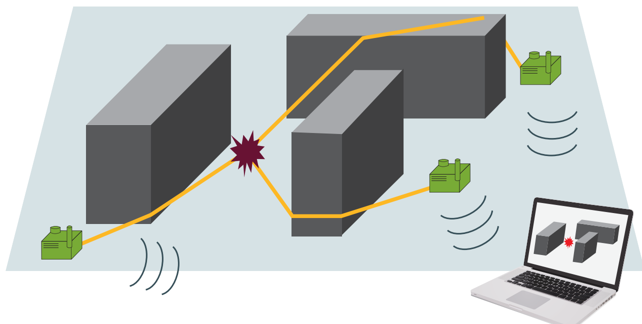
ADVANCED ACOUSTIC SENSORS ON THE BATTLEFIELD

ISL is developing advanced acoustic detection systems to improve the situational awareness capabilities of armed forces within the framework of two scenarios. Firstly, the detection and localisation of small unmanned aerial vehicles (UAVs) or small calibre gun shots at medium range using a new generation of microphones and differential antennas. Secondly, long-range surveillance and localisation of artillery weapons using acoustics models that combine physics-based models and signal processing methods.

The proliferation of unmanned aerial vehicles (UAVs) for both civil and military applications is a major concern for the protection of the armed forces as well as for security issues. In recent years, advances in digital sensors and signal processing techniques allowed the realisation of a new type of acoustic array using digital microphones for pressure and particle velocity estimation. ISL has used an MEMS-based prototype during a field experiment and compared it to standard condenser-microphone arrays. In 2019, the work focused on the development of localisation algorithms on mobile and static platforms. ISL scientists developed a smartphone and a PC application, restituting the results of multiple acoustic sensors deployed on the field. When a threat is detected, sensors send the direction of arrival and time of arrival information to the application. This is followed by enhanced detection/localisation performances using a data fusion process. This application has been tested within the framework of two field experiments to record acoustic signatures of small UAVs as shown in the figure below. The first experiment was organised at ISL's proving ground, the second at the French army's training centre dedicated to urban warfare (CENZUB) located in Sissonne. ISL's thus improved its database for further classification studies using deep learning techniques.

Acoustic detection of UAVs

Acoustic recordings of artillery shots feature the signatures of the shot's muzzle, projectile, and impact waves modulated by the environment. In this context, ISL aims to improve the sensing of such shots using a set of synchronous acoustic sensors distributed over a 1 square km area. It uses the time-matching approach which is based on finding the best match between the observed and pre-calculated times of arrivals of the various waves at each sensor. The pre-calculations introduced here account for the complex acoustic source with a 6-degrees-of-freedom ballistic trajectory model and for the propagation channel with a wave-front-tracking acoustic model including meteorological and terrain effects as shown in the figure below. The approach is demonstrated using three recordings of artillery shots measured by sensors which are more than 10 km from the point of fire and distributed at several hundred metres away from and around the target points. Using only the impact wave, it locates the impact point with an error of a few metres. Processing the muzzle and impact and projectile waves enables the estimation of the weapon's position with a 1 km error. ISL will focus future investigations on the sensitivities of the localisation method to various factors such as the number of sensors, atmospheric data, and the number of processed waves.



Localisation of an acoustic source (red) in a complex urban environment using a network of distributed sensors (green)

5.3

SENTINEL UGS FOR BATTLEFIELD SURVEILLANCE AND INTELLIGENCE

Situational awareness aims at providing information for action planning and decision-making. Missions such as surveillance and intelligence need distributed agents to understand the battlefield situation in real time. ISL has designed the Sentinel UGS (unattended ground sensor) to detect, track and recognise relevant events only directly on the sensor, and then to store, share and make the information quickly available over a small bandwidth communications network. The device can be dispatched over hazardous areas to provide local situation overviews in real time to soldiers, allowing them to stay safe.

Camouflaged soldier on a surveillance mission

The main objective of the Sentinel device is to get a better knowledge of the environment thanks to dedicated sensors, allowing armed forces to complete their surveillance and intelligence missions efficiently.

