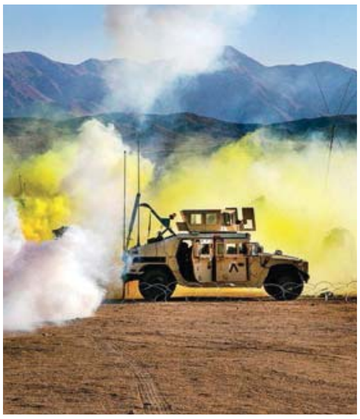
Science and Technology Organization



2018 HIGHLIGHTS

Empowering the Alliance's Technological Edge

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Foreword

organization

FOREWORD

THE NATO SCIENCE AND TECHNOLOGY ORGANIZATION
"EMPOWERING THE ALLIANCE'S TECHNOLOGICAL EDGE"

Instabilities in regions close to NATO territory did not disappear in 2018 and are likely to remain significant for many years to come. All indications are that the Alliance will experience increasing pressure as it executes its role in helping to maintain the world's strategic balance. Global trends such as demographic and economic shifts, increasingly rapid technological advances and proliferation, pressure on scarce resources, and the changing nature of conflict portend a complex geopolitical and operational environment for future NATO actions.

Maintaining the edge in Defence and Security will therefore be of critical importance for the Alliance and its Partner Nations to safeguard our freedom and shared values. Discovering, developing, and utilising advanced knowledge and cutting-edge Science and Technology (S&T) is fundamental to maintaining the technological edge that has enabled our Alliance forces to succeed across the full spectrum of operations over the past decades. The NATO Science & Technology Organization (STO) and its predecessor organisations have been instrumental in enabling that success, both within the Nations and for NATO itself.

In 2018, the STO continued to deliver a healthy and robust Programme of Work (PoW) to the Alliance and its Partner Nations by creating a shared understanding of state-of-the-art technologies, accelerating capability development, providing timely and targeted advice, and building capacity through partnerships. Allied Nations have expressed their intent to spend more, and to do so wisely. The STO Collaborative Programme of Work (CPoW) grew to more than 250 activities, while the network of scientists, engineers and analysts active in the STO increased to roughly 5,000. The STO network draws upon the expertise of more than 200,000 colleagues in Allied and Partner Nations. The activities are supported and enabled by the STO Collaboration Support Office (CSO), which provides knowledge management tools, personnel, and fiscal resources to manage planning processes, facilitate execution, and document products/results.

The STO Centre for Maritime Research and Experimentation (CMRE) advanced capability development and interoperability in areas such as autonomous maritime unmanned systems and underwater communications in 2018, enhancing our understanding of advanced technologies and systems by innovative research and experimentation at sea. For example, sailing under the Italian Navy flag and operated by an Italian Navy crew, the NATO Research Vessel (NRV) Alliance was used by CMRE to support key technological objectives in major operational exercises in the North Atlantic focused on ASW.

In support of the goal to accelerate capability development, the NATO Naval Armaments Group (NNAG) and the Science and Technology Board (STB) co-sponsored a workshop of National and NATO experts focusing on NATO Defence Planning Process medium term targets in Anti-Submarine Warfare (ASW) and Naval Mine Warfare (NMW). The subject matter experts (SME) and planners identified challenges and opportunities in ASW and NMW programmes, developed plans for advanced technology insertion in national programmes, initiated concepts for future coalition ASW operations employing new technologies, and shared information on upcoming exercises for operational experimentation. This set a framework for the S&T, Armaments and Military communities to expand to other priority targets for accelerating capability development.

The STB actively enhanced its STO governance and NATO S&T unified governance efforts, building greater coherence across the S&T community. Examples include North Atlantic Council approval of a new, more actionable NATO S&T Strategy, responding to significant changes in the strategic and technological landscape; and executing two important CPoW themes to focus efforts on rapidly emerging and important operational challenges exploiting technologies in the areas of autonomy and artificial intelligence/big data.

Providing a critical venue for knowledge development and delivery, the STO remains committed to its foundational principle: bringing together subject matter experts from across the scientific spectrum with military end-users in order to inform decision-makers on emerging challenges and opportunities, in order to sustain the technological advantage of the Alliance and its Partners.

I look forward to continue serving the Allies, NATO and STO, and consider it a privilege to work together with the fine professionals from across the Alliance and its Partner Nations.

NATO Chief Scientist (CS)
STB Chairman

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NATO Science and Technology Board Perspective

SCIENCE AND TECHNOLOGY – A FORCE MULTIPLIER FOR THE ALLIANCE, ITS MEMBERS AND PARTNERS

As a political-military Alliance, NATO's structures and processes are designed to support, inform and facilitate strategic-level planning and decision-making. In pursuing its core tasks, the Alliance benefits significantly from a range of products delivered and services rendered by Science & Technology (S&T); these include:

- maintaining the technological and knowledge advantage;
- providing the evidence-base to underpin informed decision-making;
- mitigating evolving threats and risks, including supporting public diplomacy.

NATO's topical interest in S&T broadly covers basic and applied research across the physical, information, medical, and social sciences. To facilitate the generation and exchange of knowledge and technology, and to promote the exploitation of S&T results, NATO provides trusted platforms and frameworks open to scientists, engineers, operators and policy-makers. Through these networks, participants capitalise on the diversity of approaches and perspectives to leverage and augment their own resources and investments. The nature of NATO S&T activities ranges from ad-hoc knowledge exchange to jointly planned and executed projects and programmes. The majority of these S&T efforts are funded directly by Allied and Partner Nations.

NATO S&T thrives on the voluntary collaboration between a broad range of stakeholders from many different military, organisational and scientific backgrounds, each participating according to their organisational capabilities, interests and needs. In addition to Allied and Partner Nations, many NATO committees, commands, and staffs have stake in NATO S&T as they:

- benefit from S&T as customers, exploiting S&T results without being actively involved in S&T generation;
- execute dedicated S&T programmes of various scales, topical portfolios, or funding mechanisms;
- influence requirement setting or investment decisions to inform and orient future S&T activities.

These breadth and diversity of stakeholders' interests and portfolios makes the close co-ordination, co-operation and collaboration between all stakeholders indispensable – for their individual mission success and for the overall success of the Alliance.

Avoiding unnecessary duplication, identifying complementarities, and exploiting synergies have become **the hallmarks of NATO S&T**. Taken together, they promote the alignment of S&T activities with S&T requirements so that scarce resources are efficiently allocated to effectively meet the needs of the Alliance, its Members and Partner Nations.

THE NATO SCIENCE AND TECHNOLOGY ORGANIZATION

The NATO Science & Technology Organization (STO) welcomes participants and contributors from Allied and Partner Nations, who come from government, industry or academia. Within this trusted network of experts, the STO plans, executes and delivers a Programme of Work (PoW) that covers the full spectrum of defence- and security-related S&T. This programme strives to accelerate capability development, to deliver timely, targeted advice to decision-makers, and to build capacity through partnerships, thereby supporting the core tasks of the Alliance. In pursuing its mission, the STO positions S&T so that it provides a strategic advantage for Nations and NATO.

THE NATO SCIENCE AND TECHNOLOGY BOARD

The STO is governed by the NATO Science & Technology Board (STB), which comprises the senior national defence S&T leaders and representatives of all relevant NATO S&T stakeholders. The STB reports to the North Atlantic Council and is in charge of NATO-wide S&T governance, without prejudice to the responsibilities and authority of individual stakeholders.

The STB plays a critical role in developing and maintaining strategic direction and guidance for S&T across NATO, serving as the focal point for co-ordinating all S&T programmes and activities within NATO. Internal to the STO, the STB guides and directs the future PoW and oversees its delivery.

DELIVERING THE PROGRAMME OF WORK...

The STO delivers the largest S&T PoW within NATO S&T. It is designed to enhance multinational collaboration by making available the knowledge, skills and investments of all contributors. Participating Nations fund the STO in line with their objectives. NATO provides additional funds, though to a lesser extent, in support of over-arching Alliance objectives.

...THROUGH A COLLABORATIVE NETWORK...

With more than 5,000 active subject matter experts, the STO attracts the world's largest network of defence and security researchers, scientists and engineers. In doing so, it addresses all military-relevant aspects of S&T through seven domains: Applied Vehicle Technology (AVT); Human Factors and Medicine (HFM); Information Systems Technology (IST); NATO Modelling and Simulation Group (NMSG); Systems Analysis and Studies (SAS); Systems Concepts and Integration (SCI); and Sensors and Electronics Technology (SET):

The NATO Chief Scientist

The NATO Chief Scientist chairs the STB and serves as the scientific advisor to senior NATO leadership.

He is supported by the Office of the Chief Scientist at NATO Headquarters in Brussels, Belgium.

In each domain, several hundred national subject matter experts are actively engaged in the execution of commonly agreed S&T activities such as joint research projects, conferences, workshops, lectures, or technology demonstrations. Every year, the STO runs well over 250 such activities.

NATO provides executive support to this network and its PoW through the Collaboration Support Office (CSO), located in Neuilly-sur-Seine, France.

...AND A DEDICATED RESEARCH LABORATORY

The Centre for Maritime Research and Experimentation (CMRE) is a customer-funded laboratory focused on the underwater domain. Nations reduce the cost and risk of innovative work by collaborating through the Centre and employing its unique facilities.

Using its own capabilities, infrastructure and personnel, the Centre carries out projects and experiments to deliver military relevant and validated S&T results that advance both a basic understanding of the maritime environment and naval capabilities.

Key enablers for delivering the CMRE's programme are its research vessels: the NRV *Alliance* and CRV *Leonardo*. With year-round global access to the ocean and state-of-the-art scientific facilities, satellite communications and reconfigurable deck equipment, experimentation can range from concept development through to prototype demonstration in NATO and multinational maritime exercises.

The Centre operates out of La Spezia, Italy.

2018 MAJOR ACHIEVEMENTS

In 2018, the STB revised the NATO S&T Strategy in order to ensure that the NATO S&T community marshals its forces to sustain the technological advantage of the Alliance.

This new strategy takes into account key strategic trends that influence the Alliance and the global S&T landscape. It further sets out the goals, lines of effort, and investment areas for Nations and NATO to pursue so that the NATO S&T community contributes more effectively and efficiently to the Alliance's capability to fulfil its core tasks: collective defence, crisis management, and cooperative security.

The North Atlantic Council approved this strategy in July 2018.

SUSTAINING THE ALLIANCE'S TECHNOLOGICAL ADVANTAGE – KEY STRATEGIC TRENDS –

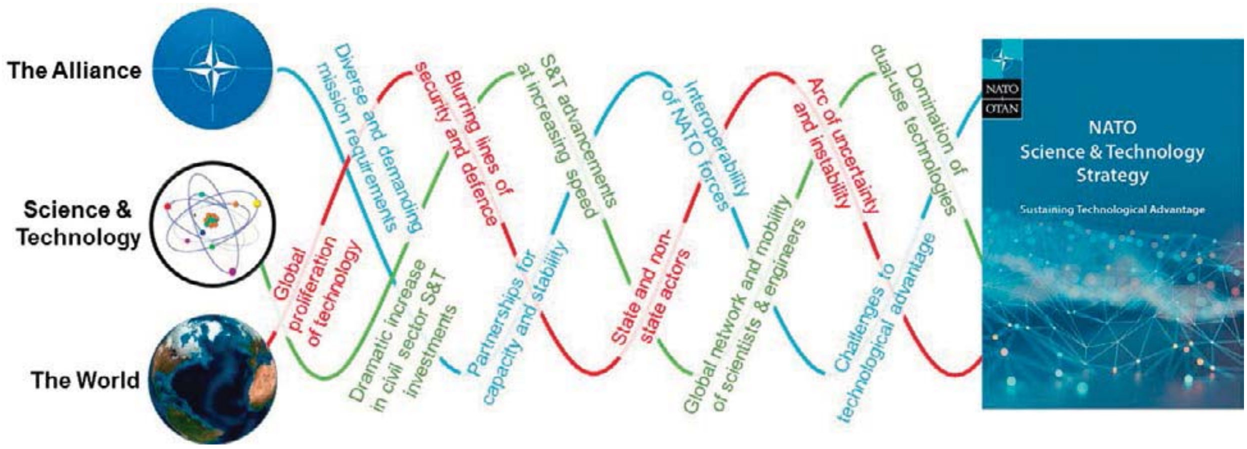


Figure 1: NATO S&T comprehensive approach to "Key strategic trends". This matches the Highlights and Strategy insides.

Throughout 2018, the STO continued to deliver a Programme of Work aligned with the needs, priorities, and interests of the Alliance and its Partner Nations. This brochure gives testament to the high scientific quality and military relevance of the STO's activities. The following short overview is structured along the new NATO S&T Strategy's goals of accelerating capability development; delivering timely, targeted advice; and building capacity through partnership.

ACCELERATING CAPABILITY DEVELOPMENT

Time-to-market is a critical factor not only for business success; it is equally vital for maintaining the technological advantage of Alliance military forces. The STO undertook a range of activities to shorten the time *"from the lab to the field"*:

- demonstrating **anti-submarine warfare decision support tools** during the NATO-led Anti-Submarine Warfare interoperability exercise Dynamic Mongoose 2018, in a fully operational environment onboard the flagship of NATO's Standing Maritime Group 2 (CMRE);
- validating several nations' simulation tools for **electronic countermeasures against anti-ship missiles** against a common scenario in order to improve effectiveness assessments for Alliance countermeasure developments (SCI-224);
- **benchmarking multidisciplinary optimisation and design problems** to create a shared repository for use in validation and verification, thereby reducing technology risk and development time and cost of future military vehicles (AVT-237);
- holding the first JANUS Interoperability Fest to exercise industry's implementations of JANUS, NATO's standard for **digital underwater communications** developed by CMRE; this event helped enhance the interoperability of commercially available products (CMRE);
- evaluating the threat and impact of **laser eye dazzlers** in order to advance the understanding of laser dazzle effects on aircrafts; the results from this field trial will underpin the development of laser warners, laser dazzle protection and hardened devices (SET-249).

DELIVERING TIMELY, TARGETED ADVICE

Knowledge and insights generated in the long-term quest for advanced capabilities are relevant in the near-term to inform decision-makers of the political, military, and procurement realms. The STO remains committed to delivering evidence-based advice through different avenues:

- assessing the state-of-the art in and potential impact of **Big Data and Artificial Intelligence for military decision-making**; thereby raising military operators' awareness of potential benefits, as well as risks, while at the same time charting a roadmap for the most promising future defence research activities (IST-160);
- developing a **threshold concept for small forces** to identify appropriate strategies and military concepts that allow smaller forces to design force structures for effective deterrence within the limits of affordability (SAS-131);
- reviewing the empirical evidence for potential linkages between **moral challenges of decision-making** and the psychological well-being of deployed military personnel, and deriving recommendations for military leaders to ensure appropriate psychological support and care (HFM-284);
- investigating the impact of portable sensors, displays, weapons, and personal protective equipment on the **cognitive burden of dismounted soldiers,** and exploring potential trade-offs between disparate technologies in procurement and investment decisions in order to increase overall combat effectiveness (SAS-107).

BUILDING CAPACITY THROUGH PARTNERSHIPS

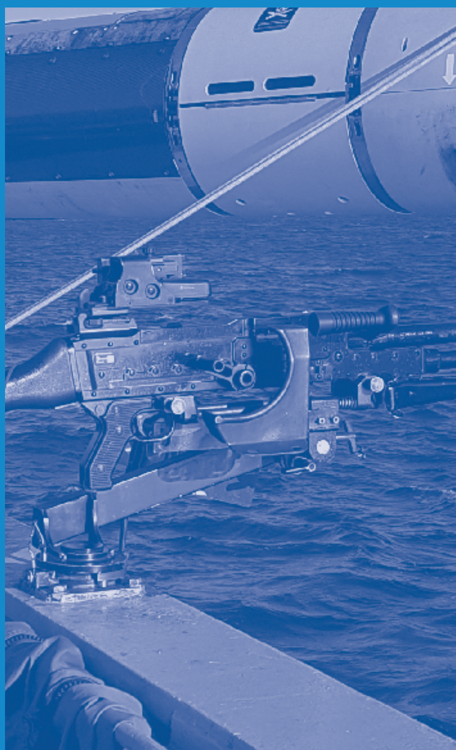
Partnerships are vital to the Alliance, and they are essential for scientific progress as well. Therefore, the STO continues to open its activities to experts from non-NATO Nations – approximately 70% of the current activities are open to Partnership for Peace (PfP) Nations, and approximately 30% are open to Mediterranean Dialogue (MD) Nations. Furthermore, the STO adopted the approach to engage the Enhance Opportunity Partner (EOP) Nations Australia, Finland and Sweden by default under the paradigm "*included in the STO unless stated otherwise*". Examples include:

- exploring **resiliency concepts to enhance preservation of NATO space capabilities** and promoting shared awareness of NATO's technical, operational, institutional and policy options to enhance the resilience of space-based capabilities (SCI-308);
- joining the expertise from across the human factors and Modelling & Simulation disciplines to identify key characteristics for realistic **human behaviour modelling** (HBM), and to define an HBM reference architecture that facilitates model reuse and information exchange, in order to ultimately save time and resources in developing particular military training applications (MSG-127).

This short overview highlights only a small selection of the many parallel activities that the STO pursued in 2018. The following sections of this brochure provide in-depth information on the STO's activities and achievements throughout the year.

As many of the STO's activities promote more than one strategic objective, the following sections are presented under the headings **Experiment**, **Cooperate** and **Develop**, in order to emphasise the core tenets of science and technology in NATO.

STO Executive Body Perspectives



S&L organization

THE OFFICE OF THE CHIEF SCIENTIST (OCS)

The OCS is the anchor of the STO at NATO Headquarters (HQ). With its small staff, the OCS supports the Chief Scientist (CS) in his two essential functions: as the Chair of the STB, and as the senior scientific advisor to NATO leadership.

Figure 2: Dr. Thomas Killion, NATO Chief Scientist, STB Chairman.

Beyond providing the executive support to the STB and its decision-making, the OCS acts as a bridge between the STO PoW and its end-users represented at NATO HQ. To that end, the OCS works with the S&T results generated through the PoW and promotes their exploitation in the political and military context. Engaging the committees and staffs at NATO HQ, the OCS selectively highlights the most relevant and recent S&T results that are available to inform NATO and national decision-making.

As scientific advisor to NATO leadership, Dr. Killion played a key role in a North Atlantic Council (NAC) Away Day and Military Committee (MC) Away Day, both of which were focused on the challenges and opportunities of the rapidly emerging applications of artificial intelligence (AI). In addition, he led a MC S&T Focus Session devoted to a discussion of on-going efforts in autonomy and in big data/AI support to military decision-making.

The Chief Scientist has focused the OCS to enhance the impact of S&T for the Nations and NATO. A highlight of 2018 includes the approval of the new, more actionable NATO S&T Strategy, which responds to significant changes in the strategic and technological landscape. The OCS worked with the International Military Staff to gain consent from the MC. Working alongside the Defence Investment (DI) staff, it was able to do the same with the Council of National Armaments Directors, on the path to approval by the NAC.

