NATO OTAN

S&T organization

Science and Technology Organization

ANNUAL REPORT 2016

Empowering the Alliance's Technological Edge

Foreword

FOREWORD

THE NATO SCIENCE AND TECHNOLOGY ORGANIZATION “EMPOWERING THE ALLIANCE’S TECHNOLOGICAL EDGE”

Instabilities in regions close to NATO territory did not disappear in 2016 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 and Technology Organization (STO) and its predecessor organisations have been instrumental in enabling that success, both within the Nations and for NATO itself.

In 2016, 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, supporting capability development, fostering partnerships, and providing knowledge and advice to senior decision-makers. Examples include the von Kármán Horizon Scanning (vKHS) Initiative, which in 2016 assessed current capabilities and future developments in laser weapons, to be followed in 2017 with an examination of quantum capabilities and 3D imaging systems. Another highlight was the S&T Board (STB) paper on “Cost-Effectively Addressing Anti-Submarine Warfare”, which identified the need for and proposed new operational concepts and technological solutions to address emerging threats.

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 2016, enhancing our understanding of advanced technologies and systems by innovative research and experimentation at sea. The NATO Research Vessel (NRV) *Alliance* used by CMRE started sailing under the Italian Navy Flag and being operated by an Italian Navy crew.

The STB actively increased its STO governance and NATO S&T unified governance execution. Examples include delivering the first STO Corporate Strategy, updating and approving the 2017 NATO S&T Priorities in alignment with the Alliance’s updated military requirements, and delivering recommendations for improving Anti-Submarine Warfare (ASW) through innovative concepts and technologies.

As the new NATO Chief Scientist, I thank my predecessor for a job well-done, particularly with regard to establishing the Office of the Chief Scientist at NATO headquarters, providing day-to-day visibility and enabling responsiveness to Alliance leadership and staff on behalf of the STO and the STB.

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
STB Chairman

Executive Summary

EXECUTIVE SUMMARY

The technological advantage of the Alliance has been increasingly challenged as the nature of conflict and identification of an attack has become progressively complex. Hybrid approaches – combining military and non-military means in campaigns – have inflicted damage and created instability. The broad proliferation of technology and explosion of digital capabilities, employed in nefarious ways, has proven to be effective for our adversaries. The STO works tirelessly to understand emerging threats, and through its S&T activities, tackles the hard problems to constantly empower the Alliance's technological edge.

Through the CSO, which facilitates the CPoW, and the CMRE, which provides an in-house capability for collaborative technology development and assessment, the STO executed a robust PoW in 2016. Funded for the most part by the Nations, this PoW encompasses a broad spectrum of S&T activities and has proven to be a cost-effective force multiplier for the Nations.

In 2016, the STO conducted a wide range of research, development, and demonstration activities. This report presents summaries[1] of some of these efforts, organised into two broad categories – Enabling Future Military Capabilities and Enhancing Interoperability and Affordability:

- **Enabling Future Military Capabilities:** This category of efforts explores emerging S&T areas that will impact the development of future military capabilities within NATO and for the Nations. The efforts run the gamut from technical investigations of future methodologies for dynamic spectrum management that address bandwidth and access issues (cognitive radio), to a detailed analysis on Hybrid Warfare (HW) documented in the Ukraine Case Study, to a Lecture Series on methodologies for the prediction of store separation to enhance aircraft safety and weapon accuracy.

- **Enhancing Interoperability and Affordability:** The activities in this category focus on enabling connected forces to operate jointly and at an affordable cost. They cover the spectrum from developing a standardised, autonomous/unmanned systems software payload architecture (interoperability in unmanned systems), to innovative training concepts that enhance the collaboration within coalition staffs (building effective collaboration in a comprehensive approach), to a detailed analysis of defence resource management practices in the face of diminishing defence spending (future defence budget constraints).

The STB recognises the value of S&T excellence within the Alliance. In 2016, Mr. Daniel Chaumette received the von Kármán medal for his outstanding work in cutting-edge, high-performance structures and materials, including composites for aircraft structures – and six Scientific Achievement Awards (SAAs) were given out in the areas of: mid-infra-red fibre lasers; Radio Frequency Directed-Energy Weapons (RFDEW); economics for evaluating fleet replacement; enhanced Computer-Assisted Exercises (CAX) architecture, design, and methodology; medical counter-measures development for biological defence; and integrated munitions health management. ■

[1] Detailed documentation of the 2016 activities is available from the STO website at: www.sto.nato.int.

TABLE OF CONTENTS

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 S&T; these include:

- Maintaining the technological and knowledge advantage;
- Providing the evidence-base to underpin informed decision-making;
- Mitigating evolving threats and risks; and
- Supporting public diplomacy.

> The investment in NATO S&T pays off as an effective force multiplier for the Alliance, its Members, and Partners.

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, analysts, 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 capabilities, interests, and needs. In addition to Allied and Partner Nations, many NATO committees, commands, and staffs have a 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; and
- Influence requirement setting or investment decisions to inform and orient future S&T activities.

This breadth and diversity of stakeholders' interests and portfolios make 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 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 PoW that covers the full spectrum of defence- and security-related S&T. This programme contributes to capability development, supports threat mitigation, and provides advice to decision-makers, thereby supporting the core tasks of the Alliance. In pursuing its mission, the STO positions S&T to the strategic advantage of Nations and NATO.