Unattended ground sensors (UGS), deployed as close as possible to the area of interest, have to fulfil operational constraints such as size, weight and power (SWaP) and low electromagnetic signature. In addition, due to the wide spectrum of operations, contexts and environments, innovative sensors need to be mission upgradable and to adapt themselves automatically to their environment. Edge computing permits the precise and instant analysis of data over longer periods of time, directly on the sensor: data does not have to travel far in a network for processing and interpretation. This UGS concept improves simultaneously soldier security, response time and discretion and it further mitigates communication bandwidth requirements.

ISL's visible (left) and infrared (right) Sentinel UGS

The figures at bottom right display the ISL-visible and infrared Sentinel systems with on-board detection, recognition and identification (DRI) functions that have been designed and tested with the armed forces.

From an operational point of view, the most promising computer vision algorithms are still using too much computational resources and too much power to achieve the aforementioned SWaP constraints. Moreover, for security reasons, cloud computing is not an option in hostile environments. ISL scientists aim to embed breakthrough artificial intelligence (AI) academic algorithms at component level.

The scientific goal and challenge of the Sentinel project is to perform close real-time DRI at sensor level. The research actions are focused on the optimal way to train embedded deep neural network (DNN) cores in order to maximise the number of recognitions per second per watt, while mitigating the false alarm rate. Today, ISL's has obtained extremely promising results with system-on-chip (SoC) and multi-processors SoC (MPSoC), registering a DRI time of ~70 ms with 300 x 300 pixel images on the Sentinel, which is well suited for any UGS application. Such an embedded SoC/MPSoC DNN enables local DRI according to a dedicated database (DB) to be used for its training. A new mission will require a specific DB to train the DNN and, after quantisation, to download the network weights to the Sentinel. The overall efficiency relies on the creation and access to mission dedicated DBs (vehicles, drones, etc.).

The Sentinel is a passive device. It is easy to use, to deploy, to hide and to recover, while it is hard to detect. It provides a remotely reconfigurable early warning system. The Sentinel detects, tracks and classifies persons and vehicles within its field of view.

The device is able to store locally geo-localised and time-referenced events. A snapshot, a short ±2s event-centred video sequence and the identified class with the corresponding confidence ratio are also stored in a database. If required, the Sentinel can send a short coded message with an AES-256 encryption to the command and control centre. From a safe place, soldiers can access the Sentinel data logger and get a local situational overview on their computer using a wired or HF gigabit ethernet link. Sentinel local information and transfer protocol have been validated with the armed forces on the proving ground by means of an IP UHF transceiver coupled to an ISL graphical user interface deployed on a rugged PC tablet.

When powered on, the Sentinel starts by analysing autonomously its surroundings, then enters the change detection mode. Any relevant event is detected and sent to the local DNN for recognition. All the events are locally stored to enlarge an existing DB and/or to reinforce the DNN efficiency. The Sentinel interoperability is currently studied within the NATO SET-256 group and will be tested in 2020.

The Sentinel UGS demonstrates that time and power consuming academic deep learning approaches can be embedded at the component level while maintaining high DRI performances. ISL targeted the SoC approach to reduce technological dependencies and to acquire a national hardware and software autonomy. Institute researchers designed their own Sentinel motherboard (see image on the right) and wrote their own drivers.

In order to increase the DRI process efficiency on computer as well as at component level, it is first of all mandatory to have access to relevant databases. It really is a challenge to get them, and most of the time these defence and security-specific labelled DBs are simply not available. Regarding infrared detection, the situation is even worse. Leveraging Sentinels on the field during armed force’s training operations will help provide relevant images to develop DBs with true visible and IR samples.

Sentinel motherboard developed by ISL

PORTRAITS OF ISL SCIENTISTS

Nicolas Expert in A.I.