Another key accomplishment was the signing of a Structured Partnership between the STO and Allied Command Transformation. The OCS and ACT staff developed both the Partnership and the accompanying annual action plan, aimed at strengthening the relationships between the organisations, identifying joint objectives and supporting ACT's enhanced warfighting development responsibilities under NATO Command Structure Adaptation.

During the pre-concept stage for Alliance Future Surveillance and Control (AFSC), the OCS led the AFSC Solutions Working Group, drawing on the STO's wide network of subject matter experts. In 2018, the OCS worked with NATO Support and Procurement Agency (NSPA) to execute key small-scale studies. It used national experts to address critical issues in information assurance and in spectrum requirements and management. During the AFSC concept stage, the STO will remain engaged to provide independent S&T advice.

The importance and challenge of maintaining a technological edge for the Alliance is increasingly recognised. In turn, there is a growing demand for the evidence-based advice and scientific insights, which the OCS brings to NATO HQ. The CS and his staff are dedicated to meeting that demand.

THE COLLABORATION SUPPORT OFFICE (CSO)
NATO STO 2019 CPoW

Figure 3: Dr. Pavel Zůna, Director, NATO Collaboration Support Office (CSO).

Each year, we are pleased to present you with the NATO Science & Technology Organization (STO) Highlights of the Collaborative Program of Work (CPoW) for the previous year. The 2018 CPoW ran on a collaborative business model, which was described as a "*FORUM where Nations and Partners ELECT to use their national resources to define, conduct and promote COOPERATIVE RESEARCH and INFORMATION EXCHANGE*".

This collaborative framework is supported by the Collaboration Support Office: one of the executive bodies of the STO, located in Neuilly-sur Seine, near Paris, France.

In 2019, we will celebrate the 70th anniversary of the signing of the North Atlantic Treaty. The reasons behind the establishement of this treaty remain the same. As stated by our political leaders at all levels, the current security situation is complex and calls for the preparation to unexpected alternatives. Therefore, NATO stresses the need for future novel capabilities and for regaining or maintaining a technological edge over our potential adversaries. NATO requires capabilities in mid-term and long-term timeframes. The development of those capabilities with NATO's common funding and national funding is usually performed under the capability development programs. These are structured, budgeted and planned. Capability owners and planners need to be informed about the current state-of-the-art in different, multi-technological domains.

This is the reason why we recently introduced the "thematic approach" to address technological requirements in the most pressing NATO operational areas: Artificial Intelligence and Big Data supporting military decision-making, Autonomy in military operations, and Operations in a contested urban environment. The aim of the "themes" are to launch S&T activities in new areas and to maintain momentum when looking for high-tech innovative solutions.

Figure 4: CSO staff.

CPoW activities support capability development at an organisational and national level. It does so in a way which was described by SACT French Air Force General André Lanata (*interpreted*): "*We may not alway know what the final product will look like, but if we recognise the potential of an idea or a concept to fill gaps or improve our capabilities – we should support it. This is a more bottom-up approach and requires a broader community to participate in the innovation process. Cooperation with broad communities of experts, S&T institutions, an industry, will bring ACT considerably closer to potential solutions that may satisfy NATO's capability requirements. New original ideas will be plugged into the capability programs and projects.*"

CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION

The mission of CMRE is to organise and conduct scientific research and technology development to deliver innovative and field-tested S&T solutions that address the defence and security needs of the Alliance. The requirements of the final customers play crucial roles in steering laboratory activities, and the STO is taking concrete steps to strengthen the collaboration between NATO/ Nations S&T, armaments, and the Allied Command Transformation.

With access to the blue water ocean through the NATO Research Vessel (NRV) *Alliance*, and deployable/expeditionary unmanned systems capabilities, CMRE has the ability to provide a collaboration hub at sea for Operational Experimentation (OPEX).

Figure 5: The LARS system was used to deploy ASW AUVS from the CRV Leonardo for the first time during REP18 Med.

At the 2018 Brussels Summit, Allied leaders agreed to reinforce the Alliance's maritime posture reaffirmed the strategic importance of the maritime domain and recognised the need to reinvigorate core maritime warfighting competencies and address maritime capability shortfalls. It is noteworthy that, as the Centre prepares to celebrate its 60th Anniversary in 2019, the original operational requirements and expectations of the Centre have re-emerged. Of note, the return of Russia as a naval power is partly responsible of this shift. Its investment and employment in submarine capability creates anti-access/area denial that threatens freedom of movement and sea lines of communication in the North Atlantic.

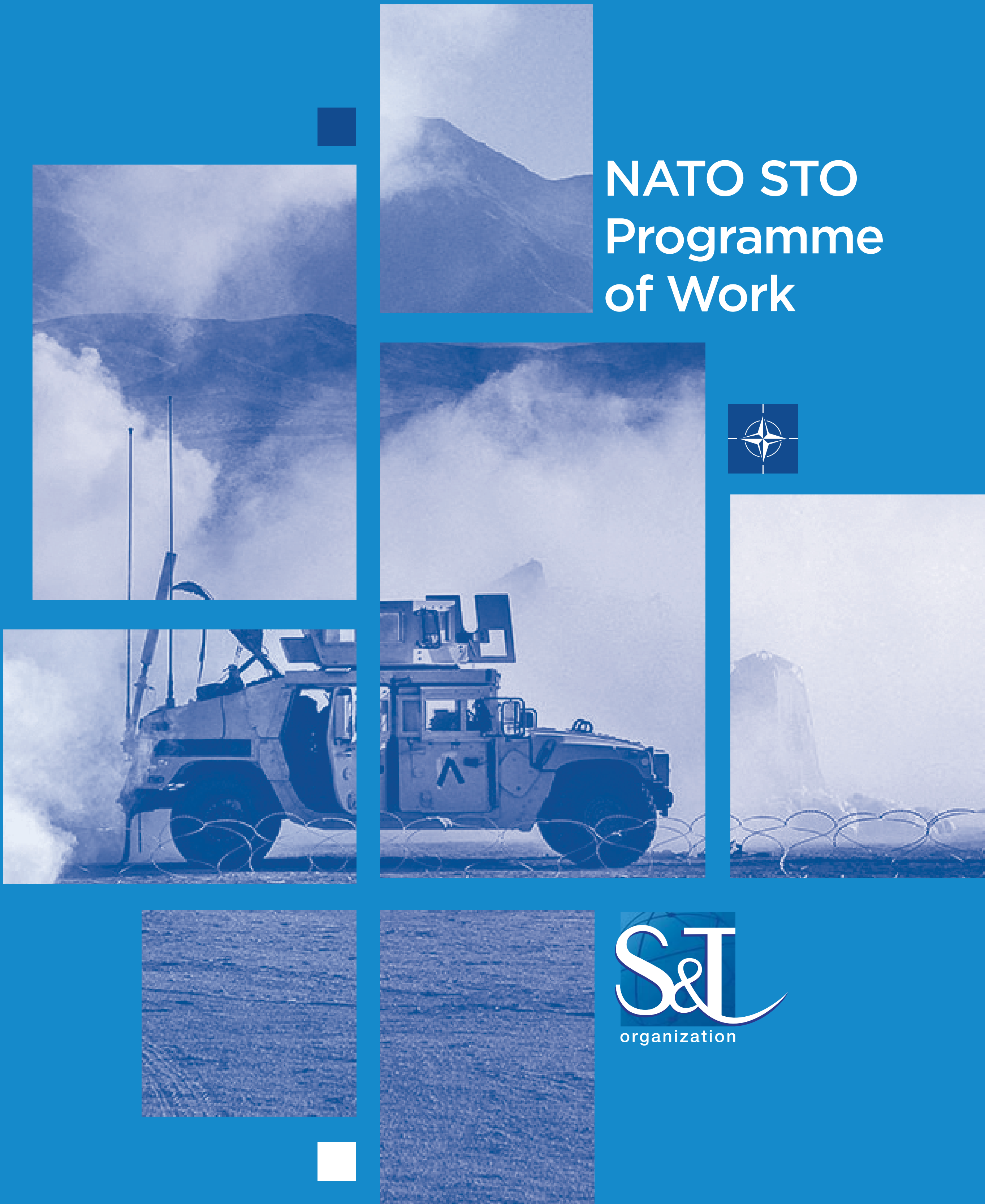
The Alliance must close technological gaps for Anti-Submarine Warfare (ASW) and Naval Mine Countermeasures (MCM). This requires improved environmental knowledge, especially in geographical areas of strategic importance, to provide increased situational awareness to our operational commanders.

The STO and the NATO Naval Armaments Group held a workshop in November 2018 to promote shared awareness between NATO/Nations S&T, operational, armaments communities; and the Allied Command Transformation. Nations presented their Medium-Term Capability Gaps and the S&T community presented current technology development in those areas. Both the ASW and MCM syndicates identified CMRE as focal point of next-generation capability in standards, interoperability, data formats, communications and planning and evaluation tools.

Operational experimentation (OPEX) is a catalyst for transformation by exposing the operational community to innovative ideas and technologies, and accelerating capability development. It is all about getting the technologists and the operators together. CMRE has exposed promising technologies directly to operators and industry through an inclusive operational exercise programme. This is also how we, as an Alliance, can bridge the "valley of death", bring S&T solutions to the operators and pave the way for industry to deliver the capability.

CMRE conducts a range of operational experimentation from low to medium technology readiness levels. These aim to address near-, medium- and long-term capability gaps in ASW, MCM, ISR, and underwater communications. Our activities have also positioned CMRE to lead and support interoperability and to provide the framework for industry to demonstrate their solutions in fair and well-characterized settings.

Working with NATO HQ (Defence Investment Division), CMRE has championed a multinational approach to address the development of maritime unmanned systems. In October 2018, thirteen NATO nations signed a Declaration of Intent (DoI) at Defence Ministerial level to collaborate on the development of MUS. The initiative promises to accelerate the instruction of MUS across the Alliance by sharing costs and de-risking implementation.



NATO STO Programme of Work

organization

EXPERIMENT

REDUCING THE BURDEN ON THE DISMOUNTED SOLDIER (HFM-238)

HFM-238 was established to provide a collaborative effort across nations to address the challenge of load related burden on the Dismounted Soldier.

Mrs. Nicola Armstrong, GBR, Defence Science and Technology Laboratory (DSTL).

BACKGROUND

Loads carried by NATO soldiers are at record highs and evidence suggests that some combat loads may be approaching the soldier's own body mass. HFM-238 was setup to establish a coherent and coordinated approach to address the problem of soldier burden related to load carriage. The outputs of this RTG were designed to be used by the scientific community to ensure that human science research in this area is appropriately exploited and knowledge gaps are identified and filled.

OBJECTIVES

The specific objectives of this RTG were to:

- define the burden;
- identify factors known to influence the size and nature of the burden;
- identify strategies to mitigate the threats from burden in order to maintain operational effectiveness;
- identify an exploitable strategy for burden reduction.

S&T ACHIEVEMENTS

This work has identified the equipment categories which provide the greatest contribution to load related burden. Recommendations for reducing the mass and modifying the make-up of these categories are provided. Existing literature was consolidated to inform burden reduction strategies that target the soldier, equipment, environment or task. This includes identifying a number of technological solutions that could be applied to maintain the operational effectiveness of the soldier. It is recognised that the introduction of burden reduction strategies is equally as important as the solutions themselves. Therefore, a framework has been developed to support the implementation of such strategies using the DOTMPLF framework across all stages of the deployment cycle.

SYNERGIES AND COMPLEMENTARITIES

Nine nations actively participated in HFM-238 and engaged with the NATO Land Capability Group, Dismounted Soldier Systems. An exploratory team has been established to take forward some of the recommendations from this work (HFM ET-181).

EXPLOITATION AND IMPACT

The outputs of HFM-238 will be exploited by the defence scientific community. The identified knowledge gaps and burden reduction strategies will be addressed through national research programs and procurement processes. The outputs of this work were presented at the 4th International Congress on Soldier Physical performance in 2017 to maximize the reach of this work amongst the scientific community.

CONCLUSIONS

A number of strategies to reduce load-related burden have been provided. It is recommended that future strategies move away from applying a point solution and apply a systems approach to implementing burden mitigations. This will achieve a sustainable and progressive solution to soldier burden.

Figure 6: Soldier in full gear.

Figure 7: Future gear.

C2 AGILITY: NEXT STEPS (SAS-104)

In the 21st century, military organisations must face non-traditional missions. These are characterized by unanticipated problems and actions that result in unintended consequences. The complexity inherent in these operations makes it imperative that NATO develops the agility needed to deal with highly uncertain and dynamic situations. SAS-104 improved and disseminated Command and Control (C2) Agility theory, which enhanced NATO's ability to be successful in the face of increasing mission uncertainty and complexity.

Mrs Micheline Belanger, CAN, Defence Research and Development Canada (DRDC), Dr. Bjorn Johansson, SWE, Swedish National Defence Research Institute (FOI).

BACKGROUND

Current and future NATO missions will include NATO and non-NATO military coalitions, interagency partners, international organisations, host governments, non-governmental organisations, private industry, and local authorities. C2 Agility relates to the organisational capacity to use the most appropriate C2 approaches required for a mission's success in such context. It has been used successfully in previous STO work on C2 Agility, which showed that entities adopting an appropriate approach to C2 are better able to affect, cope with and/or exploit changes in circumstances.

OBJECTIVES

SAS-104's three main objectives were to raise C2 Agility awareness in NATO, operationalize the C2 Agility concept (*i.e.* bring the C2 Agility theory into practice) and Conduct further C2 Agility research and analysis.

> Agility is the capability to successfully effect, cope with, and/or exploit changes in circumstances.

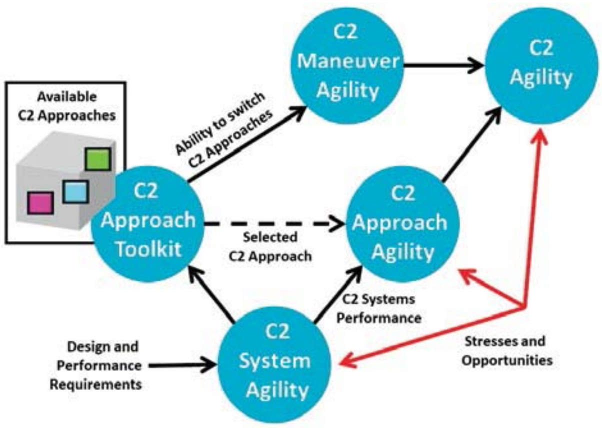


Figure 8: C2 Agility relates to mission success.

S&T ACHIEVEMENTS

SAS-104 raised C2 Agility awareness in NATO by increasing the knowledge in the area. SAS-104 members contributed to more than 50 papers published in international conferences and journals. They further participated in NATO Allied Command Transformation (ACT) TIDE Sprint events, C2 focused symposia and workshops and developed material for teaching C2 agility concepts in military courses. Military operations on C2 agility provided case studies and lessons learned to advance the operationalisation of the C2 Agility concept from theory into practice. SAS-104 conducted further C2 Agility research to refine the concept and to assess the C2 agility of a number organisations.

SYNERGIES AND COMPLEMENTARITIES

SAS-104 worked closely with the NATO C2 and Modelling and Simulation Centres of Excellence, the Multi-National Capability Development Campaign (MCDC), and NATO ACT. It alos worked with numerous nations contributing to the inclusion of the C2 agility concept into the training, concept papers and doctrines of NATO and member nations.

EXPLOITATION AND IMPACT

SAS-104's work described eight new case studies on C2 Agility. Additionaly, it outlined research efforts on selected C2 Agility-related topics to put theory into practice and developed C2 Agility assessment frameworks. Throughout SAS-104's tenure, an extensive body of knowledge was produced addressing theory, concepts, research, experimentation, education and training.

CONCLUSION

SAS-104 improved the understanding of NATO, member nation and coalition partners of C2 Agility. It also provided tools to help deliver more agile C2 to the Alliance.

LASER EYE DAZZLE – THREAT EVALUATION AND IMPACT ON HUMAN PERFORMANCE (SET-249)

NATO-wide, laser dazzle attacks on aircrafts are persistently carried out using powerful, compact, off-the-shelf lasers. Temporary impairment of vision that occurs during a critical task (*e.g.* piloting a vehicle) can disrupt entire combat operations. A field trial in airborne scenarios supports the effort to assess these risks.

Dr. Bernd Eberle, DEU, Fraunhofer Institut für Optronik Systemtechnik und Bildauswertung (IOSB).

BACKGROUND

In 2016, over 7,000 NATO-wide, laser dazzle attacks were reported. This represents a more than 20-fold increase in the number of attacks over the last decade. In the same period, the available power for these devices increased tenfold, while the cost has dropped by 90%. Even for laser power levels that do not result in permanent eye damage, high risks may exist. Temporary impairment of vision that occurs during a critical task/phase can disrupt entire combat operations.

OBJECTIVES

The main objectives of the SET-249 were to assess live laser dazzling events in airborne scenarios.


Figure 9: Cable car and experimental set-up used in the field trial.

Figure 10: Laser dazzling during night using a blue laser pointer at a distance of 600 m.

S&T ACHIEVEMENTS

The field trial took place over a period of ten days at the WTD52 cable car facility in Oberjettenberg (DEU). It offered optimal conditions to study laser dazzle effects on a slant path over distances up to 1,200 meters. Using a military aircraft canopy, we analysed scattering effects by means of a camera mounted below the canopy (see figure 1). To ensure laser-safety, SET-249 developed an elaborated safety concept for safe laser operation in the field, which was strictly followed during the trial. An advantage of the rock face, which served as a natural backstop for the laser radiation (see figure 2) has been taken.

SYNERGIES AND COMPLEMENTARITIES

Each nation contributed both their expertise and hardware, enabling the best possible utilisation of the cable car facility during the conceded ten days of measurement time.

EXPLOITATION AND IMPACT

The results of the field trial highly enhance the understanding of laser dazzle effects on aircrafts. The outcome of this field trial will improve the development of laser warners, laser dazzle protection and hardened devices.

A new constant threat: laser dazzle attacks.

CONCLUSIONS

Various experiments on laser dazzle on an aircraft-like target were performed in a realistic engagement environment, using a military aircraft canopy. This allowed for the collection of valuable information about the laser dazzle protection.

ELECTRO-OPTICAL AND INFRARED-COUNTERMEASURES AGAINST ANTI-SHIP MISSILES (SCI-224)

Defending against anti-ship missiles is difficult. A layered defence concept is generally used upon detection of an incoming missile. The outer layer defence uses interception missiles while the inner layer defence uses close-in weapon systems. The defensive layer in-between uses soft kill techniques: either active Electronic Countermeasures (ECM) or passive decoys.
In some cases, the soft kill is the preferred defensive layer solution. To optimally deploy passive decoys, however, position and timing are critical. As a result, modelling and simulation tools are necessary to predict passive decoy effectiveness.

Mr. Carlos Maraviglia, USA, Naval Research Laboratory, Tactical Electronic Warfare Division.

BACKGROUND

The activities of the SCI-224 Research Task Group (RTG) were guided by its collective capabilities in electro-optical/infrared (EO/IR) anti-ship missile (ASM) simulations. Member nations of the RTG developed a common simulation scenario that included target and decoy models, decoy deployment tactics, geometry engagement information and missile/sensor characteristics. This common scenario was then used as input data for each nation's simulation tool of preference.

OBJECTIVE

The objective of this RTG was not to optimise an engagement sequence, but rather, to validate the methodology applied with each national digital tool. If the comparison of results converged on the same conclusion, simulation methodologies were considered effective.

S&T ACHIEVEMENTS

The common scenario developed by the RTG was an EO/IR ASM engagement. The simulated passive decoys used included a two-flare and a four-flare decoy tactic. Seven nations reported ECM effectiveness from their nation's simulation tool: Australia, Canada, France, Germany, The Netherlands, Turkey and The United States of America.

SYNERGIES AND COMPLEMENTARITIES

An existing unclassified IR ship model (DDG Type 052C air warfare destroyer) was provided by Canada-based W. R. Davis Engineering Ltd. as a common model for use in the common scenario.

EXPLOITATION AND IMPACT

The RTG demonstrated that the common scenario could be imported to national simulation tools. These tools can be used to support NATO electronic warfare (EW) trials such as the Norwegian or the American flyable simulators and EO/IR countermeasure development by the Alliance. Furthermore, the tools can help the development of a NATO Anti-Ship Missile Defence Evaluation Facility (NASMDEF) IR simulator.

> Once acquired, a ship cannot out-manœuvre an ASM. To counter the threat posed, the surface warfare combatant has to either avoid being detected, destroy the missile launch platform before it fires its missile, or destroy or decoy all of the incoming missiles.

CONCLUSIONS

Seven nations developed an unclassified derivative of a classified model that was imported into the common scenario. Afterwards, the ECM effectiveness results were distributed to all nine nations participating in the RTG. The Alliance could realize long-term gains to its NASMDEF by engaging other activities such as the NATO Naval Electromagnetic Operation (NEMO) Trials for IR capability inputs.

Figure 11: Anti-ship missile being fired from the deck of a destroyer.

DYNAMIC MONGOOSE 2018: ASW DECISION SUPPORT DEMONSTRATED ON BOARD SNMG1 DURING NATO'S NORTHERN ASW EXERCISE

CMRE has a long history of providing assessments of predicted sonar detection ranges, given current environmental conditions, during NATO antisubmarine warfare (ASW) exercises .

Mr. Christopher Strode, Dr. Manlio Oddone, STO-CMRE.

BACKGROUND

Through past development of the Multistatic Tactical Planning Aid (MSTPA) and its recent transition towards the web-based Rapid Acoustic Prediction Service (RAPS) analysts are able to provide acoustic predictions as a service with simple operator interaction though a web-based interface.

OBJECTIVE

The objective of this RTG was to determine the added value of accurate range dependent acoustic predictions for operators onboard ASW assets. The potential scalability of the web-based approach (whether running on local network or over the Internet) makes it suitable for intensive optimisation tasks. Discussions at sea determined the optimised metrics of most interest to ASW operators. This included an assessment of the best sensor depth with the likely optimum counter detection depth for an enemy submarine.

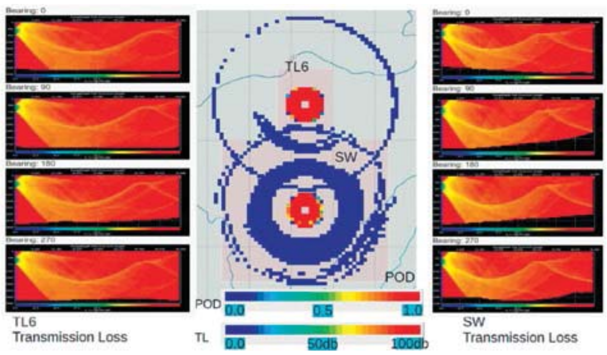


Figure 12: Acoustic predictions generated at sea during DMON18.

S&T ACHIEVEMENTS

Analysis conducted onboard the NATO flagship *HDMS Niels Juel* during Exercise DYNAMIC MONGOOSE 2018 showed good agreement between predictions made using both RAPS and the WADER model. This gave supporting evidence that the tool can handle complicated range dependent environments. In addition, passive sonar predictions were conducted using MSTPA to determine the likely depth of the submarine. This functionality will be added to RAPS in due course. In addition to providing analysis to those on board, a number of analysis products were sent to the in stride debrief team. This provided CMRE products to other ships within the exercise.

The generation of acoustic reports detailing predicted detection and counter detection ranges was of great value to the exercise participants. However, it required a large degree of analysis and formatting by the CMRE analyst on board. To this end, a Matlab framework has been developed allowing for the fully automated generation of acoustic prediction reports. The framework requests multiple acoustic predictions to determine best depths, and outputs the results in a formatted pdf presentation which may be sent to exercise participants. This functionality was tested in a reachback configuration during exercise Trident Juncture 18 at CMRE.

SYNERGIES AND COMPLEMENTARITIES

An automated user friendly framework able to leverage scalable parallel processing over a local network will allow for more advanced optimisation studies. Future studies will be able to determine optimum deployment configurations for multiple unmanned systems conducting ASW missions alone or in cooperation with manned assets.

EXPLOITATION AND IMPACT

The service based architecture of RAPS can easily be exploited by Nations over a VPN protected Internet connection. This functionality was demonstrated with the GBR Maritime Warfare Centre. A virtual machine version of RAPS could be deployed on any national local network enabling more detailed experimentation.

CONCLUSIONS

RAPS is of great value to sonar operators and planners during at sea demonstration in NATO ASW exercises.

DEMONSTRATION OF CMRE AUTONOMOUS MINEHUNTING CAPABILITY ONBOARD SNMCMG2 FLAGSHIP DURING ESPMINEX18 AND ITAMINEX18

Following numerous scientific trials in NATO exercises, CMRE's mine hunting autonomous underwater vehicle systems were considered sufficiently mature for deployment from a military platform: HMS Enterprise, Standing NATO MCM Group 2 flagship, during ESP and ITA MINEX of 2018.

Mr. Christopher Strode, Mr. Thomas Furfaro, STO-CMRE.

BACKGROUND

NATO Navies are considering autonomous platforms for mine hunting. Generally, these platforms use side-looking sonars, which deliver very high-resolution "images" of seafloor objects. CMRE has been at the forefront of this technological development for unmanned platforms and the supporting technologies – sonar processing, automatic target recognition, machine-learning and collaborating networks.

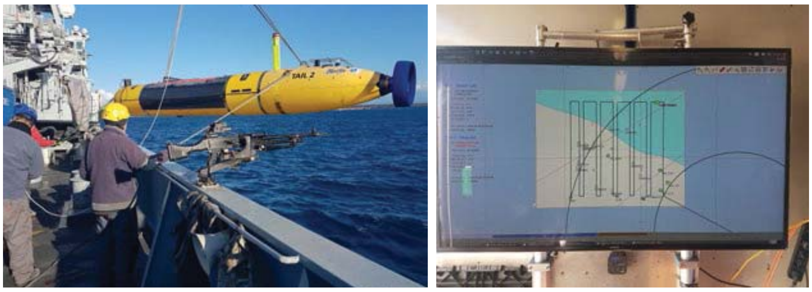


Figure 13: MUSCLE vehicle deployed from *HMS Enterprise* (left). Real time detections sent from vehicle in-mission and displayed on the operator's console (right).

OBJECTIVES

CMRE sought to demonstrate a modular autonomous mine hunting capability deployed from a military platform. This capability used an AUV with advanced synthetic aperture sonar and onboard automatic target recognition algorithms (ATR). Another AUV, with complementary visual and acoustic cameras carries the reacquisition. Contact information is to be injected automatically through the underwater network, over which all the unmanned systems communicate. Importantly, this type of cooperation should reduce the mission time significantly with respect to legacy capabilities. The concept no longer requires the recovery of a vehicle for data download and post mission analyses.

S&T ACHIEVEMENTS

Mine-like detections were relayed in real time for operators to plan subsequent actions while showing that vehicle recovery and data download was no longer necessary. The parallel classification and identification operations reduces mission time significantly. Moreover, a collaborative autonomy concept was demonstrated: detections were received directly by other unmanned assets, triggering follow-on reacquisition missions. This task-based approach relies on a task-decision framework built on top of an underwater communications network. In turn, it allows the network of unmanned assets to construct a mission federation autonomously. The operator remains "in-the-loop" simply for monitoring and safety purposes.

SYNERGIES AND COMPLEMENTARITIES

This closely parallels several nations' strategies that foresee the use of unmanned systems for MCM from vessels not suited to mine threat areas. These concepts rely on technologies that CMRE develops: from generic vehicle technologies, security, interoperability and communications aspects, to MCM-specific applications of next-generation sonar systems, collaborative autonomy and machine learning.

EXPLOITATION AND IMPACT

The engagement with operators is a multi-faceted outreach and interaction strategy for CMRE's ANMCM programme. The experience aboard the *SNMCMG2* flagship gave commanders a glimpse of a technical capability available for future generations. Conversely, CMRE scientists were able to receive feedback and viewpoints on the utility and applicability that CMRE promotes directly from sailors.

CONCLUSIONS

Integrated demonstrations of future technologies promote direct conversations between technology experts, such as CMRE scientists, and operators, who must own the risk and reward of using such systems in the future. The ongoing dialogue helps CMRE to address early concerns, and provides an opportunity for future users to become familiar with the concepts at an early stage before their future toolbox is completed.

THE GENERATION OF GAME BASED PROTOTYPES AS A PROOF OF CONCEPT IN THE USE OF MODELLING AND SIMULATION FOR NATO TRAINING AND EDUCATION

Following the collection and analysis of requirements provided by the training and education communities across NATO, a series of prototypes were developed, presented and discussed during Military Training related events.

Dr. Alberto Tremori, Dr. Pilar Caamaño, Dr. Arnau Carrera, Dr. Thomas Mansfield, Mr. David Solarna, Mr. Gianluca Maglione and Mr. Robert Been, STO-CMRE.

BACKGROUND

Following the elicitation of Collective Training and Exercise (CT&E) requirements, the CMRE has identified areas, topics and processes in need of revision and enhancement. These must fulfil the expectations of training audiences and trainees with respect to the future NATO Training Capability and Environment. They are summarised as:

- Realistic Representation of the Operational Environment
- Credible Information of the Operational Environment
- Continuity over time: support of all the stages of Exercise Process
- Building and maintaining knowledge and proficiency on NATO processes
- Optimisation of Exercise Control Activities
- Interoperability and Connectivity
- Quality (non-functional) factors

Analysis also showed that they could be addressed by M&S-based tools and services.

OBJECTIVES

Design, develop and use a list of prototypes to further explore, understand and develop potential applications and benefits for M&S in training and education.

S&T ACHIEVEMENTS

Building upon Concept Development and Experimentation (CD&E) principles, CMRE developed software prototypes that demonstrate the benefits of applying M&S in the identified areas of improvement. Those prototypes also explain complex requirements and improvements of the current NATO CT&E process.

P_ESII (figure 14, top) is a prototype to model and simulate the impact of crisis operations over the whole spectrum of the societal dimensions.

NATO Puzzle (figure 14, middle) is a serious game tool aimed at helping NATO newcomers to learn and understand complex NATO processes and organisational structures prior to exercises or posting.

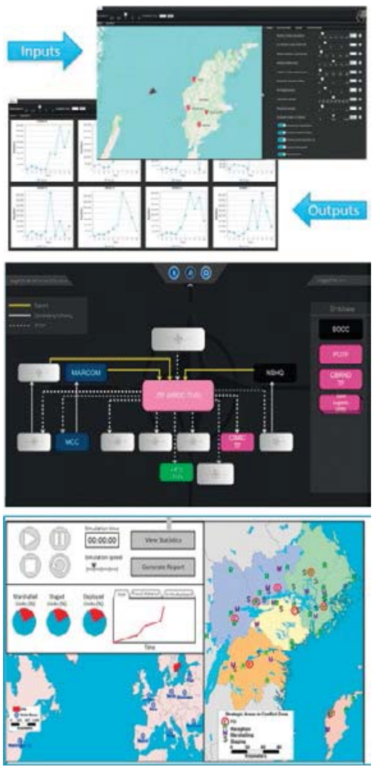


Figure 14: Software demonstrator screenshots.

For Four (figure 14, bottom) demonstrated the benefits of using an M&S-based tool for creating an exercise path for logisticians (J4). It provides means for training, planning, monitoring and analysing logistics operations.

SYNERGIES AND COMPLEMENTARITIES

The CMRE M&S project team participated in Operation Blended Warrior during ITSEC 2017 / Viking 18, a Swedish multinational exercise.

EXPLOITATION AND IMPACT

CMRE has demonstrated the potential benefits of M&S-based tools to support and enhance military training. The response of the audience has been very positive and helped to demonstrate the capability of CMRE as a provider of M&S services for the military community for a broad spectrum of application areas.

CONCLUSIONS

The work has been of strategic relevance for CMRE. It has represented a consistent and successful opportunity to demonstrate a growing capability to design and deliver innovative concepts based on knowledge acquired by the collection of requirements. It has also helped to consolidate a network of valid and motivated partners, both on the customer and supplier side. This work was funded by Allied Command Transformation.

NEW EXPERIENCES ON THE ADOPTION OF MODELLING AND SIMULATION (M&S) TO BETTER INFORM THE NATO DECISION-MAKING PROCESS

The recent delivery of simulation study from the Strategic Commands to the Military Committee and the North Atlantic Council has highlighted the potential benefits of M&S for decision support within NATO and the Nations. This article describes the collection of best practices during NATO's most recent use of M&S for Advanced Planning, and the identification of recommendations and requirements for capability development.

Dr. Alberto Tremori, Dr. Pilar Caamaño, Dr. Thomas Mansfield, Mr. Gianluca Maglione, Dr. Arnau Carrera and Mr. Robert Been, STO-CMRE.

BACKGROUND

NATO has recently employed an M&S methodology to support and inform Advanced Planning. This represents the most recent use of M&S towards a new approach for planning and decision-making within NATO. Such step is required given the increase in the complexity of the problem space and required responses. A stochastic simulator was used to conduct experimentation at the operational level for the exploration of the problem space. Specific vignettes were identified. In a second stage, using man-in-the-loop deterministic (some stochastic) simulation, SHAPE and Single Service planners challenged Courses of Action for an in-depth analysis on specific activities.

OBJECTIVE

The objective was to observe, discuss and analyse NATO's use of M&S for decision support at the operational level, and report key findings, best practices and opportunities for improvement.

S&T ACHIEVEMENTS

Best practices and opportunities for improvement were identified in five key areas:

- **stakeholders** focus on roles, responsibilities, and their impact in the process. Areas of improvement include the support to the customer, the encouragement of a multi-cultural approach, and the facilitation of human interactions and information flow;
- **culture** relates to leadership, experiment approaches, level of experience and prior M&S education. Identified areas of improvement include aspects such as setting the proper expectations and motivating the planners to follow a more challenging "what-if" approach for planning;

Figure 15: The witnessed M&S based decision support process.

- **materiel** refers to the simulations, databases and other tools for cross-syndicate management. The analysis focused on improving the use of existing tools and acquiring new ones. It further considered the capability to run multi-level simulations and the efficient management of an experiment;
- **data** is an area that focuses on the availability, level of detail and maturity of the data. Recommendations include: the maintenance, improvement and availability of databases and the management of the level of detail and aggregation of data;
- The **process** category covers the doctrine, methodology, and the organisation and management of the experiment. Recommendations include the development of a specific NATO doctrine or the organisation of the experiment.

SYNERGIES AND COMPLEMENTARITIES

Other applications that leverage these findings use a similar approach to assess deployment planning in logistics. They also investigated if, and how, computer-based Wargaming can enhance and stimulate studies like the one here described. This work also relies on activities of the NMSG and the SAS panel, which creates a cross-panel community complementing the expertise of each individual group.

EXPLOITATION AND IMPACT

To realising the potential of the described approach, NATO and Nations are investing in its application. The operational community has showed its interest promoting similar studies in the near future. Results of a survey run by ACT demonstrated national interest in this area of application and revealed that NATO cannot capitalise solely on national expertise and investments, but needs to work side-by-side with Nations to pull together good practices and lessons learned.

CONCLUSIONS

The experimentation observed by CMRE represents the earliest step of a new process for planning and decision-making. Including initial planning, this process ran over a period of twenty-six months. The achievements made so far have demonstrated the potential of M&S to provide support and contribute to a new approach in decisions and analysis.

COOPERATE

BENCHMARKS IN MULTIDISCIPLINARY OPTIMISATION AND DESIGN FOR AFFORDABLE MILITARY VEHICLES (AVT-237)

The purpose of this task group is to identify and collect enduring benchmark problems in Multidisciplinary Optimisation and Design that represent a variety of issues for military vehicles. The purpose of the benchmarked problems is to aid the development, assessment and promotion of multidisciplinary optimisation and design methods.

Dr. Raymond M. Kolonay, USA, Air Force Research Laboratory (AFRL) and Dr. Melike Nikbay, TUR, Istanbul Technical University (ITU).

BACKGROUND

The implementation of rapid analytical design development methodologies can lead to a reduction in technology risk and discovery of late defects, which further reduces the need to correct or compensate for late defects. In addition, it decreases cycle time and cost of development. An automated multidisciplinary approach also permits a more in-depth consideration of operational and maintenance issues in the design process, which in turn reduces operational and maintenance costs. Validation and verification (V&V) are key tools to developing successful rapid analytical design methodologies. The range of available methodologies and processes need to be evaluated and benchmarked.

OBJECTIVES

The objectives of the task group were to develop documentation standards for multidisciplinary design optimisation (MDO) benchmarks, to apply those standards to a number of MDO problems and to form a repository to facilitate future research. The driving principal was to develop standards that would provide researchers with the necessary information to understand and implement vehicle optimisation performed in a benchmark problem.

Figure 16: Enhanced development by benchmarking of optimisation and design methods.

S&T ACHIEVEMENTS

The topics of interest for this working group fall into three categories: optimisation and design methods, analytical methods, and physical testing. Problems of interest in these categories address land, sea and air vehicles. The efforts resulted in a repository of MDO benchmark problems for the NATO community to be used for validation, verification and reference. The task group will also provide a list of references that quantify the impact of using MDO *versus* traditional design methods for military vehicles.

SYNERGIES AND COMPLEMENTARITIES

Leverage models and design studies were performed by AVT-251 Multi-disciplinary Design and Performance Assessment of Effective, Agile NATO Air Vehicles and AVT-252 Stochastic Design Optimisation for Naval and Aero Military Vehicles.

EXPLOITATION AND IMPACT

Participating nations will leverage benchmarks for V&V of models used in the development of future systems. They will also use quantifiable benefits of MDO and identify missing capabilities and limitations within the MDO methods, processes and tools that can drive future MDO research investment strategies.

CONCLUSIONS

Physical benchmarks were used to validate point designs within the design space. These increased confidence in the analytical results and provided exhausted information to improve the reusability of the test results. The benchmark problems aid the development, assessment and promotion of multidisciplinary optimisation and design methods for more affordable military vehicles.

> "Affordability matters […]. The Department [of Defence] is transitioning to a culture of performance and affordability that operates at the speed of relevance." *U.S. Secretary of Defense, Jim Mattis.*

MORAL DECISIONS AND MILITARY MENTAL HEALTH (HFM-284)

This RTG organised and delivered a Research Lecture Series (RLS) on the impact of moral decisions in military operations and their relationship to mental health outcomes.