Autonomous observation systems

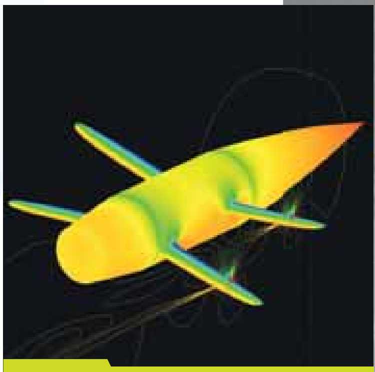
Silke Chemical engineer

Various mixtures of chemical materials

Reflexion chamber for acoustic testing

Acoustic engineer **Oussama**

COOPERATION
FRENCH-GERMAN
EUROPE
RESEARCH
INNOVATION
COMBAT
PROTECTION
VALORISATION
LANDBASED



Very long-range projectile

Expert in aerodynamics **Patrick**

PLURIDISCIPLINARY

FRONTLINE

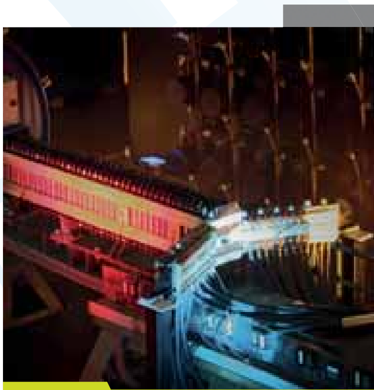
EXCELLENCE

CREATIVITY

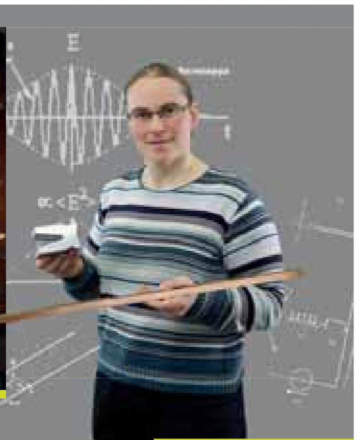
DEFENCE

SECURITY

SUCCESS



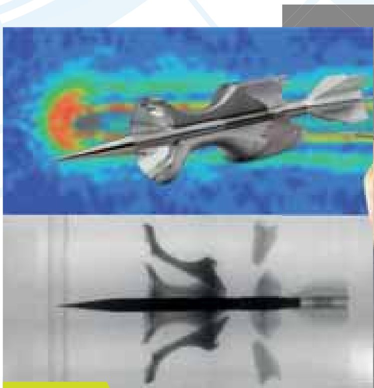
Material testing in railguns



Material expert **Corinna**

Vadim Laser expert

Laser-matter interaction



Experiment in terminal ballistics

Expert in ballistics **Teresa**

WORKSHOPS AT ISL

29-30 JANUARY 2019

1st Workshop on Antennas and Propagation for Defence and Security

Antennas and propagation are two key parameters of efficient wireless data links, which form the basis for numerous systems today, in both the area of defence and that of homeland security and civil applications. This ISL workshop focused on recent advances made in these two domains and covered the following topics:

- Antennas (miniaturisation, reconfigurable antennas, meta-materials, multi-band antennas),
- Antenna arrays (phased array, digital beam-forming, signal processing),
- Antenna measurements,
- Digital communications (channel sounding and modelling, high data rate modulation techniques, hardware design),
- GNSS systems (antennas, receivers, anti-jamming),
- Electromagnetic techniques and applications for defence and security.

15-16 OCTOBER 2019

33th CapTech* Ammunition Technologies Meeting & 3rd ETPEM Meeting

* EDA capability technology groups

15-17 OCTOBER 2019

3rd Workshop on Ageing Effects in Protective Systems, Components and Materials

A first mover in drawing attention to the ageing effects of protective systems, components and materials on soldier safety, ISL enjoys sustainable international recognition in this field.
By achieving a well-balanced interaction between the different material components used, ISL is able to improve the performance of protection systems so that they can withstand the harsh military environmental conditions which otherwise accelerate the ageing process.
Thanks to ISL's comprehensive approach combining material science and terminal ballistic effects, it is possible to define technological and methodological tools that will help nations and industry anticipate and manage the ageing effect on soldier protective systems with greater efficiency.

23-24 OCTOBER 2019

37th CapTech* Guidance, Navigation and Control (GNC) Meeting

* EDA capability technology groups

EUROPEAN DEFENCE AGENCY

20-21 NOVEMBER 2019

7th Workshop on Active Imaging 2019

Taking place every two years, this workshop brings together more than 60 scientists and experts from Europe and the rest of the world in active-imaging systems. Recent advances in component technology, coupled with increased processing capability, have led to a surge in the development and implementation of laser-based imaging systems for diverse military or civilian applications.

2-3 MARCH 2020

Workshop on Switches for Pulsed Power Applications

This workshop addressed mainly but not exclusively the following specific topics:
• Opening and closing switches,
• High-power semiconductor switches,
• High voltage gas and vacuum switches,
• Trigger and protection technologies,
• Switch cooling,
• Assemblies and systems.