Col. Prof. Dr. Eric Vermetten, NLD, Militaire Mental Health Service, Head of Research.

BACKGROUND

Military operations often involve difficult decisions that can affect the well-being of: the decision-makers, their subordinates and peers, their adversaries, and civilians impacted by the conflict. Although noted as a potential consequence of earlier conflicts. The post-Vietnam period saw an increased focus on the psychological consequences of war, including real or perceived ethical lapses and violations. While decisions and their potential psychological impacts are primarily associated with war, they take place throughout the full-spectrum of military operations (*i.e.* during peacekeeping, peacemaking, humanitarian, and combat).

OBJECTIVES

Moral decisions are among the most difficult tasks that soldiers will face, and they occur at all levels of military operations. A single bad decision can erode local, national, international and host nation support, thereby derailing the strategic mission and putting troops at risk. Evidence exists linking moral decisions, attitudes and behaviours to military mental health and well-being. decision-makings is thus a crucial component of leaders' responsibility towards their soldiers.

Figure 17: Morality/WendyWalker.

S&T ACHIEVEMENTS

This series of lectures present the empirical evidence on the potential links between moral challenges and mental health outcomes for deployed military personnel. They further present operational ethics and mental health training programs of contributing NATO countries. The findings concerning moral issues of decision-making and the psychological well-being of personnel have been translated into recommendations for military leaders. This work was achieved through a series of keynote lectures and workshops.

SYNERGIES AND COMPLEMENTARITIES

The lectures recommended good practices in coping with moral dilemmas and should allow military leaders to develop awareness of tragic dilemmas. Besides good practices, the results of these lecture series should also provide a better understanding on how to develop and implement operational ethics training/education to promote better moral decision-making, attitudes and behaviour during deployment. Furthermore, these lecture series reached a wide (international) array of psychosocial caregivers, which optimises the chances for preventing mental health problems in the aftermath of (wartime) deployment. They also framed recommendations for pre-, peri- and post-deployment psychosocial support and care.

EXPLOITATION AND IMPACT

These lecture series lead to a series of recommendations concerning both psychological and operational pre-deployment in education, training, post-mission reviews, counselling, and reintegration programs. All of which seek to mitigate the threat to the mission and soldier well-being.

CONCLUSIONS

After three successful lecture series during the autumn of 2018 in Canada, the UK and The Netherlands, the HFM Panel in Portsmouth, UK, supported the organisation of one more RLS event in Poland in 2019.

BIG DATA AND ARTIFICIAL INTELLIGENCE FOR MILITARY DECISION-MAKING (IST-160)

"Artificial Intelligence: the capability of a computer system to perform tasks that normally require human intelligence, such as visual perception, speech recognition and decision-making." Mary L. Cummings, Artificial Intelligence and the Future of Warfare, Chatham House (January 2017).

Dr. Ing. Michael Wunder, DEU, Fraunhofer-Institut für Kommunikation, Informationsverarbeitung und Ergonomie (FKIE) and Dr. Robert J. Bonneau, USA, Office of the Secretary of Defense.

BACKGROUND

Artificial Intelligence (AI) is used extensively commercially and is the subject of extensive research. The militaries have extremely good facilities for collecting data, which, coupled with the enhanced AI tools, should maintain information superiority. IST-160 was initiated by the Science and Technology Board as a first step towards a road map/strategy to align various options seeking solutions for legal, operational, technical, implementation and project management questions. The results reflect both a military and scientific perspective on the state of AI and the impact of the vast amount of data available. The methods to incorporate machine assistance through AI (such as the OODA loop) and the means to present relevant data to a decision-maker in a succinct and timely fashion are addressed. This Research Specialist Meeting activity considered areas of research that will benefit the operators in the field as well as the decision-makers. Critical to this aim is the availability of appropriate training data.

"Artificial Intelligence remains a machine, and like any machine, it will have to be mastered if you want to trust it." *Patrice Caine, CEO THALES.*

Figure 18: IST-160 Specialists' Meeting: Big Data and Artificial Intelligence for Military Decision-Making.

OBJECTIVES

The main objective was to provide a forum for operational experts and scientists to work together and define a common road map for future research activities in the AI and Big Data domain that meet NATO's operational needs regarding Military Decision-Making.

EXPLOITATION AND IMPACT

AI's potential for Defence was widely acknowledged. However, its current state of progress, with its operational requirements, anticipated benefits and risks, requires that its users exercise a high level of critical judgement for its use as a component in critical decision-making. Appropriate levels of training will be needed. Furthermore, the general public will need to better understand the use of AI in military operations.

A follow-on Specialist Team will present and discuss future technologies and develop technical activity proposals (TAPs). These will be used for Panel-overarching research activities that address knowledge gaps or pursue the assessment of recognised opportunities offered by available techniques.

SYNERGIES AND COMPLEMENTARIES

For three days, attendees discussed major challenges in the use of AI. These included understanding how to integrate autonomous and human decision support; the dangers of a "poisoned" data environment; edge computing; and the ethical and legal considerations of AI in the battle space. The way forward will see further collaboration between the scientific and military communities to integrate research, commercial technologies, and military capabilities that support NATO's mission to protect its member states.

CONCLUSIONS

The Specialists' Meeting provided a forum for operational experts and scientists to work towards a common road map for future research activities in the AI and Big Data domain. Through this forum, they explored potential research areas to enable NATO to retain Information Superiority.

FACTORING SITUATIONAL AWARENESS AND COMMUNICATIONS IN OPERATIONAL MODELS OF DISMOUNTED COMBAT (SAS-107)

Defence funds dedicated to dismounted soldier systems are finite, and must be divided among multiple programs. In the process, decision-makers must balance investments between disparate combat technologies. Each of these technologies have, on their own, the potential to improve combat outcomes. However, deciding on the right mix can be difficult. SAS-107 presents a way to perform such comparisons.

Dr. Jérôme Levesque, CAN, Defense Research and Development Canada (DRDC), and Mr. Roy Benda, NLD, Netherlands Organisation for Applied Scientific Research (TNO).

BACKGROUND

Today, dismounted forces are equipped with portable electronic devices for digital communications and assisted mission planning. The effectiveness of these units depends on the kinetic effects that it has available and its knowledge of the battlespace. This knowledge allows the commander to decide how to apply these effects. Therefore, any investigation of the effectiveness of the dismounted unit should consider both kinetic effects and situational awareness in combination, regardless of whether the investigation is tasked with examining only kinetic interventions or not.

OBJECTIVES

SAS-107's aims were to determine the key operational factors describing the effects of changing situational awareness in dismounted operations; to define a methodology for better integrating these factors in the operational analysis, modelling and simulation of dismounted operations; and to conduct a pilot study demonstrating that, with a specific scenario, the model properly represents the change in operational effectiveness due to variations in the situational awareness of the dismounted teams.

Figure 19: The application of force in combat, and ultimately combat effectiveness, depends on the information available (or unavailable) to the soldier.

Which combination of sensors, displays, weapons, and personal protective equipment provides the best expected mission outcomes?

S&T ACHIEVEMENTS

SAS-107 developed a mathematical combat model that considers the joint effects of situational awareness and lethality, and looks at combat outcomes in terms of expected lives saved. The model can be used to design an optimal equipment portfolio (*i.e.* one that will save the most lives). The approach relies on solving Partially Observable Markov Decision Process (POMDP), and the examples presented are limited to dismounted soldier systems. However, the models are also applicable to other scales of ground, air and maritime combat.

SYNERGIES AND COMPLEMENTARITIES

The topic of situational awareness is rooted in cognitive science and questions usually studied by human factors scientists. SAS-107 collaborated with the Human Factors and Medicine Panel group HFM-238 to further inform their efforts.

EXPLOITATION AND IMPACT

The SAS-107 work addresses two audiences: scientists, as operators, and decision-makers, as users. The models will be used by the Alliance to enhance decision-making in procurement, capability development and assessing the effects of cognitive burden on dismounted combat effectiveness. It also provides an additional approach for research in the field of cognitive science and military operations research.

CONCLUSIONS

SAS-107's model can be used to explore trade-offs in investing between disparate technologies such as weapons and personal protection, and portable information technologies. It allows NATO Nations to derive an optimal portfolio of technologies for soldier systems.

DESIGN AND ANALYSIS OF COMPRESSIVE SENSING TECHNIQUES FOR RADAR AND ESM APPLICATIONS (SET-236)

Compressive Sensing (CS) is an emerging technique that has the potential to both improve the performance of radar and ESM systems, and reduce their size, weight and power. This RTG has identified metrics that can be used to quantify the performance of CS techniques and design new CS based sensor systems.

Dr. Laura Anitori, NLD, Netherlands Organisation for Applied Scientific Research (TNO).

BACKGROUND

The proliferation of reconnaissance sensors is currently stressing both the ability of analysts to access and exploit the data volume and the communications links by which the data and derived products are disseminated. One solution that could address the problem is to reduce the data volume without significantly losing exploitable information. CS is an emerging technology that offers such an opportunity. It has the potential to substantially improve the intelligence yield of existing ISR sensor assets and to achieve improved target engagement (*e.g.* detection, tracking, identification, fire control).

OBJECTIVES

The main objectives of the SET-236 were:

- to define metrics and procedures for performance and trade off analysis of CS systems with specific attention to robustness, resiliency and reliability;

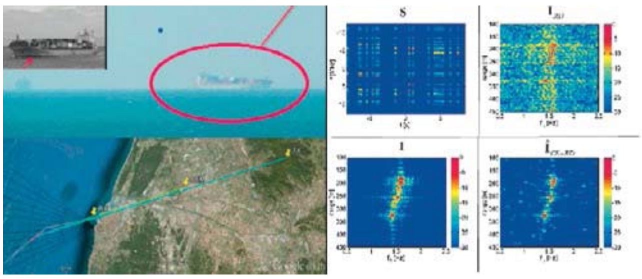


Figure 20: Optical image of a target.

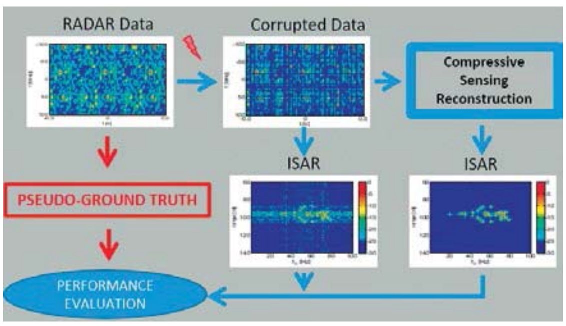


Figure 21: ISAR subsampled raw data Range-Doppler reconstructed image.

Compressive Sensing: more from less.

- to assess the performance and robustness of CS based system architectures and algorithms for radar and ESM (Electronic Support Measure) applications/scenarios;
- to identify and quantify benefits and challenges in the transition to operational CS based radar and ESM systems.

S&T ACHIEVEMENTS

The results of the group have shown that compressive radar hardware can outperform traditional methods. The compressive architectures investigated in this group can inspire new design paradigms for the next generation sensor systems, furthering NATO's technical capabilities.

SYNERGIES AND COMPLEMENTARITIES

The group achieved excellent results thanks to the sharing of knowledge, in the form of data, algorithms and hands-on experience between all the participating nations.

EXPLOITATION AND IMPACT

The results of this RTG provide guidelines to radar and ESM manufacturers that can be used for the specification of future military systems. The use of CS-based systems in military operations is especially foreseen in situations when:

- large quantities of data must be passed around, stressing communications links;
- data rates impose a burden on the hardware (for example on analogue-to-digital conversion);
- some of the data is "missing" and must be reconstructed based on other prior information.

CONCLUSIONS

SET-236 evaluated the effectiveness of CS techniques in support of decision-making and has made recommendations regarding the future of CS in NATO systems.

ARTIFICIAL INTELLIGENCE FOR MILITARY MULTISENSOR FUSION ENGINES (SET-262)

AI-assisted situational awareness is essential for intelligent military action. The RSM discussed logical and reliable cognitive tools that exploit large sensor data streams, make context information accessible, integrate heterogeneous sensors, check the plausibility of sensor information, suggest options to act properly, and help respect constraints of action.

Prof. Dr. Wolfgang Koch, DEU, Fraunhofer-Institut für Kommunikation, Informationsverarbeitung und Ergonomie (FKIE).

BACKGROUND AND MILITARY RELEVANCE

Vast amounts of sensor data and context knowledge are available during NATO's missions. Recent advances in Artificial Intelligence (AI) enable more powerful Multisensor Fusion Engines. These advances form the backbones of NATO's situational awareness, and play an increasingly essential role.

OBJECTIVES

Eighteen invited papers were presented in six sessions covering many relevant aspects: AI Methodology and Robustness, AI in Detection and Classification I/II, AI for Management and Action, AI for Situational Understanding, AI for Internet of Military Things. Deeper insights were provided by four keynote presentations: Integrating Deep Learning and Model-based Reasoning for Robust Sensor Data Fusion; AI/ML for Multi-Domain Battle; Sense-making in Cyber Social Spaces; and Artificial Intelligence for Military ISR, EW Problems and Applications.

S&T ACHIEVEMENTS

In a systems-of-systems point of view, guidelines were provided to seamlessly embed AI-empowered fusion engines into overarching C5JISR systems. Disruptive effects on military situational awareness and decision-making are expected. It was shown that sensor-focused AI may improve multiple hypothesis analysis, decision-making, and classification. Issues in sensor data integrity have been identified. Besides EW, this comprises "malicious" sensors as well as navigation and cyber warfare. Tomorrow's fusion engines will be inherently "cognitive" to scenario and mission requirements.

> AI-empowered Military Multisensor Fusion Engines – the backbone of military situational awareness and intelligent action.

SYNERGIES AND COMPLEMENTARITIES

The RSM was the sensor-focused counterpart of IST-160/RSM on "Big Data and Artificial Intelligence for Military Decision-Making", Spring 2018, Bordeaux (FRA). It took advantage from ongoing research activities in a variety of SET-RTGs (223, 233, 242, 256, 277).

EXPLOITATION AND IMPACT

AI-empowered Multisensor Fusion Engines are crucial to unburden military decision-makers from routine and mass task. It will allow human beings do what they can do – act intelligently and responsibly.

CONCLUSIONS

The RSM identified the AI-aspects in multiple sensor data fusion pertinent to military activity. In turn, it highlighted specific considerations for NATO and R&D efforts. Moreover, the pressing need for a lecture series on military aspects of AI for ISR – AI's opportunities and limitations – makes it evident that it is to be designed for military users, planners, and decision-makers.

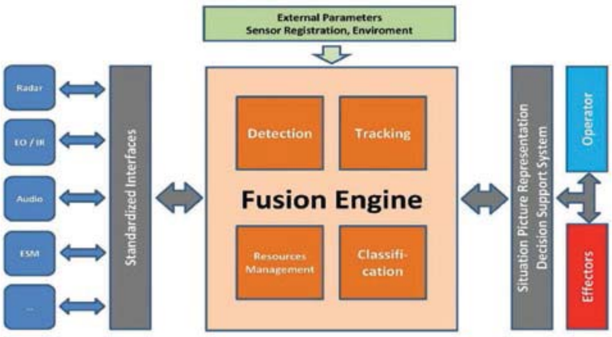


Figure 22: Schematic overview of a Multisensor Fusion Engine.

RESILIENCY CONCEPTS TO ENHANCE PRESERVATION OF NATO SPACE CAPABILITIES (SCI-308)

NATO leadership increasingly recognises the improvements in the net resilience of space capabilities provided to the Alliance as a critical imperative. Furthermore, NATO can benefit from increased network redundancy by identifying space capable nations, creating better interoperability, facilitating international interaction and offering support to nations that do not have space capabilities.

Dr. Eva C.M. Bernhardsdotter, SWE, Försvarets Materielverk (FMV), and Dr. Ulpia-Elena Botezatu, ROU, Romanian Space Agency (ROSA).

BACKGROUND

Resiliency of the space domain is essential in the context of leveraging space for the warfighter. NATO is especially dependent on space services to conduct its military missions and related responsibilities. The NATO Alliance does not own infrastructure in space but relies on the availability of shared national capabilities. NATO nations, and by extension NATO, do not have a resilient space architectures.

Space: The ultimate high ground.

Figure 23: Satellite communications dishes deployed to the area of operations.

OBJECTIVE

The objective of the SCI-308 Research Specialists' Meeting (RSM) was to explore and promote a shared awareness of NATO's technical, operational and institutional/policy space options.

S&T ACHIEVEMENTS

SCI-308 RSM syndicate work was carried out on four topics:

- concepts of operations (CONOPS) for space systems and services affecting resilience;
- spacecraft and component resilience, as well as architectural and constellation options for resilience;
- ground segment considerations to increase resilience;
- institutional and policy considerations contributing to or reducing resilience.

SYNERGIES AND COMPLEMENTARITIES

A presentation session on related topics preceded the SCI-308 RSM syndicate work. The RSM was followed by a technical visit to the CHEIA Satellite Communication Centre in the Prohava region of Romania. Overall, the activity benefitted from the presence of 95 participants who represented eight nations and whose work resulted in recommendations for follow-on technical activities.

EXPLOITATION AND IMPACT

SCI-308 RSM called attention to priorities associated with enhancing the resilience of the Alliance and its operations in response to hostile, environmental, or unintentional interference effects against sovereign and commercial space capabilities, which are critical to NATO.

CONCLUSIONS

Firstly, NATO should identify the critical space products required for mission execution and develop plans to mitigate losses and degradation. Secondly, it is essential that NATO commanders, staffs and forces continue to gain knowledge and experience to better orchestrate space support to operations. Lastly, it is critical for NATO to formulate an agreement between member states and issue an approved space policy or strategy, as the resiliency of the space capabilities resides with the national actors and should be included in a broader multi-national and cooperative framework.

REQUIREMENTS GENERATION BEST PRACTICES FOR MULTI-DOMAIN/DISCIPLINARY PROJECTS

The effective management of distributed teams in the development of multi-domain and multi-disciplinary projects. Standards to develop and validate requirements across the full DOTMLPFI spectrum and a wide range of stakeholders.

Dr. Alberto Tremori, Dr. Thomas Mansfield, Mr. Gianluca Maglione, Dr. Arnau Carrera, Dr. Pilar Caamaño, and Mr. Robert Been, STO-CMRE.

BACKGROUND

Two recent Modelling and Simulation (M&S) based requirements elicitation tasks provided CMRE with the challenge of maximising the potential opportunities offered by multi-domain and multi-disciplinary development projects. In NATO, obsolescence monitoring needs to furnish the operational commands with a new generation of M&S tools and methodologies to support Collective Training and Exercise (CT&E). Allied Command Transformation's (ACT's) CORESIM2020 project aims to maximise the impact of new approaches across NATO and the Nations. In parallel, the European Defence Agency (EDA) has launched OCEAN2020, which requires partners to identify innovative approaches that maximise the benefits of unmanned systems during wide area surveillance and maritime interdiction.

OBJECTIVES

Challenges include the engagement of a cross-domain operational community to elicit requirements. This calls for the cooperation of a range of geographically distributed industrial, academic and small-to-medium enterprise partners. The complete and extensive requirement sets need to be validated by the End Users. The completion of these tasks requires the latest standard-based approaches to systems and M&S engineering. Particular emphasis is placed on tailoring Model Based Systems Engineering (MBSE) approaches for military audiences with the innovative use of the NATO Architectural Framework (NAF).

S&T ACHIEVEMENTS

A process based on the latest Requirements Engineering Standards (ISO/IEC/IEEE 29148) was constructed. Building upon NATO Concept Development and Experiment (CD&E) principles, emphasis was placed on the iterative communication of complex technical and operational concepts among specialised, geographically distributed, and multi-cultural technical and operational communities. The process begins with a series of formalised End User workshops that, supported by the targeted application of NAF Conceptual View toolsets, develops a joint understanding of the opportunities and shortcomings of novel operational concepts and innovative new technologies. Following the identification of initial concepts, structured activities allow key tactical level military tasks and data flows to be identified, developed and validated by NAF Operational Views. Analysis allows a complete set of operational, mission and systems requirements to be documented.

SYNERGIES AND COMPLEMENTARITIES

The CORESIM2020 and OCEAN2020 projects have each developed mature and comprehensive requirement sets that will ensure quality in subsequent M&S development tasks. To carry forward the benefits, a comprehensive set of lessons have been identified and documented using the NATO Lessons Learnt process.

EXPLOITATION AND IMPACT

This approach enabled a cross-community operational and technical understanding that brings a particular range of benefits to subsequent conceptual modelling stages of the M&S development process. The availability of a mature and proven requirements elicitation and verification process enables further development of processes throughout the M&S development lifecycle. This includes the augmentation of the IEEE recommended practice for Distributed Simulation Engineering and Execution Process (DSEEP), along with additional NAF requirements management views to support future distributed M&S projects.

CONCLUSIONS

Building upon standards and best practices from industry, academia and NATO, CMRE has developed and documented a process that can be used to produce high quality requirement sets across the full DOTMLPFI spectrum in multi-disciplinary and multi-domain projects.

Figure 24: Successful OCEAN2020 Systems Requirement Review.

INTEROPERABILITY, STANDARDS AND SECURITY ASPECTS OF MULTI-DOMAIN AUTONOMOUS/UNMANNED SYSTEMS

The Persistent Autonomous Reconfigurable Capability (PARC) project participates in the interoperability aspects, standardisation efforts and the security posture of multi-domain (maritime, air, land) autonomous and unmanned systems. CMRE's contributions extend to collaboration through NATO STO panel participation, collaboration with NATO Nations, NIAG studies and STANAG projects.

Mr. Gianfranco Arcieri, Mr. Thomas Furfaro, Dr. Francesco Baralli, Mr. Robert Been, STO CMRE

BACKGROUND

CMRE has developed a research project, PARC, that addresses some of the remaining barriers to the introduction of autonomous systems and their underlying technologies for maritime operations. A subset is discussed here: open architectures, interoperability (standards), mission assurance and V&V.

OBJECTIVES

With the help of a multi-disciplinary team of subject matter experts, the overall goal is to bridge three different elements:

- standardised Multi-Domain Control Systems (MDCS);
- standardised software payloads for maritime AUXV;
- AUXV security aspects, risk assessment, and cyber resilience.

This includes standardised "open" AUXV software payloads and generic AUXV security design elements as an exemplar of a STANAG-compliant architecture/software. In addition to input to STANAG 4817, PARC longer-term objectives include the creation of a standard for autonomous and unmanned system risk assessment.

S&T ACHIEVEMENTS

Contributions to the STANAG included updating use cases and identifying a pathfinder mission thread. In addition, the CMRE team has been working on a sample implementation of part of the STANAG based on their efforts relative to a service-oriented open architecture. This work will continue in 2019. Work in an STO Panel activity on "autonomy in communications-limited environments" included design and implementation aspects of a reference architecture for collaborating robots. Most of the work was on messages, data models and protocols through which the messages are delivered. A demonstration in simulation is envisioned for 2019 and will connect heterogeneous squads in an *ad-hoc* network for high-level task collaboration. Work on AUXV security included scoping activities of another Panel activity on Mission Assurance. PARC has attended and contributed to the Verification of Autonomous Systems Working Group (VASWG) and an STO group focusing on V&V for Autonomy.

SYNERGIES AND COMPLEMENTARITIES

PARC is an ACT project that provides expertise to NATO Nations, Industrial Advisory Groups, and STO Panel activities. It also supports and collaborates with other warfare areas. The closest collaboration is with the Mine Countermeasures team, in the field of collaborative autonomy, open (service-oriented) architectures and standardised software payloads. Since these are transversal activities, collaboration will be extended to Anti-Submarine Warfare (ASW) in 2019.

EXPLOITATION AND IMPACT

Findings have been disseminated to ACT and the NIAG. Since the project generates expertise on broad concepts for generic autonomous and unmanned systems, it provides useful insights and opportunities for exploitation. NATO Nations have expressed an interest in expanding the work on AUXV risk assessment and cyber resilience. Exploitation of the work within the European Union is foreseen.

Figure 25: MDCS STANAG 4817 logo.

CONCLUSIONS

PARC has contributed to the field of interoperability, standards and AUXV security aspects, disseminating knowledge towards NATO Nations, Study Groups and Panels. This work was funded by Allied Command Transformation.

NATO STO Programme of Work

DEVELOP

JOINT EXERCISE ON INFRA-RED SIGNATURE PREDICTION (AVT-232)

The accuracy Infra-Red signature model directly impacts electronic warfare self-protection, intelligence threat assessment, and signature management specifications and design. This activity provided a means to validate methods and understand the propagation of uncertainty from models and inputs through to operational decision-making.

Dr. Nigel Smith, AUS, DST Group, Department of Defence, and Dr. Martin Fair, GBR, Defence Science and Technology Laboratory (DSTL), Ministry of Defence.

BACKGROUND

Vehicles and weapons are sources of infra-red (IR) radiation – IR signatures are routinely used to detect, track and identify these systems. The accurate understanding and modelling of IR signatures is essential to the militaries of partner nations in meeting operational requirements for stealth, surveillance and electronic warfare survivability. This exercise established the understanding of the current state of validation and verification of IR signature prediction tools and identified capability gaps and uncertainties.

OBJECTIVE

The objective was to investigate key technical aspects of IR signature prediction for aerospace systems. The primary focus is on validation and verification of the techniques, and the sharing of best practice, algorithms, codes and supporting techniques.

S&T ACHIEVEMENTS

Quantitative test cases, from five partner nations, with corresponding blind predictions were employed to examine each element individually and in an overall sense. A validation methodology and signature prediction framework was articulated. Together, these concepts allowed for the identification of uncertainties in each model component, as well as the propagation of uncertainties through the end-to-end prediction process.

> *"A means to validate methods and understand the propagation of uncertainty from models and inputs through to operational decision-making."*

SYNERGIES AND COMPLEMENTARITIES

No one partner nation has had access to all the requisite test case data necessary to make a full assessment – different nations provided test cases specific to different model elements. The synergy of all these test cases and the subject matter experts from each nation has provided a rare opportunity to definitively assess the state-of-the-art of IR signature prediction and its impact on the military user. In order to gain useful inputs and deliver useful outputs, AVT-232 also established links with the NATO Air Capability Group 3/Sub Group 2/Threat Warning Tech Team; SET-211 on Naval Platform Protection in the EO/IR Domain; and AVT-251 on Multi-disciplinary design and performance assessment of effective, agile NATO air vehicles.

EXPLOITATION AND IMPACT

AVT-232 provided evidence of the validation status and uncertainties of IR signature prediction models, which impacts Doctrine and Materiel in the DOTMLPFI framework. Signature model confidence impacts military doctrine in susceptibility applications (EW protection measures) and threat modelling for intelligence applications. It impacts materiel in providing *a priori* methods to specify and design signature management requirements for military systems.

CONCLUSIONS

The test cases have been completed and compared to provide valuable input to each nation's subsequent code development programmes. A follow-on activity (AVT-281) is widening the scope of investigations to adopt a cross domain application of techniques as well as addressing shorter wavelengths too.

Figure 26: Modelling of IR-Signatures is key for system designs and detection methods.

USE OF BONDED JOINTS IN MILITARY APPLICATIONS (AVT-266)

With the increasing demand for lighter, stronger and more durable military systems, significant effort has been made to enable a wider application of adhesive bonded joints for both part manufacturing and repair of structural components on aircraft, land vehicles, space, protective armour, electronics and other military systems. This Specialist Meeting assessed the state-of-the-art of adhesively bonded joints with respect to design, fabrication, certification and failure analysis, and to identify the gaps for future work.

Dr. Lucy Li, CAN, National Research Council Canada, and Mr. Henri de Vries, NLD, Netherlands Aerospace Centre.

BACKGROUND

Use of adhesively bonded joints is regarded as one of the enabling technologies to enhance performance and reduce costs of military systems in all domains. Significant progress has been made in bonded joints in the areas of materials, design, processing, failure analysis, and maintenance. However, challenges remain to utilise bonded joints to their full potential to optimise military systems.

OBJECTIVES

This Specialist Meeting assessed the state-of-the-art of bonded joints, including bonded repair with respect to design, fabrication, certification and failure analysis. It identifies gaps and need for future research.

S&T ACHIEVEMENTS

The activity identified current usage and future needs of adhesive bonding for air, land and navy applications. Recent progress, technical challenges and gaps were addressed at this Specialist Meeting with an ultimate goal to optimise the military systems by taking full advantage of bonded joints. This activity focused on information exchange and fostering collaborations that could lead to technological progres. One main challenge identified was on certification of primary structures.

> "Billions of dollars are spent by commercial and military operators every year as a direct consequence of the unreliability, lack of maintainability and poor supportability of the systems they are expected to operate."
> Dinesh U. Kumar, *Reliability Maintenance and Logistic Support: A Life Cycle Approach*. Boston, MA: Kluwer Academic, 2000, 2.

SYNERGIES AND COMPLEMENTARITIES

If this activity leads to the formation of a task group, it is expected that mutual alliance could lead to faster technology development and maturity, which may not be possible otherwise, and reduced S&T time and budget.

EXPLOITATION AND IMPACT

This activity was expected for the participating nations to gain knowledge and experience in bonded joints that help optimise design, fabrication and maintenance of the military systems to enhance performance and reduce life cycle costs.

CONCLUSIONS

The outcome of the Specialist Meeting provided advice to NATO Nations on how to optimise the support of current systems and enhance the design, manufacturing, certification and maintenance of future systems.

Figure 27: Bonded Joints are already widely used in military systems.

DEVELOPMENT OF A DEPOSITORY FOR FAST AND RELIABLE DETECTION METHODS FOR ZOONOTIC AGENTS (HFM-230)

To enable fast and reliable identification of pathogens that could (or actually do) pose a danger to deployed troops, a standardised depository of available diagnostics in military/civil environment could be beneficial. This would also allow for the tracking of technical progress and the distribution of these data amongst NATO members.

Maj. Leen Wilmaerts, BEL, Military Hospital Queen Astrid Brussels, and Mrs. Christel Cochez, BEL, Military Hospital Queen Astrid Brussels.

BACKGROUND

A zoonosis is any infectious disease that can be transmitted from non-human animals, both wild and domestic, to humans. Zoonoses have been known since early historical times (*i.e.* plague, anthrax). Of the 1,415 pathogens known to affect humans, 61% are zoonotic. Given recent and regular outbreaks of (re-) emerging pathogens (*e.g.* Ebola, Lassa, Nipah, Hendra viruses, new Influenza strains, EHEC strains, some Salmonella strains), the interdisciplinary fields of human and veterinary medicine are already largely concerned with zoonosis. Features of zoonosis that make them of military interest include: their recurring emergence, their increased virulence in populations lacking immunity, and their ability to take the form of unrecognised diseases. Moreover, one of the major factors contributing to the appearance of new zoonotic pathogens in human populations is the increased contact between humans and wildlife.

OBJECTIVES

The RTG will define:

- depository of fast, reliable detection and identification methods for viral zoonoses;
- depository of fast, reliable detection and identification methods for bacterial zoonoses;
- charting existing pathogen collections/defining priority pathogens;
- outbreak alert communication;
- on-sight surveillance of priority pathogens.

S&T ACHIEVEMENTS

Priority lists for vector-borne and zoonotic bacteria, parasites and viruses were created *via* a comprehensive literature review and input from RTG country representatives. These priority lists were combined to one final master priority list. The group also summarised information on biosafety levels, sample collection and transport. An intensive review of available field and laboratory detection methods for the previously prioritized viruses, bacteria and parasites was accomplished.

SYNERGIES AND COMPLEMENTARITIES

History has repeatedly shown the importance of protecting the health of forces during military operations. Access to established surveillance systems such as EPINATO is necessary for medical personnel to make informed recommendations to the chain of command and support Commanders decisions. In addition, the reliance on and the confidence in different laboratory systems used by the various NATO member countries calls for a standardised platform whereby member laboratories can share data, discuss diagnostic protocols and exchange scientific information. Therefore, the development and installation of a laboratory network for near real-time surveillance is strongly recommended.

EXPLOITATION AND IMPACT

A major outcome was the comprehensive collection of detection methods for the selected important zoonotic and vector-borne pathogens. The work of the RTG HFM-230 members reflects efforts undertaken from 2012 to 2016. It is a live document that will require on-going revision by a future RTG as new diseases emerge and technology improves.

CONCLUSIONS

HFM-230 identified priority zoonotic and vector-borne pathogens, and compiled a consolidated list of fast and reliable detection methods for 81 of these pathogens. These methods were divided into "first line methods" not requiring a high-tech environment and "second line methods". As new diseases emerge, and technology improves, this work requires on-going revision by a future RTG.

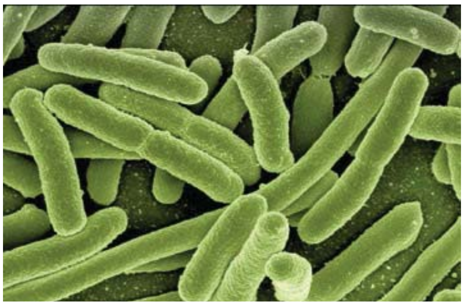


Figure 28: Bacillus, microorganism.

REFERENCE ARCHITECTURE FOR HUMAN BEHAVIOUR MODELLING (MSG-127)

Human Behaviour Models (HBM) are used to develop realistical simulation of human characters that can interact with Live players. This technology has broad applications, ranging from training for urban operations to decision support tools. MSG-127 has developed an initial approach to a Reference Architecture (RA) for HBM and makes recommendations for the way-ahead towards greater use and reuse of HBMs.

Dr. Thomas Alexander, DEU, Fraunhofer-Institut für Kommunikation, Informationsverarbeitung und Ergonomie (FKIE) and Mr. Wim Huiskamp (MSc), NLD, Netherlands Organisation for Applied Scientific Research (TNO).

BACKGROUND

Virtual humans should adequately model behaviour based on general human aspects (*e.g.* cognition, emotion, physiology) and cultural background. The behaviour should be validated and fit-for-purpose to meet the requirements for military applications. NATO STO military modelling, analysis and simulation communities would be well served by a standardised Reference Architecture for HBM that can facilitate model reuse and provide savings in time and resources for the development of particular training applications.

OBJECTIVE

The objective was to develop a Reference Architecture (RA) for human behaviour modelling of individual players intended for use in military training applications.

S&T ACHIEVEMENTS

MSG-127 investigated several use-cases to identify key behaviour factors including: physical properties (*e.g.* strength, endurance); cognitive properties (*e.g.* perception, reasoning); and social properties (*e.g.* cultural norms, role in social group). The relevance of a factor depends on the model's purpose. An initial RA concept was proposed to adequately represent behaviour for selected military training applications. Publications and presentations on the RA approach were made at the International Training and Education Conference (ITEC) and NATO Modelling and Simulation Group (NMSG) Symposia. These served to engage with the scientific and military community and initiate further development and validation in follow-on research.

"A common framework for HBMs will facilitate model reuse and information exchange, and ultimately provide savings in time and resources for the development of particular training applications."

SYNERGIES AND COMPLEMENTARITIES

The challenge in HBM is the integration of scientific based models, which reckon with parts of human behaviour, into complex military training settings. Exploration of the state-of-the-art in human behaviour modelling, architectures and implementations required a cross-disciplinary approach that involved NATO experts from HFM (Human view), NMSG (architectures and standards), academia and industry. The next phase of the development should include military training staff to support the validation of RA use-cases.

EXPLOITATION AND IMPACT

Given the increasing demand for realistic HBMs, there is a need for flexible and generic architectures that support behaviour generation across a diverse set of tasks and applications. A flexible architecture, as envisioned by MSG-127, allows for easy inclusion and exclusion of such factors in the development and use of HBMs.

CONCLUSIONS

MSG-127 has developed an initial approach to a RA for HBM and makes recommendations for the way-ahead towards greater use and reuse of HBMs. The successful collaboration between experts from different domains (HFM, NMSG) will continue in the context of the STO Thematic Approach to "AI and Big Data for Decision Support" and other activities.

Figure 29: Virtual Human Teamplayers (picture credit TNO).

MODELLING AND SIMULATION USE RISK IDENTIFICATION AND MANAGEMENT (MSG-139)

Models and simulations are developed and employed to provide technologies with the means to support a wide range of military and operational domains. As such, it is critical to understand where the Modelling & Simulation (M&S) should be applied with confidence, and where there are associated risks. MSG-139 focused on developing a methodology to identify, calculate, and manage M&S Use Risk.

Ms. Simone Youngblood, USA, The Johns Hopkins Applied Physics Lab.

BACKGROUND

The application of M&S has increased significantly in support of military operations, training and decision-making. This has lead to far-reaching ramifications to decisions informed by applying M&S results. M&S are abstractions of the real world and using M&S to inform decisions carries with it risk: namely, M&S Use Risk. This drives a critical need to efficiently and effectively analyse and assess this specific type of risk by applying a systematic M&S Use Risk Methodology. The methodology defined leverages the concepts of maximum information entropy. It establishes a disciplined and rigorous mathematical construct able to compute the underlying risks associated with the application of an M&S for an intended use.

OBJECTIVES

The MSG-139 objectives were two-fold. The first was to develop a systematic M&S Use Risk Methodology that provides quantitative and qualitative measures of risk associated with the application of the M&S. The second was a widely-applicable framework for M&S use risk identification and management.

S&T ACHIEVEMENTS

S&T achievements from MSG-139 include: providing widely applicable methods and guidance for M&S use risk identification; providing a set of methods and techniques for risk analysis; and defining use risk remediation solutions, as well as analysis solutions applicable to the various M&S technologies and system life-cycle paradigms.

SYNERGIES AND COMPLEMENTARITIES

MSG-139 was able to leverage verification and validation (V&V) products produced by several previous NATO tasks groups. Additionally, the M&S Use Risk Methodology built upon National research efforts that focused on developing both rigorous mathematical solutions for risk assessment and prototype applications centred on assessing the viability of resulting solutions.

EXPLOITATION AND IMPACT

Given the increasing importance and usage of M&S for military operations, training, acquisition and decision-making, the expected main impact of the MSG-139 activities is an internationally accepted technical framework that enables the identification and management of M&S Use Risk.

CONCLUSIONS

MSG-139 has developed a means to provide quantitative and qualitative measures of risk associated with the application of M&S to an intended use. The defined methodology informs users of existing M&S limitations that might lead to use risk, and further provides direction to remediate certain limitations.