ISL AT TRADE FAIRS

2-4 APRIL 2019

SOFINS – Special Forces Fair at Camp de Souge near Bordeaux

At the SOFINS trade fair, ISL focused on its work in the field of the detection, identification and neutralisation of micro-unmanned aerial vehicles (UAV). It also presented the results of its research at the main exhibition space of the French Defence Innovation Agency (AID). Topics included the ISL long distance vision tele-operated observation tool, the active imaging goggle for all weather conditions RETINight and the ARISTOTE detection system.
At the front right of the photo: General François Lecointre, Commander in chief of the French army and Vice-Admiral Laurent Isnand, Commander of the Special Forces in Camp de Souge,

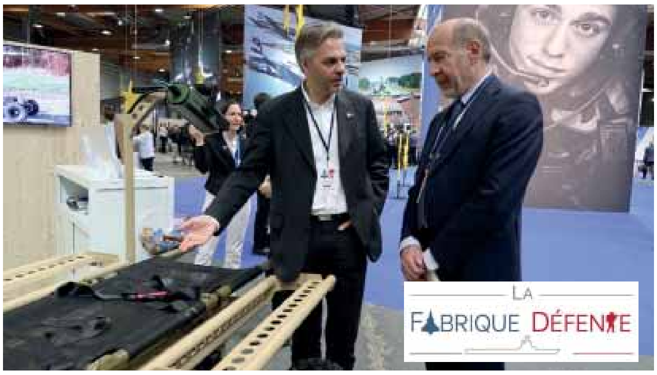
14-15 MAY 2019

Looking for qualified staff at Connecticum in Berlin

ISL actively looking out for highly qualified staff at the recruitment fair Connecticum.

17-18 JANUARY 2020

STAMINA-UGV Aurochs presented at "The Defence Factory" in Paris



"The Defence Factory" organised at the Paris Event Centre from 17 to 18 January 2020 was initiated by the French Ministry for the Armed Forces to get young people interested in defence issues. On this special occasion, ISL presented its STAMINA-UGV Aurochs system, a polyvalent, solid and powerful tactical robot. The STAMINA technology consists of a self-driving, automatically guided vehicle using computer vision on its itinerary. Running without GPS, it resists jamming. To the right of this photo: MP Jean-Jacques Bridey, member and former Chairman of the Commission for Defence and Armed Forces in France.

3-5 MARCH 2020

ISL at the German Armament conference with exhibition in Bonn

ISL participated at the biennial conference for applied defence and security research in Germany organised by the "Studiengesellschaft" of DWT, the German society for Armament Technologies. ISL's contribution included several oral and poster presentations as well as an exhibition stand. Visitors discovered the ISL AUROCHS robot equipped with the STAMINA image-based navigation system, its new generation of the audio-communication system BANG and audio 3D as well as several examples of protection materials and new forms of projectiles.

16-18 MAY 2019

Vivatech in Paris

The Vivatech trade fair is the yearly meeting point for technological innovations and start-ups at the Paris Conference Centre "Porte de Versailles". On the invitation of the newly created French Defence Agency for Innovation, ISL presented the following projects alongside the Ministry of Defence:

- STAMINA (autonomous follow-up of trajectories without external signals (GPS, GNSS),
- Long-distance vision Sentinel (standoff teleoperated optronic analysis of earth, airborne or satellite pictures by deep learning).

18-20 FEBRUARY 2020

ISL at GPEC – the General Police Equipment Exhibition & Conference, Frankfurt

From 18 to 20 February 2020, ISL presented for the first time some of its most recent innovations at the international Conference for Police Equipment (GPEC) in Frankfurt am Main, Germany.
Fully in line with the requirements of the security forces, the research projects presented focused on the following subjects:

- Acoustic surveillance of urban areas,
- VLD – an observation tool especially designed for very long distances (VLD),
- BANG, the new acoustic protection device with integrated communication, and
- Protection materials designed at ISL.