The M&S Use Risk Methodology supports the simultaneous visualization of individual use risks. This can be used to understand the current overall M&S use risk, identify aspects that are the most problematic, and identify courses of action that provide the most significant buy-down of use risk.

Figure 30: Risk Identification and Management for Modelling and Simulation Applications

THE THRESHOLD CONCEPT FOR AND BY SMALL FORCES (SAS-131)

Conventional Threshold is a concept for analysing the different roles that armed forces in small states need to deter and defend against aggression. SAS-131 developed an analytical framework of six dimensions that small states forces need to consider. The concept can be used in defence planning to develop, analyse and assess alternative force configurations.

Dr. Jaan Murumets, EST, Estonian National Defence College, and Dr. Robert Dalsjo, SWE, Swedish Defence Research Agency.

BACKGROUND

Small states that need to deter or defend themselves against aggressive neighbours need armed forces in order to:

- force an aggressor to openly resort to the use of military force, thereby alerting allies that an act of aggression is under way;
- prevent an attacker from achieving their aims before a defence can be mounted or allies arrive;
- ensure that allied access to the small state is secured.

This is relevant for all nations with smaller forces relative to the threats they face. In this context, resource constraints make it necessary to explore new deterrence strategies and to identify the most effective and efficient options.

> What strategies or military concepts can smaller forces choose from and how can we design cost-effective force structures to deter an attacker?

OBJECTIVE

SAS-131 Activity was established to address the following problem: how does a smaller country make the threshold for a potential attacker as high as possible within the limits of affordability?

S&T ACHIEVEMENTS

A conceptual analysis of six possible dimensions of a threshold defence was presented. Participating Nations addressed the problem of the weak deterring the strong, highlighting the role of deterrence and resilience, and the importance of creating favourable conditions for allies and partners to provide assistance. To link the concept to policy-making and defence planning processes, SAS-131 utilised generic planning tools and developed an analytical framework of six distinct functions of threshold. They outlined two alternative threshold strategies to provide conventional deterrence, assessed these functions against the strategies, and developed findings on the strengths and weaknesses. The study shows that the concept of conventional threshold is applicable to Western defence planning methodology.

SYNERGIES AND COMPLEMENTARITIES

The two workshops brought together members from eight NATO and Partner Nations to leverage available expertise.

EXPLOITATION AND IMPACT

The SAS-131 report provides a summary of the framework and key findings, papers and presentations from the two workshops. The framework will assist Alliance long range capability planners in determining appropriate levels for defence capabilities.

CONCLUSIONS

The analysis conclusively showed that the Threshold Concept is applicable to the defence planning context and when using tools for defence planning, the Threshold Concept further facilitates the comparison of alternative force configurations.

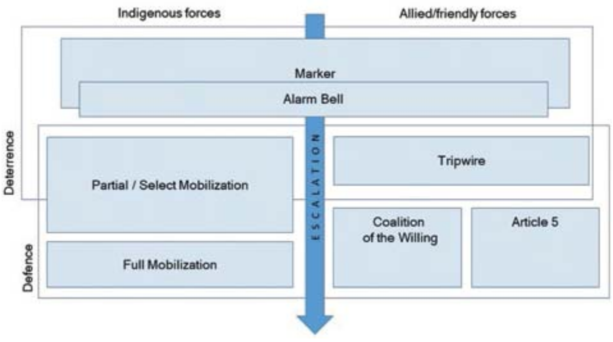


Figure 31: Graphic Representation of the Concept

GUIDELINES FOR TOXICITY TESTING OF SMOKES, OBSCURANTS, AND PYROTECHNIC MIXTURES (SCI-273)

The adoption of a "tiered approach" to carry out toxicological evaluation on new smokes and obscurants is recommended to assess their effects on human health. It further aims to minimise and even eliminate the use of animal models.

A three-tiered approach consists of the following: Tier I is a non-experimental approach towards risk assessment through computer modelling and analysis; Tier II is an approach utilising cell culture assays and chemical characterisation; and Tier III involves traditional toxicology testing in animal models.

Dr. Johannes Pieter Langenberg, NLD, Netherlands Organisation for Applied Scientific Research (TNO), Prins Maurits Laboratory, Dr. Robert Kristovich, USA, Army Research, Development & Engineering Command (RDECOM), Edgewood Chemical Biological Centre, Ms. Florence Hélène Fedou, FRA, Direction générale de l'Armement (DGA), Land Systems Division.

BACKGROUND

Camouflage, Concealment, Deception and Obscuration (CCDO) has historically played a key role in complex battlefields. The variety of missions entrusted to operational forces and the ubiquity of the threats of "Surveillance of the battlefield" require the development of adapted "Counter-Surveillance". Use of multispectral smokes or obscurants as decoy is a primary means to address such threat.

OBJECTIVES

The objectives for the SCI-273 Research Task Group (RTG) were to investigate the feasibility of developing a tiered guideline approach to measure the intrinsic properties of toxicity, and to assess the risk and human incidence in using pyrotechnics and obscurants.

S&T ACHIEVEMENTS

The RTG investigated technologies that assess human health risk; specifically, technologies with predictive codes and *in vitro* alternative models to replace *in vivo* tests. The RTG sought to develop a solid understanding of the emission products in smokes, and propose ways to assess the toxicity of mixtures.

SYNERGIES AND COMPLEMENTARITIES

SCI-273 succeeded the SCI-008 Exploratory Team (ET). The latter conducted three meetings in 2013 prior to graduating into an RTG in 2014.

EXPLOITATION AND IMPACT

SCI-273 generated a toxicological database that can be used to assess risk of exposure to new smoke and obscurant materials.

CONCLUSIONS

Assuming Occupational Exposure Level (OEL) threshold values are known and published for each component in the smoke, the following is possible:

- the health impact can be assessed by calculating the Hazard Quotient (HQ) for individual non-carcinogenic components;
- when non-carcinogenic components have the same toxic effects and/or the same target organ, their health impact can be assessed by calculating Hazard Index (HI);
- for carcinogenic components in smoke, the health impact can be assessed by calculating an excess cancer risk for users exposed to the smoke.

If toxicity data is not available, the smoke needs to be evaluated in Tier II or Tier III through *in vitro* or *in vivo* tests to perform the risk assessment.

Although decoys have their military merit, obscurants can present chemical and toxic risks towards humans.

Figure 32: Operational forces being exposed to smoke.

HIGH RESOLUTION LOW FREQUENCY SYNTHETIC APERTURE SONAR

To enhance detection, classification and identification of sea bottom mines, CMRE has developed an advanced 2D elements and individually drivable acoustic source array that works at low frequency. The output of the source array, which is an essential component for the realisation of a synthetic aperture sonar for Mine Countermeasure (MCM) operations, needs calibration.

Dr. Stefano Fioravanti, Dr. Yan Pailhas, Mr. Federico Aglietti, Mr. Alessandro Carta, Mr Domenico Galletti, Mr Alessandro. Sapienza, STO-CMRE

BACKGROUND

Conventional MCM sonar antennas, both synthetic and physical, work at high frequency to optimise the trade-off between range and resolution. Their output image describes the shape of the objects lying on the seafloor. A high-resolution low frequency synthetic aperture sonar (HRLFSAS) aims to provide similar image resolution with additional characteristics pertaining to the structures inside the objects, both on the seabed and buried in the sediment. The design of such a system requires the realisation of an advanced sound source completely characterised in terms of signal amplitude and phase.

OBJECTIVES

The experiment objectives were:

- to acquire relevant acoustic data with the new hardware;
- to measure the far field beam-pattern of the newly designed 2D fully independent drivable array;
- to assess the influence of multipath on image forming to evaluate the possibility of reducing the array size;
- to assess the performance of the transmitter array with different waveforms.

S&T ACHIEVEMENTS

The full 2D array has an uncommon number of independent channels, and a modular and scalable design. For the first time, the full transmitter array, powered by the new electronic housing, was tested in an open water environment and the far-field response of the array was gathered. A calibration of all single elements was carried out alongside the calibration of the full array. The sonar transmitter stayed in the water and operated flawlessly for two weeks in its new configuration. Output source level was tested up to a remarkable 215 dB/ref 1μPa at 1 m level.

SYNERGIES AND COMPLEMENTARITIES

The calibration of the 2D LFSAS transmitting array is required by the coherent SAS image forming algorithms to achieve the best resolution and to maintain the resonant features inherent to the parts inside the object under investigation.

EXPLOITATION AND IMPACT

The independently drivable acoustic 2D array is the basic component to build an advance HRLFSAS sonar. It will also allow innovative sonar system design such as spotlight SAS, multiresolution, and tomography approaches. The system modularity and scalability will allow the porting to unmanned platforms.

CONCLUSIONS

The HRLFSAS sonar system is a novel design that will allow future studies and innovative research. The transmitter provides ultra-wide bandwidth over carrier frequency capabilities, a modular and scalable design, scalable and efficient power requirements, versatile wave-synthesis capabilities, and high source levels.

Figure 33: HRLFSAS sonar transmitter, transducer element, and sonar driver electronics.

MARITIME ANOMALY DETECTION BASED ON IMPROVED LONG-TERM VESSEL PREDICTION

With the increasing availability of Automatic Identification System (AIS) data, advanced information-processing strategies detect deviations from standard routes, building on a programme of long-term vessel motion modelling for accurate prediction and compact representation of maritime traffic.

Ms. Enrica d'Afflisio, Dr. Nicola Forti, Mr. Leonardo M. Millefiori, Dr. Paolo Braca, STO-CMRE.

BACKGROUND

The detection of anomalous behaviour is key to Maritime Situational Awareness (MSA) and the guarantee of security at sea. Operators receive AIS satellite and terrestrial data from commercial and national providers in high volumes, intractable to human operators, which calls for a high degree of automation to convert data into usable knowledge.

OBJECTIVES

The aim is to develop algorithms to combine large volumes of AIS data with realistic dynamic models to understand better the behaviours and activities that have an impact on the maritime environment.

S&T ACHIEVEMENTS

CMRE developed an anomaly detection capability, tested on real-world AIS data. The capability detects anomalous kinematic behaviours by running statistical procedures[1,2], which process AIS streams and integrates all the available legacy data (*e.g.* radar). Filtering versions[3,4], for joint anomaly detection and tracking have been also developed. These strategies can handle data unavailability due to sensor coverage gaps, intentional disablements of AIS, and to unknown model parameters.

CMRE has recently developed an anomaly detection capability, tested on real-world data from vessel trajectories observed by the AIS.

[1] E. d'Afflisio, P. Braca, L. M. Millefiori, P. Willett, *Detecting stealth deviations from standard routes using the Ornstein-Uhlenbeck process*, IEEE Transactions on Signal Processing, 2018.

[2] E. d'Afflisio, P. Braca, L. M. Millefiori, P. Willett, *Maritime anomaly detection based on mean-reverting stochastic processes applied to a real worl scenario*, FUSION, 2018.

[3] N. Forti, L. M. Millefiori, P. Braca, *Hybrid Bernoulli filtering for detection and tracking of anomalous path deviations*, FUSION, 2018.

[4] N. Forti, L. M. Millefiori, P. Braca, *Anomaly detection and tracking based on mean-reverting processes with unknown parameters*, IEEE ICASSP, 2019.

SYNERGIES AND COMPLEMENTARITIES

The first Specialists' Meeting on MSA was held at CMRE in 2019. Additionaly, a session was held on anomaly detection at the 44th IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP) 2019. These events will promote the discussion between worldwide experts and identify follow-up research activities.

EXPLOITATION AND IMPACT

Driven by the growing availability of big maritime data, the potential of anomaly detection capabilities is huge. This opens up new possibilities for maritime border security organisations, as well as policy-makers and operational end users who represent the primary market sectors of MSA.

CONCLUSIONS

CMRE plays a key role in the development of maritime anomaly detection tools. These tools enable enhanced situational awareness of surface maritime traffic in support of operational planning and execution.

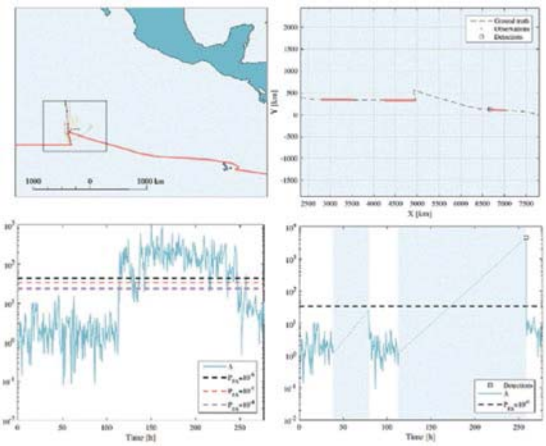


Figure 34: Effective and robust performance of the maritime anomaly detector with complete and incomplete AIS data.

AIS DATA DRIVEN MARITIME ROUTE FORECASTING

Long-term forecasting of vessel routes is a highly desirable capability for safety analysis and planning in maritime situational awareness (MSA). CMRE has developed learning algorithms that find trajectory patterns in recorded Automatic Identification System (AIS) messages and use these patterns to make long-term forecasts when queried with recent AIS transmissions from a vessel.

Dr. Murat Uney, Mr. Leonardo M. Millefiori, Dr. Paolo Braca, STO-CMRE.

BACKGROUND

AIS messages constitute an invaluable resource for understanding the global maritime traffic, which spans an overwhelming portion of the global economy: from cargo transportation in the international waters to strategic industrial operations such as offshore oil and natural gas operations. Current technology supports commercial data services that provide real-time global ship tracking capability in NATO member nations and large databases of past AIS messages. Exploitation of this data might facilitate interrelated capabilities including: forecasting vessel routes, automated monitoring of intent, and detection of suspicious behaviour such as deviations from initially intended routes and rendezvous, and data driven planning of maritime resources.

OBJECTIVES

The AIS data exploitation research at CMRE aims to enhance MSA by developing scientific theory for and practical demonstration of data driven traffic analysis and decision-making algorithms.

S&T ACHIEVEMENTS

CMRE has demonstrated AIS data driven maritime route forecasting capability using models and algorithms. A mathematical framework to generate an arbitrarily large number of trajectories mimicking the maritime traffic data underpins this capability. This generative model is used to specify algorithms that learn traffic patterns and exploit them to forecast future one when queried with streaming data (figure 35).

> "CMRE has demonstrated AIS data driven maritime route forecasting capability using models and algorithms."

SYNERGIES AND COMPLEMENTARITIES

The principles and results will be presented at IEEE ICASSP 2019[5] in a special session on anomaly detection and intent inference in object tracking.

[5] M. Uney, L. Millefiori, P. Braca, *Data driven vessel trajectory forecasting using stochastic generative models*, IEEE 44th International Conference on Acoustics, Speech, and, Signal Processing (ICASSP), 2019, to appear.

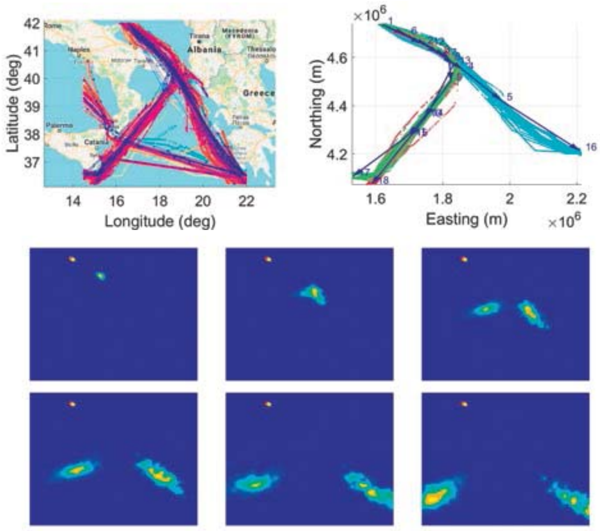


Figure 35: Data driven trajectory forecasting (a) AIS data and trajectory classes (b) Subgraph queried for trajectory forecasting (c) Querying trakectory and forecast densities from 20,000 seconds steps.

EXPLOITATION AND IMPACT

Industrialists have expressed interest in the research on AIS data exploitation in meetings such as the ISIF Fusion 2018 conference. AIS data service providers and data exploiters such as marine management organisations will seek to leverage their existing data services with CMRE algorithms and move beyond basic statistics based decision-making. The impact is likely to be complemented by its potential in aerospace applications, which is exemplified by a recent Alan Turing Institute UK data study group event on next-generation trajectory prediction for air traffic control hosted by the National Air Traffic Control Services UK[6].

CONCLUSIONS

AIS data driven route forecasting algorithms developed at CMRE enhances MSA by facilitating automated intent monitoring and detection of suspicious behaviour. The research outcomes should have a transformative impact on both maritime stakeholders and aerospace applications.

This work was funded by Allied Command Transformation.

[6] https://www.turing.ac.uk/events/data-study-group-december-2018

RADAR/AIS DATA FUSION FOR MARITIME SITUATIONAL AWARENESS

CMRE has developed a Bayesian multitarget tracking algorithm able to fuse data from multiple radar systems and the Automatic Identification System (AIS).

Dr. Domenico Gaglione, Dr. Giovanni Soldi, Mr. Leonardo M. Millefiori, Dr. Paolo Braca, STO-CMRE.

BACKGROUND

Maritime Situational Awareness (MSA), for which radar and AIS are complementary sources of information, aims to provide a seamless wide-area picture of ship traffic in coastal areas and the oceans in real time. AIS relies on the cooperation of vessels that can share their identity, position and motion information autonomously. However, not all the ships are obliged, or even willing, to provide this data. Conversely, radars are also capable of detecting and tracking ships that aim to conceal their presence or identity.

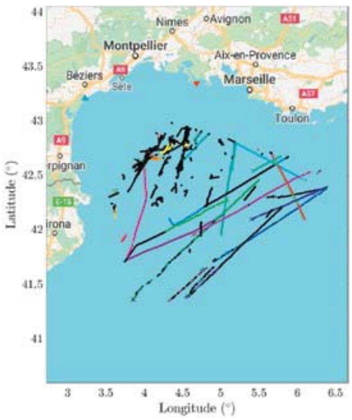


Figure 36: Estimated ship trajectories obtained with radar/AIS fusion by the tracking algorithm on sample data from the RANGER consortium.

OBJECTIVE

The objective is to fuse radar and AIS information efficiently in real time to generate a comprehensive picture required for search and rescue, fishery monitoring, pollution control, and national security.

S&T ACHIEVEMENTS

The fusion of radars and AIS data is not trivial because of the asynchronicity and scarcity of the messages. Uncertainty about the origin of the information represents another challenge, *i.e. a priori* it is unknown if a ship has been detected or missed by the radar or if it has generated any AIS message. Leveraging on the flexibility and scalability provided jointly by the factor graph representation and the Sum-Product Algorithm (SPA), CMRE has developed a Bayesian multitarget tracking algorithm to fuse data produced by multiple radars and the AIS[7,8]. The Bayesian statistical model overcomes these difficulties while the SPA solves the tracking problem with low computational complexity.

SYNERGIES AND COMPLEMENTARITIES

The findings of the proposed radar/AIS data fusion and tracking algorithm, developed in close collaboration with the Massachusetts Institute of Technology (MIT), have been passed to NATO's Allied Command Transformation (ACT), the customer. Furthermore, the method has been implemented and tested in a sea trial in the EU funded RANGER (RAdars for loNG distance maritime surveillancE and SaR operations) project in France in October 2018.

EXPLOITATION AND IMPACT

The SPA-based data fusion and tracking technique allows effective and efficient exploitation of data from radar and AIS. Furthermore, it can be integrated with an adaptive tracking algorithm previously developed by CMRE in order to provide the Alliance and individual nations with a complete MSA tool.

> CMRE has developed a scalable, efficient and effective data fusion algorithm capable of handling heterogeneous data provided by radars and AIS.

CONCLUSIONS

CMRE has developed a scalable, efficient and effective data fusion algorithm capable of handling heterogeneous data from radar and AIS to provide a complete tool for MSA.

[7] F. Meyer, T. Kropfreiter, J. Williams, R. Lau, F. Hlawatsch, P. Braca, M. Z. Win, *Message Passing Algorithms for Scalable Multitarget Tracking*, Proceedings of IEEE , 2018.

[8] D. Gaglione, P. Braca and G. Soldi, *Belief Propagation Based AIS/Radar Data Fusion for Multi-Target Tracking*, Proc. of the 21th International Conference on Information Fusion (FUSION 2018), Cambridge, 2018.

NATO STO Programme of Work

EXCELLENCE IN NATO SCIENCE AND TECHNOLOGY

EXCELLENCE IN NATO SCIENCE AND TECHNOLOGY

NATO recognises the value of S&T excellence within the Alliance. The key elements for evaluating scientific activities and individuals for recognition include: the quality of S&T, the breadth and depth of collaboration within NATO, and their potential impact and exploitation.

Every year, the Science and Technology Board (STB) grants NATO S&T awards: the von Kármán Medal and the Scientific Achievement Award (SAA). These landmarks of excellence are granted when the STB considers that appropriate candidates were nominated. The NATO Chief Scientist, as Chair of the STB, ceremonially recognises the awardees during the STB meeting at the Fall.

The von Kármán Medal is the most prestigious scientific and technological award. It is an individual award that recognises contributions to the STO Collaborative Program of Work or a single outstanding Science and Technology Organization (STO) achievement of the laureate. Exemplary service and significant contribution to the enhancement of progress in S&T collaboration among NATO member and partner nations within the STO are key. The medal is presented together with an accompanying certificate signed by the STB Chair.

Scientific Achievement Awards were instituted in 1989 to recognise outstanding contributions in the context of activities in aerospace science and technology or aerospace systems applications. Under the STO, this tradition continues to reward the best of the best across the broader scope of the STO's technological mandate. Candidates or teams, proposed by the Collaboration Support Office (CSO) Panels and Group and the Centre for Maritime Research and Experimentation (CMRE), must have made significant contributions to S&T activities sponsored by the organisation during the preceding four years. The SAA consists of a certificate signed by the STB Chair.

THE 2018 VON KÁRMÁN MEDAL WAS PRESENTED TO PROFESSOR DR. HÜSEYIN NAFIZ ALEMDAROĞLU.

He is a globally recognised expert in aerospace engineering, specialised in aerodynamics and thermo-fluid sciences. Throughout his exceptional career, he has exemplified the best of collaborative Science & Technology, with lasting international impact.

He first entered the NATO S&T community as a member of the Flight Vehicle Integration Panel in AGARD. He worked on the transition team to the NATO Research & Technology Organization (RTO), was an appointed expert to the Systems Concepts and Integration Panel (SCI) and was later elected as the Chair of SCI. He also served as a national member of the NATO Research & Technology Board (RTB) and the NATO Science & Technology Board (STB).

Over these decades of leadership responsibilities in NATO S&T, he worked fervently and maintained close engagement in ongoing research projects, participating in, mentoring and chairing numerous technical activities.

Most notably, he served as an eminent member of the Flight Test Technology Team (**FT3**), as the mentor of the Cooperative Demonstration of Technology (CDT) of Camouflage, Concealment and Deception, and as the Chair of the STB Symposium on Autonomous Systems.

Throughout his academic career as a professor in universities in Turkey and the United States, he systematically broadened the curricula for aeronautic engineers to study and incorporate space applications. In his work with NATO's flight test community, he expanded FT3's programme to include unmanned aerial vehicles and to develop Lecture Series and Symposia in order to further disseminate the community's knowledge.

Through his unwavering commitment to defence research, he paved the way to develop military capabilities at the cutting edge of technology. He is equally devoted to building the S&T capacity required to stay at the forefront of technology. As a dedicated teacher, he supervised more than 50 doctorate and master theses, inspiring many of his students to become active contributors in the NATO S&T community.

As a visionary leader and entrepreneur, he drew expertise from across NATO countries to support the establishment of the Turkish flight test centre and the refurbishment of the Ankara wind-tunnel. Thanks to his relentless efforts, both facilities today serve to develop military capabilities and provide training grounds for future researchers and engineers.

For his steadfast dedication and leadership within NATO Science & Technology, and his remarkable contributions to the S&T Community, we hereby recognise Professor Dr. Hüseyin Nafiz Alemdaroğlu for his exemplary work by presenting him with the 2018 von Kármán Medal.

DR. DONALD LEWIS distinguished himself as a member of the Systems, Concepts and Integration (SCI) Panel by entering the Science and Technology Organization (STO) community in 2010 as the first Member-at-Large (MaL) for space-related scientific discovery. From the start, Dr. Lewis has ceaselessly applied his talents toward establishing a space savvy community of technologists aligned with the vision of Theodore von Kármán, who sought to synergistically enhance the understanding of cross-domain warfare amongst warfighting professionals within the Alliance.

Dr. Lewis' first point of order as space MaL was to launch an investigation that assessed the dependencies of the NATO alliance on space capabilities. Following the assessment, a space program-of-work (PoW) took root. To date, fifteen STO activities have come to realisation. Similarly, Dr. Lewis has collaborated with NATO Allied Command Transformation (ACT) to advance a PoW for the preservation of space capabilities Long-term Capability Requirement (LTCR). Similarly, his influence extended even further as he provided counsel to NATO military committee staff and NATO Air Force Armaments Group (NAFAG) leadership on an initiative to establish a Joint Team of Experts on Space (JToES). The overall aim of the JToES is to advise NAFAG on multi-national cooperation of interoperable national military Space Services in order to improve NATO forces effectiveness in support of current and future operations.

Since 2011, Dr. Lewis has represented NATO-STO equities as an affiliate member of the NATO Bilateral-Strategic Command (Bi-SC) Space Working Group (SWG). He deftly bridged the critical divide between NATO's Science & Technology (S&T) community and the space operations community by recruiting non-technical NATO space operators to participate in STO space-related activities. These activities then provided more military-relevant context and promoted a broader networking opportunity. Subsequently, STO has a standing role within the Bi-SC SWG, which enabled its participation in the Trident Javelin (TRJN) series of command post exercises.

Concurrently, Dr. Lewis' sage leadership birthed the concept and definition for Space Domain Awareness (SDA). As a result, the concept and definition are now "officially" used by the NATO S&T and space operations communities. As a sign of scientific progress, the conceptual has become the actual. Planning for injecting SDA into the TRJN exercises commenced in 2017 as Dr. Lewis provided technical counsel on-site as a member of the Exercise Control (EXCON) space response cell to the NATO Joint Warfare Centre (JWC) in Stavanger, Norway.

In recognition of outstanding work and significant scientific contribution, the Science and Technology Board (STB) recognised Dr. Donald Lewis for his exemplary work by presenting him the 2018 Science and Technology Scientific Achievement Award.

PROF. ING. FULVIA QUAGLIOTTI actively conducted collaborative research par excellence on behalf of Italy for three decades. As a Panel Member on NATO's Science and Technology Organizations (STO) Systems Concepts and Integration (SCI) and Applied Vehicle Technology (AVT) Panels, she took over leadership as SCI Vice-Chair and was the acting Italian Principal Panel Member for AVT. During this time, she acted as panel mentor, activity chair, technical team member and program committee member in numerous NATO activities. She also made significant contributions to NATO's S&T capabilities in the field of autonomous unmanned aerial systems (UAS).

Since the start of her career with NATO Science and Technology activities, Prof. Ing. Quagliotti actively contributed to five internationally well-recognised research symposia in Unmanned Aerial System requirements. As a panel mentor, she was a tireless advocate of her activities as well as an excellent communicator between young scientists and the established NATO S&T community. As a champion in micro- and mini-unmanned aerial vehicles, Prof. Ing. Quagliotti successfully implemented a number of forward-looking activities that will change the way the Alliance will utilise their potential. One of these activities resulted in a risk-based safety assessment of operational airworthiness and certification, which has high interest for civil and military operations, and was initiated by a specialists' meeting she chaired.

Prof. Ing. Quagliotti's tremendous commitment to the NATO Science and Technology community is evident in her ability to organise an AVT scientific conference with about 500 international participants after her retirement.

In recognition of her outstanding work and significant scientific contribution, we hereby present the 2018 Science and Technology Scientific Achievement Award to Prof. Ing. Fulvia Quagliotti.

**CAPTAIN (BGR-N)
PROF. DR. SC. YANTSISLAV YANAKIEV** has been a principal national representative to the NATO Science and Technology Organization, Human Factors and Medicine Panel since 2005. In this time, he has been active as panel mentor, chair of exploratory teams and research task groups, member of the programme committees of research symposia and workshops and lecture series director. He contributed significantly to NATO S&T priorities in the areas of cultural, social and organisational behaviours and advanced human performance and health.

In 2007-2011, Prof. Yanakiev chaired the Research Task Group on "Improving the Organisational Effectiveness of Coalition Operations". Furthermore, in 2013, he was appointed as HFM-232 Lecture Series Director, organising sessions in Sofia (Bulgaria), Brussels (Belgium) and Patrick AFB (USA). The research findings were published both by NATO STO and in peer-reviewed scientific journals. They could be used to improve military training and the organisation of coalition teams.

Another key area of Prof. Yanakiev's research and teaching activities is related to diversity management and cross-cultural competence (3C) building in defence organisations. In 2012-2013, he was a Fulbright Senior Visiting Scholar at the Defence Equal Opportunity Management Institute (DEOMI), at Patrick AFB (USA). The outcomes of the research are instrumental to the education and training of NATO military members to work in culturally diverse environments.

Most recently, Prof. Yanakiev was the co-chair of the Research Task Group "Human Systems Integration Approach to Cyber Security". The group organised a workshop "Integrated Approach to Cyber Defence: Human in the Loop" held in Sofia (Bulgaria) earlier this year.

The significant scientific accomplishments of Prof. Yanakiev prove his respectable ability to establish cooperation in multinational teams, both in the framework of NATO STO and broader inter-NATO bodies.

In recognition of the outstanding work and significant scientific contribution, we hereby present the 2018 Science and Technology Scientific Achievement Award to CAPT (BGR-N) Prof. Dr. Sc. Yantsislav Yanakiev.

SERVICE ORIENTED ARCHITECTURE (SOA) RECOMMENDATIONS FOR DISADVANTAGED GRIDS IN THE TACTICAL DOMAIN (IST-118)

"Service Oriented Architecture (SOA) can enable agile C2 functionality. The flexibility and loose coupling offered by the SOA paradigm means that both NATO and many member nations can base their future information infrastructures on this paradigm." Peter-Paul Meiler, TNO, NLD.

Mr. Peter-Paul Meiler, NLD, Netherlands Organisation for Applied Scientific Research (TNO), Ms. Trude H. Bloebaum and Dr. Frank T. Johnsen, NOR, Norwegian Defence Research Establishment (FFI).

BACKGROUND

The Service Oriented Architecture (SOA) paradigm has been chosen by the NATO C3 Board as the method to achieve interoperability at the information infrastructure level. The current technologies used to implement SOA (*e.g.* Web services, which is our focus) were not specifically designed to handle the conditions found when working with tactical networks. This fact remains a major impediment to achieving interoperability among the nations in the battlespace.

OBJECTIVE

This Task Group's primary objective was to identify improvements and demonstrate how to make SOA applicable at the tactical level, which typically includes communication over disadvantaged grids. These disadvantaged grids are characterised by low bandwidth, variable throughput, unreliable connectivity, and energy constraints imposed by the wireless communications grid that links the nodes. The group has successfully achieved their goal; the work was completed with a series of demonstrations of military systems working using SOA over disadvantaged grids. In doing so, it leaves a positive legacy for NATO and the nations.

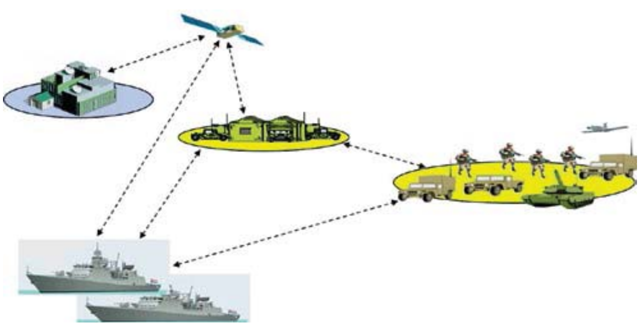


Figure 37: SOA Profile.

EXPLOITATION AND IMPACT

The availability of SOA at the tactical level can (partly) remove the need to develop and implement separate HQ and tactical versions of the same functionalities. In turn, this reduces the cost of both the research and development, as well as training. Tighter integration of the HQ and battlefield C2 and simplified multi-national collaboration will in turn increase military response times and actually delivered firepower.

SYNERGIES AND COMPLEMENTARIES

The work of IST-118 was performed in synergy with SOA-related specification and profiling work done as part of other NATO efforts such as Network Enabled Capabilities (NEC) and Federated Mission Networking (FMN). IST-118 reached its goal of involving the NATO and academic research community by publishing papers, presenting at conferences and providing demonstrations.

CONCLUSIONS

IST-118 provides guidance on which technical modifications should be used in across several different types of disadvantaged grids that are used by NATO member states. IST-118 builds on the findings by IST-090, which demonstrated that SOA can work better in disadvantaged conditions than previously thought. IST-090 also identified SOA challenges for real time and disadvantaged grids, and suggested technical modifications that can be used to overcome those challenges.

The work focused on generating concrete recommendations for a subset of the core services from the NATO C3 Taxonomy, based on systematic testing and evaluation, rather than providing higher level recommendations for a wider set of services. This ensures that their work can have a direct impact on NATO operations.

REALISING CLOUD-BASED MODELLING AND SIMULATION AS A SERVICE (MSG-136)

Modelling and Simulation (M&S) is a critical capability for NATO. It is essential that M&S products, data and processes are conveniently accessible to a large number of users whenever and wherever required. M&S as a Service (MSaaS) combines service orientation and the as-a-service delivery model of cloud computing to enable more composable simulation environments that can be deployed and executed on-demand.

Dr. Robert Siegfried, DEU, aditerna GmbH, Mr. Tom van den Berg, NLD, Netherlands Organisation for Applied Scientific Research TNO.

BACKGROUND

NATO and partners extensively use simulations for various purposes (*e.g.* training, mission rehearsal, or decision support). Improving efficiency in simulation use and better utilisation of valuable simulation resources is critical to sustain the asymmetrical advantage that simulation provides to NATO. M&S as a Service and Cloud-Based M&S impacts all future simulation environments and acquisition programs.

OBJECTIVES

The objective is to investigate, propose and evaluate standards, agreements, architectures, implementations, and cost-benefit analysis of MSaaS approaches.

> "Modelling and Simulation as a Service is a concept that will make models and simulations available in an easier and more flexible way for users across the world." (Brigadier General Henrik Sommer, NATO Allied Command Transformation, I/ITSEC 2017).

S&T ACHIEVEMENTS

MSG-136 developed unique techniques for deploying and executing simulation applications that did not exist before. Through innovative combination of techniques (*e.g.* containers, virtualisation, web standards, cloud computing technologies) and operational procedures, a whole new eco-system for simulation applications was developed.

Figure 39: "Modelling and Simulation as a Service Logo"

Figure 38: MSaaS supported exercise Viking 18 and will support next Viking exercise (probably 2021)

SYNERGIES AND COMPLEMENTARITIES

MSG-136 successfully brought together more than 120 subject matter experts from 16 nations (including partner nations) and 6 NATO bodies. MSG-136 conducted 10 face-to-face meetings and held more than 70 web meetings were held to synchronise task group members, track progress and discuss the various S&T topics. MSG-136 established pooling and sharing of M&S resources (simulation systems, terrain data sets, etc.).

EXPLOITATION AND IMPACT

MSG-136 efforts resulted in 7 peer-reviewed journal publications, 10 special events, 35 conference papers and a promotional MSaaS video clip. Major simulation programs around the globe have aligned efforts and work towards the goal of "interoperability by design". Nations save resource thanks to pooling and sharing of M&S resources. It will be extended in the follow-on activity MSG-164.

CONCLUSIONS

MSG-136 was a flagship activity for the NATO Modelling and Simulation Group (NMSG). It investigated, proposed and evaluated standards, agreements, architectures, implementations, and cost-benefit analysis of Modelling and Simulation as a Service. MSG-136 defined MSaaS in the NATO context and developed operational, technical and governance concepts for establishing the "Allied Framework for MSaaS". MSG-136 conducted significant experimentation activities to validate the concepts. An extensive outreach and dissemination program around the world informed stakeholders and decision-makers in government, industry and academia. Over its lifetime, MSG-136 was recognised as global thought leader and pacemaker in this area.

INTELLIGENCE EXPLOITATION OF SOCIAL MEDIA: EXPLOIT SOCIAL MEDIA BEFORE THE BULLETS FLY – (SAS-IST-102)

Social Media (SM) continues to evolve and is now a powerful weapon in hybrid warfare. SAS-IST-102 studied the exploitation of SM for intelligence (INT) to counter its effect. It examined monitoring, methods and algorithms, and covered sense-making, validity, veracity and bias, and deception. Finally, it provides practical examples to make it applicable for NATO.

Dr. Bruce Forrester, CAN, Defence Research and Development Canada (DRDC).

BACKGROUND

How do military organisations exploit SM? Understanding the complex nature and potential uses of SM is the starting point. Many signals exist within SM that precede enemy action. Intelligence can tap into the first phase of the Organise, Recruit, Plan, and Act cycle that is needed to carry out attacks. Gaining actionable INT during the Organise phase is the best place to intervene in potential violence – "before the bullets fly".

OBJECTIVES

The objectives were to determine rational and effective ways of exploiting SM as a source for INT and to investigate potentially relevant methods and tools for INT.

S&T ACHIEVEMENTS

SAS-IST-102 defined SM uses for INT and differentiated SM from traditional Open-Source INT (OSINT) use. Using a design methodology, they conducted research through real-world exploitation of SM. They examined theoretical and methodological considerations to produce a practical understanding of the nature of SM data and associated challenges. This allowed for genuine progress as many nations went from having no knowledge in this space to being able to produce actionable INT. The team communicated their results through numerous publications, conferences, and presentations.

SYNERGIES AND COMPLEMENTARITIES

SAS-IST-102 created a strong synergy between OSINT practitioners and defence scientists, involving 2 CSO panels, 17 NATO countries plus Sweden, and 5 NATO organisations. Given that all entities faced the same challenges with respect to SM exploitation, and an authentic desire to share, the community grew together and reached an ability to use SM source for INT.