KEY EVENTS

21 MARCH 2019

ISL welcomes Vice-Admiral Carsten Stawizki, Head of the Defence Procurement Division of the German Ministry of Defence (BMVg/Abteilung A)

9 JULY 2019

ISL is visited by the Presidents of the Defence Commissions of the German Bundestag and the French National Assembly and Senate

On the initiative of Wolfgang Hellmich, member of the German Parliament and President of the German Defence Commission, a bilateral meeting was held with Jean-Jacques Bridey, the then French President of the Commission for National Defence and Armed Forces of the French National Assembly and Christian Cambon, President of the Commission for Foreign Affairs, Defence and Armed Forces of the French Senate. This unique opportunity allowed ISL to present its wide range of scientific domains.

27 JUNE 2019

ISL and HSU cement a strategic partnership in defence research

During the celebration event marking ISL's 60th Anniversary, Prof. Dr. Beckmann (President of the Helmut Schmidt University / University of the Bundeswehr in Hamburg), Christian de Villemagne (French Director, ISL) and Dr.-Ing. Thomas Czirwitzky (German Director, ISL) signed a strategic partnership agreement. This agreement aims to intensify collaboration between ISL and the university by mutualising existing resources and equipment in a complementary way. In addition, ISL researchers will lecture at the university as well as support and supervise shared PhD students.

4 NOVEMBER 2019

Celebration of the 100th testing of canons produced by John Cockerill Defence (JCD) in Distroff

On Monday, 4 November 2019, a special event was organised at the ISL shooting ground to celebrate the successful shooting tests of the 100th canon produced by JCD. Since the beginning of 2019, JCD has conducted several testing campaigns at the ISL shooting ground. The JCD Directorate invited the ISL staff who had participated in the campaign and the ISL Directors to assist in the 100th shooting test in order to celebrate this highly appreciated partnership. Accompagnied by ISL, the guests, JCD Management, Patrick Ribayrol, President and General Director of JCD SAS and Thierry Renaudin, President of JCD SA, were able to discover other parts of the proving ground.

ACADEMIC EXCELLENCE

THESES DEFENDED IN 2019-2020

Studying and modelling the effects of a laser irradiation on composite materials
Vadim ALLHEILY
Supervisors/Directors: Lionel MERLAT (ISL), Gildas L'HOSTIS (UHA), Bernard DURAND (LPMT)
Defended on 30 September 2019

Furtivité acoustique: analyse et réduction du bruit de friction de la tenue du combattant
Floriane LECLINCHE
Supervisors: Véronique ZIMPFER (ISL), Dominique ADOLPHE, Emilie DREAN (LPMT)
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Free-flight projectile behaviour: LPV modelling and global sensitivity analysis
Dawid MACHALA
Supervisors/Directors: Marie ALBISSER, Simona DOBRE (ISL), Floriane COLLIN, Marion GILSON (Université de Lorraine), Christophe GRIGNON (DGA)
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High Power 2 µm fiber laser for mid-infrared super-continuum generation in fluoride fibers
Giuseppe SCURRIA
Supervisors/Directors: Stefano BIGOTTA, Anne DHOLLANDE (ISL), Inka MANEK-HONNINGER (CELIA - Université de Bordeaux)
Defended on 6 December 2019

Elaboration of ND based core-shell energetic composites and reactive properties of the composites in relation with their morphology
Mazheva GUILLEVIC
Supervisors/Directors: Vincent PICHOT (ISL), Université de Strasbourg, NS3E UMR 3208 ISL-CNRS-UNISTRA
Defended on 16 December 2019

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Louise SARRABEZOLLES
Supervisors/Directors: Pierre RAYMOND (ISL), Antoine MANZANERA (ENSTA)
Co-supervisor: Nicolas HUEBER (ISL)
Defended on 8 January 2020

Application de techniques d'apprentissage profond pour le véhicule à conduite déléguée
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Supervisors: Nicolas HUEBER (ISL), Mohamed-Cherif RAHAL (VEDECOM), Frédéric DUFAUX (L2S-CNRS-CentraleSupelec), Centrale Supelec-University Paris-Sud-University Paris-Saclay
Defended on 3 February 2020

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James COOPER
Supervisors: Lionel BORNE (ISL), Gérard COQUEREL (Université de Rouen-Normandie, Laboratoire Sciences et Méthodes Séparatives), Université de Rouen-Normandie
Defended on 5 March 2020

Étude et réalisation d'antennes compactes en cavités multi-bandes
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29 January 2020