EXPLOITATION AND IMPACT

Many NATO countries have built their SM INT policies and capabilities based on the work of this RTG. Actionable INT reports and policy have already been produced by participating countries using the knowledge and experience of the RTG. The real-world case studies along with the "How-to guide" on monitoring, filtering, collection, analysis, and estimation will allow other partners to follow suit. Methods and techniques developed can also be used to monitor and discover fake news, propaganda and deception.

CONCLUSIONS

SAS-IST-102 was the first team to study SM for INT exploitation. Practitioners and scientists worked together to unravel the complexities and produced practical knowledge important to INT analysts. The results have already provided both NATO and the nations valuable tools and insight to build a SM exploitation capacity and to improve their INT capabilities.

Figure 40: Typical propaganda type tweet. (Source: Twitter 2017.)

Figure 41: One tool for analysing tweets. (Source: Forrester B. 2017.)

JANUS: THE FIRST DIGITAL UNDERWATER COMMUNICATIONS STANDARD

NATO Nations recently agreed that JANUS is the NATO Standard for digital underwater, opening the wayfor interoperable machine-to-machine underwater operations.

Mr. João Alves, STO-CMRE

BACKGROUND

Underwater communication capabilities have always faced the hurdle of interoperability. Until recently, manufacturers of underwater communications equipment didn't have a common "language" that could serve the purpose of standardised, universal data exchange. This meant that capabilities were necessarily manufacturer dependent and therefore scalable, interoperable and ad-hoc underwater networking was not practicable.

OBJECTIVES

To fill this gap, CMRE, together with its collaborators from the Nations, academia and industry, has developed JANUS, an underwater digital Modulation and Coding Scheme, that can now be used as a common format to announce a presence, exchange low volumes of data, and create an ad-hoc network.

S&T ACHIEVEMENTS

Following 10 years of research, development, experimentation and collaboration, JANUS was recognised as a NATO standard (STANAG 4748) by all NATO Allies on March 24th 2017. This marks the first time that a digital underwater communication protocol has been acknowledged at international level and opens the way to develop many exciting underwater communication applications. JANUS is also a different kind of standard: It was designed to not override the efforts being made within the nations and industry but rather to provide the means for their co-existence. The technical specification of JANUS (ANEP87) is available from the NSO website without any classification marking and example implementation code can be obtained from the JANUS wiki (www.januswiki.org)

SYNERGIES AND COMPLEMENTARITIES

CMRE led the JANUS development effort that included the input of industry and academia. Coordination was achieved via community meetings held at CMRE, online discussions via a dedicated wiki page, international conferences and workshops. The strong commitment from Nations like DEU, NOR, NLD, USA and PRT, with their operational expertise, scientific background, and experimental commitment was decisive to achieve such ambitious goal. In 2014 NATO setup an Industrial Advisory Group (NIAG) that delivered a report focusing on JANUS application scenarios, future JANUS revisions (including improvements and new frequency bands) and definitions for compliance of JANUS equipment. The study included experts from DEU, ITA, NLD, NOR, PRT, ESP, TUR, GBR and USA. In 2016 CMRE started a close engagement with the International Submarine Escape and Rescue Liaison Office (ISMERLO) and the Submarine Escape and Rescue Working Group (SMERWG) that eventually led to an operational experimentation activity during the NATO exercise Dynamic Monarch 2017.

EXPLOITATION AND IMPACT

One specific area where JANUS can have an almost immediate impact in submarine rescue operations. Currently, communications during rescue operations are performed solely with the analogue underwater telephone. This has the clear problem of needing an operator (that may be required for other equally critical tasks) to handle the communications on the submarine side. By employing JANUS for rescue communications, automation may be introduced, with the on-board systems transmitting critical data in case of distress. Additionally, the use of interoperable underwater digital communications in rescue scenarios opens the way for radically different concepts of operation where information is more rapidly and readily available and where personnel may not be required for data exchange, paving the ground for the seamless employment of unmanned vehicles.

CONCLUSIONS

JANUS is the first-ever digital underwater communications standard. It is open and free for use by military and civilian operators, opening the way for critical underwater communications interoperability. The pressing requirement for cost-effective underwater surveillance requires an enabling underwater communications capability where equipment from different manufacturers can be used to establish networks. JANUS is able, for the first time, to provide a solution for the underwater interoperability barrier contributing also to de-risk the Nation's procurement programs by reducing the dependence on individual manufacturers.

Figure 42: Use of JANUS off TUR in Exercise DYNAMIC MONARCH 2017.

Annexes

ANNEX A – STO PoW ACTIVITIES/DISTRIBUTION

Provided below are graphs and charts detailing the STO's PoW activities/distribution for both the CSO and CMRE.

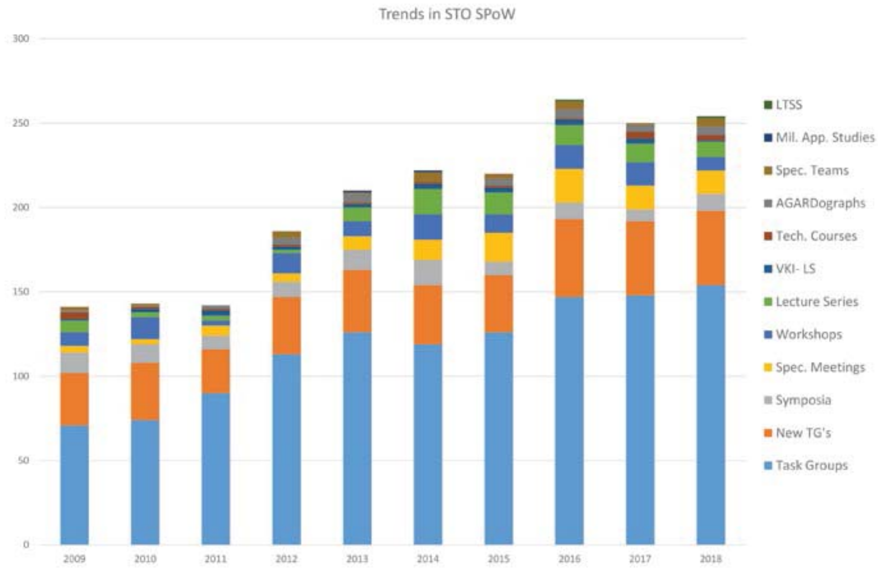


Figure 43: 2018 Trends in STO CPoW.

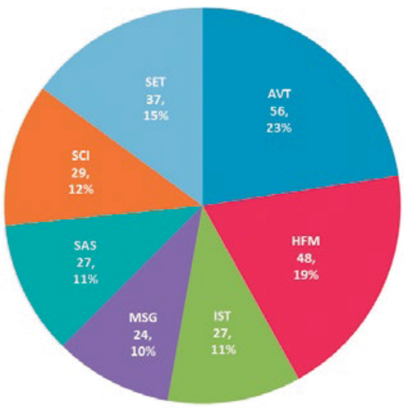


Figure 44: Distribution and number of activities for each panel and group, including all types of activities (task groups, workshops, lecture series…).

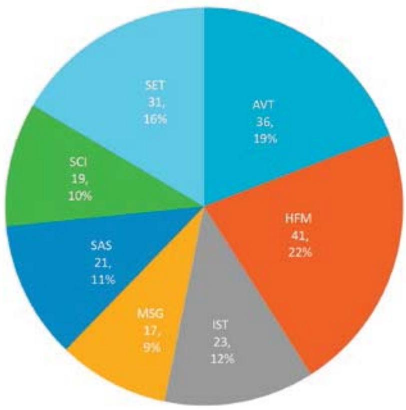


Figure 45: 2018 Number of STO CPoW RTGs per panel and group.

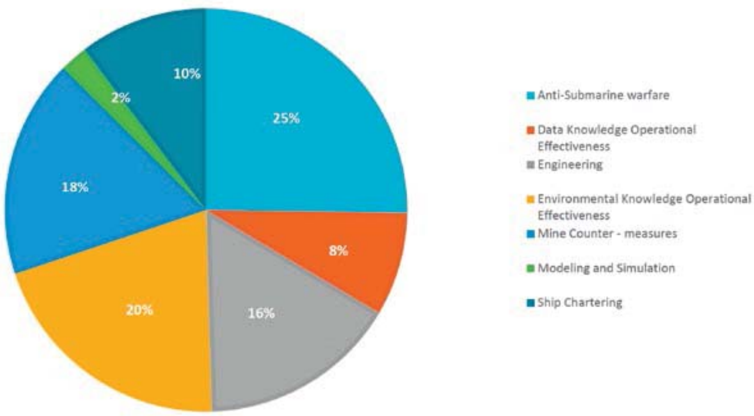


Figure 46: 2018 distribution of activities over the STO CMRE PoW.

ANNEX B – LIST OF ACRONYMS

24/7	24 hours a day / 7 days a week
2D	Two-Dimensional
3C	Cross-culture competence
3D	Three-Dimensional
A2/AD	Anti-Access and Area Denial
ACT	Allied Command Transformation
AF	Air Force
AFB	Air Force Base
AFSC	Alliance Future Surveillance and Control
AI	Artificial Intelligence
AIS	Automatic Identification System
AmphibOps	Amphibious Operations
AMSP	Allied Modelling and Simulation Publication
ANEP	Allied Naval Engineering Publication
ANMCM	Autonomous Naval Mine CounterMeasures
ASM	Anti-Ship Missile
ASW	Anti-Submarine Warfare
ATR	Automatic Target Recognition
AUS	Australia
AutoLARS	Autonomous Launch And Recovery System
AUV	Autonomous Underwater Vehicle
AVT	Applied Vehicle Technology
AWACS	Airborne Warning And Control System
AWWCG	Above Water Warfare Capability Group
BBC	British Broadcasting Corporation
BEL	Belgium (or Belgian)
BioMedAC	Biological Medical Panel (COMEDS)
Bi-SC	Bilateral-Strategic Command
BSL	Brillouin Scattering Lidar
C2	Command and Control
C2-DS	Command and Control – Decision Systems
C3	Command, Control, Communications
C4	Command, Control, Communications and Computers
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CAD	Computer-Aided Design
CAN	Canada
CaT	Architecture Capability Team (NC3B)
CAX	Computer-Assisted eXercise
CBRN	Chemical, Biological, Radiological and Nuclear
CCDO	Camouflage, Concealment, Deception and Obscuration
CD&E	Concept Development and Experimentation
Cdr	Commander
CDT	Co-operative Demonstration of Technology
C-IED	Counter Improvised Explosive Device
CMRE	Centre for Maritime Research and Experimentation
CNAD	Conference of National Armaments Directors
CO	Commanding Officer
CoE	Centre of Excellence
CoI	Community of Interest
COL	Colonel
COMEDS	Committee of the Chiefs of Military Medical Services
CONOPS	Concept of Operations
COP	Common Operational Picture
CPoW	Collaborative Programme of Work
CRV	Coastal Research Vessel
CS	Compressive Sensing
CSO	Collaboration Support Office
CT&E	Collective Training and Exercise
CWIX	Coalition Warrior Interoperability exploration, experimentation and examination eXercise
D-CAF	Decoupled Collaborative Autonomy Framework
DDS	Data Distribution Service
DEAR	Directed Energy At Radio (frequencies)
DETOUR	DMPAR Evaluation Trials for Operationally Upgraded Radar

DEU	Germany
DEW	Directed-Energy Weapon
DI	Defence Investment
DMPAR	Deployable Multi-band Passive/ Active Radar
DMS	Discovery Metadata Specification
DND	Department of National Defence (CAN)
DNK	Denmark
DoD	Department of Defense (USA)
DoI	Declaration of Intent
DOTMLPFI	Doctrine, Organisation, Training, Material, Leadership, Personnel, Facilities and Interoperability
DPCS	Defence Planning Capability Survey
DRDC	Defence Research and Development Canada
DRG	Defence Research Group
DSEEP	Distributed Simulation Engineering and Execution Process
DSM	Dynamic Spectrum Management
DSTL	Defence Science and Technology Laboratory
EC	European Commission
ECM	Electronic Countermeasures
EDA	European Defence Agency
EO	Electro-Optical
EOP	Enhanced Opportunities Partner
ESA	European Space Agency
ESC	Emerging Security Challenges
ESM	Electronic Support Measure
ESP	Spain
ET	Exploratory Team
EU	European Union
EW	Electronic Warfare
EXCON	Exercice Control
FFAO	Framework for Future Allied Operations
FL	Florida (USA)
FMN	Federated Mission Networking
FOM	Federation Object Model
FRA	France
FT3	Flight Test Technology Team
GBR	Great Britain
GDP	Gross Domestic Product
GE/NL	Germany/Netherlands
Gen	General
GEOMETOC	Geographic, Meteorological and Oceanographic
GHz	Gigahertz
GNC	German/Dutch Corps
HBM	Human Behaviour Modelling
HFM	Human Factors and Medicine
HI	Hazard Index
HLA	High-Level Architecture
HPM	High-Power Microwave
HQ	Headquarters
HQ	Hazard Quotient
HRLFSAS	High-Resolution Low Frequency Synthetic Aperture Sonar
HW	Hybrid Warfare
I&W	Indication and Warning
I/ITSEC	Interservice/Industry Training, Simulation, and Education Conference
IH2	Integrated Health and Healing
IMHM	Integrated Munitions Health Management
In-ISAR	Interferometric Inverse Synthetic Aperture Radar
IPOE	Initial Preparation of Operating Environments
IR	Infra-Red
ISAF	International Security Assistance Force
ISAR	Inverse Synthetic Aperture Radar
IS-DI	International Staff – Defence Investment
ISEG	Independent Scientific Evaluation Group (SPS)
ISMERLO	International Submarine Escape and Rescue Liaison Office
ISR	Intelligence, Surveillance and Reconnaissance
IST	Information Systems Technology
ITA	Italy
ITU	International Telecommunication Union
JFTC	Joint Force Training Centre
JIP LAURA	Joint Industry Project on Launch and Recovery of Autonomous (systems)

JWC	Joint Warfare Centre
km	kilometre
LIME	Local Inventory Metadata Engine
LOGMEC	Long-Term Glider Missions for Environmental Characterisation
LRTC	Least Restrictive Technical Condition
LS	Lecture Series
LTCR	Long-Term Capability Requirement
M&S	Modelling and Simulation
MAF	Maritime Autonomy Framework
MaL	Member-at-Large
MANEX	Multi-national Autonomous Experiment
MARCOM	Maritime Command
MC	Military Committee
MBSE	Model Based Systems Engineering
MCCIS	Maritime Command and Control Information System
MCDC	Multi-National Capability Development Campaign
MCM	Mine CounterMeasures
MCMV	Mine CounterMeasures Vessel
MCR	Minimum Capability Requirement
MD	Medical Doctor
MD	Mediterranean Dialogue
MDCS	Multi-Domain Control Station
MDO	Multidisciplinary Design Optimisation
MESAS	Modelling and Simulation of Autonomous Systems
METOC	Meteorological and Oceanographic
MGen	Major General
MIMO	Multiple Input, Multiple Output
MoU	Memorandum of Understanding
MS3	M&S Standards Sub-Group
MSA	Maritime Situational Awareness
MSaaS	Modelling and Simulation as a Service
MSTPA	Multistatic Tactical Planning Aid
MUSCLE	Mine-hunting UUV for Shallow-water Covert Littoral Expeditions
NAAG	NATO Army Armaments Group
NAC	North Atlantic Council
NAF	NATO Architectural Framework
NAFAG	NATO Air Force Armaments Group
NASMDEF	NATO Anti-Ship Missile Defence Evaluation Facility
NATO	North Atlantic Treaty Organization
NC3B	NATO Consultation, Command and Control Board
NCIA	NATO Communications and Information Agency
NCTI	Non Co-operative Target Identification
NCTR	Non Co-operative Target Recognition
NDPP	NATO Defence Planning Process
NEC	Network Enabled Capabilities
NEMO	Naval Electro Magnetic Operation
NETN	NATO Education and Training Network
NIAG	NATO Industrial Advisory Group
NLD	Netherlands
NLW	Non Lethal Weapon
NMSG	NATO Modelling and Simulation Group
NMSMP	NATO M&S Master Plan
NMW	Naval Mine Warfare
NNAG	NATO Naval Armaments Group
NOAA	National Oceanographic and Atmospheric Administration
NOR	Norway
NRV	NATO Research Vessel
NS	NATO SECRET
NSC	NATO Shipping Centre
NSO	NATO Standardisation Office
NSPA NATO	Support and Procurement Agency
NSRL	NATO Simulation Resource Library
NRV	NATO Research Vessel
NTP	NATO Terminology Programme
OCS	Office of the Chief Scientist
OEL	Occupational Exposure Level
OGC	Open Geospatial Consortium
OODA	Observe, Orient, Decide and Act
OPEX	Operational Experimentation
Ops	Operations
OR&A	Operational Research and Analysis
OSINT	Open Source Intelligence
PA	Parliamentary Assembly

PARC	Persistent Autonomous Reconfigurable Capability
PCL	Passive Coherent Location
PfP	Partnership for Peace
PoL	Pattern of Life
POMDPs	Partially Observable Markov Decision Process
PoW	Programme of Work
PRT	Portugal
QIA	Quality of Interaction Assessment
RA	Reference Architecture
RAPS	Rapid Prediction Acoustic Service
R&D	Research and Development
RAdm	Rear Admiral
RDT&E	Research Development Test and Evaluation
REM	Radio Environment Map
ret	Retired
RF	Radio Frequency
RFDEW	Radio Frequency Directed-Energy Weapon
RFW	Radio Frequency Weapon
RLS	Research Lecture Series
ROS	Robotic Operating System
ROSA	Romanian Space Agency
RSM	Research Specialists' Meeting
RTG	Research Task Group
S&T	Science and Technology
S4	SG/2 Shareable Software Suite
SAA	Scientific Achievement Award
SACT	Supreme Allied Commander Transformation
SAR	Synthetic Aperture Radar
SAS	Systems Analysis and Studies
SCI	Systems Concepts and Integration
SDA	Space Domain Awareness
SET	Sensors and Electronics Technology
SFA	Strategic Foresight Analysis
SG/2	Sub-Group 2
Smallsat	Small satellite
SME	Subject-Matter Expert
SMERWG	Submarine Escape and Rescue Working Group
SOA	Service-Oriented Architecture
SPS	Science for Peace and Security
STANAG	NATO Standardisation Agreement
STB	Science and Technology Board
STC	Science and Technology Committee
STO	Science and Technology Organization
SubOps	Submarine Operations
SWE	Sweden
SWG	Space Working Group
TAPs	Technical Activity Proposals
TL	Transmission Loss
TRJN	Trident Javelin
TRL	Technology Readiness Level
TTCP	The Technical Collaboration Programme
TTX	Table-Top eXercise
TUR	Turkey
TV	Television
UAS	Unmanned Aerial System
UIMA	Unstructured Information Management Architecture
UK	United Kingdom
UMS	Unmanned Maritime System
US/USA	United States of America
USD	American dollars
UUV	Unmanned Underwater Vehicle
VASWG	Verification of Autonomous Systems Working Group
V&V	Validation and Verification
vKHS	von Kármán Horizon Scanning
WPT	Wireless Power Transfer

organization CMRE

organization CSO

organization OCS

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