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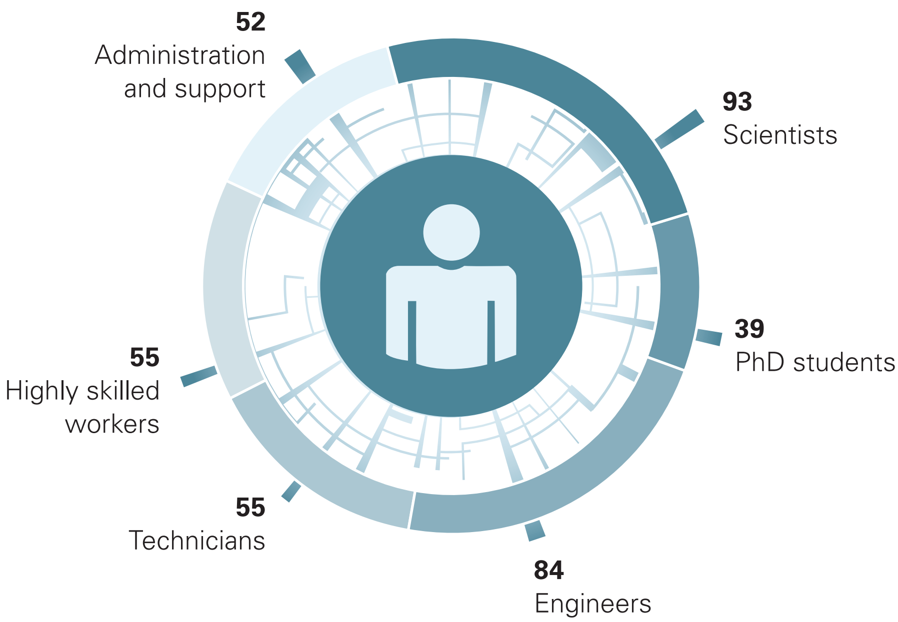

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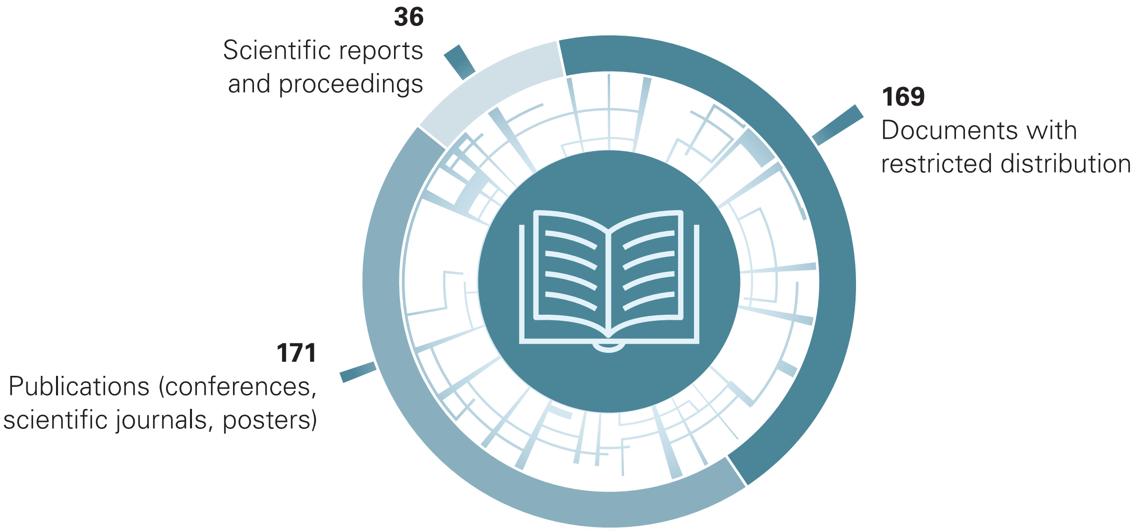

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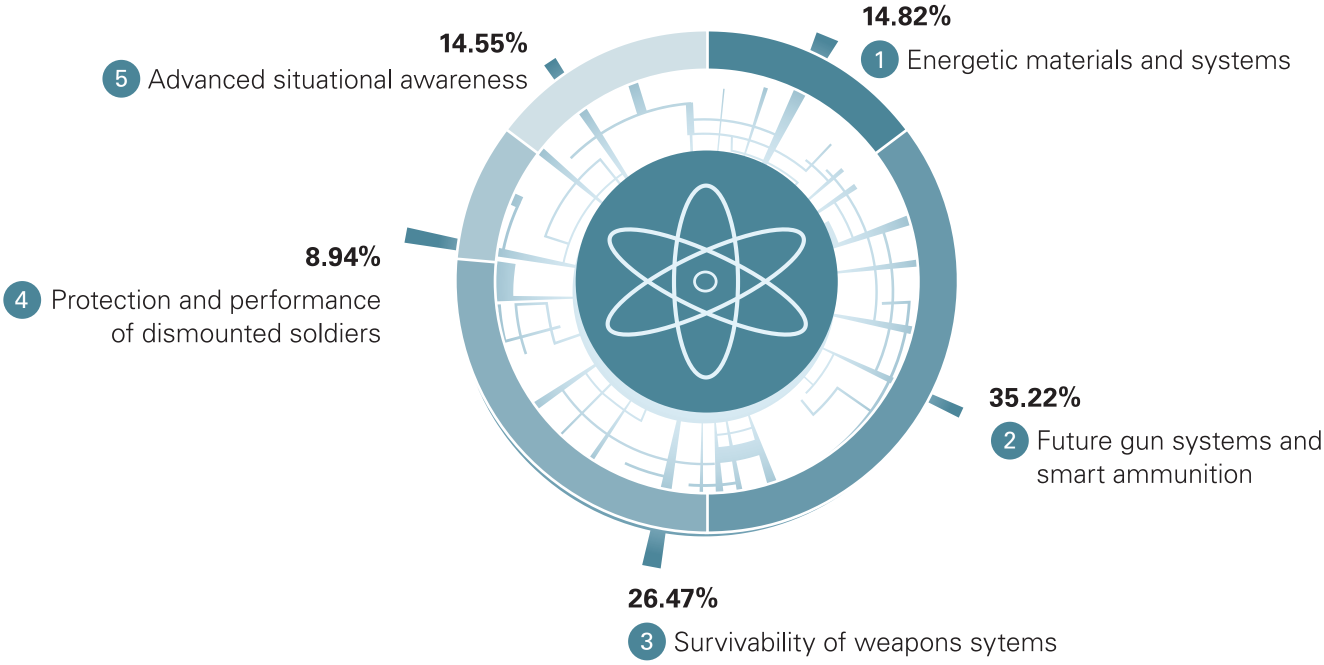

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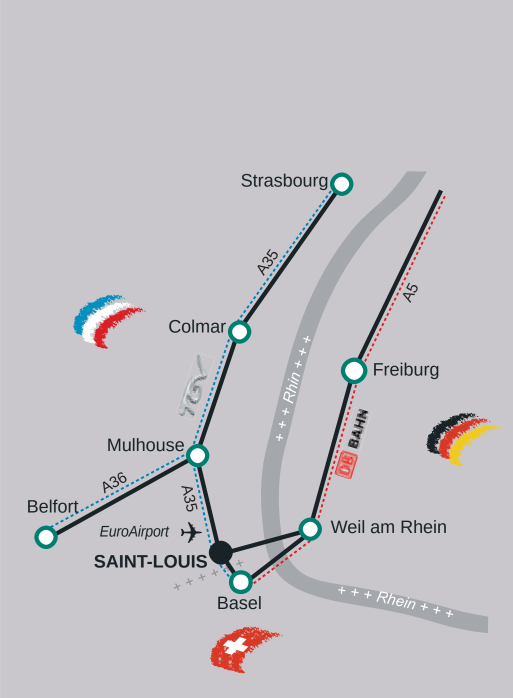
Content support and coordination
Communication - ISL
Phone: +33 (0) 3 89 69 53 18
Fax: +33 (0) 3 89 69 58 58
E-mail: communication@isl.eu



French-German Research Institute of Saint-Louis (ISL)
5 rue du Général Cassagnou • BP 70034 • 68301 SAINT LOUIS Cedex • France
German postal address: Postfach 1260 • 79547 WEIL AM RHEIN • Deutschland
Phone: +33 (0)3 89 69 53 18 • Fax: +33 (0)3 89 69 58 58
E-mail: communication@isl.eu

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