THE NATO SCIENCE AND TECHNOLOGY BOARD

The STO is governed by the NATO 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 (NAC) 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, designed to enhance multi-national collaboration by making available the knowledge, skills, and investments of all contributors. It is predominantly funded by participating Nations in line with their objectives; to a lesser extent, it is funded by NATO in support of the over-arching Alliance objective.

... THROUGH A COLLABORATIVE NETWORK ...

With some 5,000 active Subject-Matter Experts (SMEs), the STO attracts the world's largest network of Defence and Security researchers, scientists, engineers, and analysts, addressing all military-relevant aspects of S&T through the seven domains associated with the Level II S&T Committees (STCs): Applied Vehicle Technology (AVT); Human Factors and Medicine (HFM); Information Systems Technology (IST); Modelling and Simulation (M&S); Systems Analysis and Studies (SAS); Systems Concepts and Integration (SCI); and Sensors and Electronics Technology (SET).

In each domain, hundreds of national SMEs are actively engaged in the execution of commonly-agreed S&T activities such as joint research projects, conferences, workshops, lectures, or technology demonstrations. In 2016, the STO ran over 250 such activities.

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

THE NATO CHIEF SCIENTIST

Leadership of the STO is exercised by the NATO Chief Scientist, who chairs the STB and serves as the scientific advisor to senior NATO leadership.

The Chief Scientist is supported by the Office of the Chief Scientist (OCS) at NATO Headquarters (HQ) in Brussels, Belgium.

... AND A DEDICATED RESEARCH LABORATORY

The CMRE is a customer-funded laboratory focussed 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, validated S&T results that advance the basic understanding of the maritime environment as well as naval capabilities.

Key enablers for delivering the CMRE's programme are its research vessels: the NRV *Alliance* and Coastal Research Vessel (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 multi-national maritime exercises.

The Centre operates out of La Spezia, Italy.

2016 STRATEGIC FOCUS AND MAJOR ACHIEVEMENTS

The STB is the highest authority in the STO and is chartered to exercise both NATO S&T unified governance and STO governance.

In 2016, the STO delivered a high-quality PoW, well-aligned with the common needs, priorities, and interests of NATO, NATO Nations, and Partner Nations.

S&T TO SUPPORT OBJECTIVES

Through executing its mission, the STO supports the Alliance core tasks of collective defence, crisis management, and co-operative security. To deliver to that mission, the STB defined three strategic S&T objectives: Supporting Capability Development; Fostering Consultation and Partnerships; and Delivering Knowledge, Analysis, and Advice.

SUPPORTING CAPABILITY DEVELOPMENT

The STO continued to support the development of a broad spectrum of capabilities of its stakeholders through its PoW activities, i.e., both the CPoW, supported by the CSO, and the PoW of the CMRE.

The STO's CPoW is composed of S&T activities that Nations nationally fund and elect to perform together within the STO framework, in which Nations have built confidence and trust for over six decades:

- The CPoW grew to more than 250 formal activities in 2016, confirming the upward trend observed since 2009 (120 activities). This level of activity underlines the increasing importance of the STO as a forum for multi-national S&T collaboration.

- The STO collaborative network of SMEs in support of capability development is estimated to be composed of some 5,000 scientists, engineers, and analysts. This STO network draws upon the expertise of over 200,000 colleagues in Allied and Partner Nations.

The STO's CMRE, which has been customer-funded since 2013, continued to make significant research advances for its largest customer, Allied Command Transformation (ACT):

- The Centre continued its healthy project portfolio in 2016. It further diversified its PoW and customer-base by participating in European Commission (EC)-funded projects and executing work for the NATO Maritime Command (MARCOM) and the National Oceanographic and Atmospheric Administration (NOAA) of the United States.

- The Centre also reached out to other stakeholders, in particular the individual Nations, the NATO Naval Armaments Group (NNAG) and its sub-committees, the NATO Consultation, Command and Control Board (NC3B) Architecture Capability Team (CaT), NATO Centres of Excellence (CoEs), and industry.

- NATO Nations, including those with extensive maritime expertise, acknowledged the importance of the Centre and highlighted the exploitation of the results of the ACT PoW in their Nation. The Centre was recognised as being of significant relevance to knowledge development and technology transfer in the maritime domain.

Through the OCS at NATO HQ, the STO actively works with NATO HQ International Staff – Defence Investment (IS-DI) Division, contributing S&T content from the STO PoW to the development of NATO capability roadmaps, which address selected priorities of the Wales and the Warsaw Summits.

More broadly, the work of the STO (through both its PoW and network of experts) has contributed meaningful support to a number of NATO initiatives:

- The STO has continued to support the development of knowledge and concepts for the Alliance Future Surveillance and Control (AFSC), a follow-on capability for the NATO Airborne Warning And Control System (AWACS). The conclusions of this work were drawn together in early 2016 to inform the debate on the most promising options to be considered in the concept phase for AFSC. This integrated approach across military, armament, and S&T communities to addressing longer-term capability development is proving to be very successful.

- The STO composed a NATO ASW document that identified the need for new operational concepts and technological solutions to address emerging threats, through contributions and consultations from across NATO Staff and Nations. This Alliance-wide effort was a novel approach that supports initiating the development of a NATO ASW Future Concept by the Alliance.

- The STO SCI Panel provided scientific support to the Above Water Warfare Capability Group (AWWCG) under the NNAG, aiming at improving the effectiveness, reliability, and responsiveness of NATO Electronic Warfare (EW) assets. Specific contributions consisted of an assessment of EW capabilities, shortfalls, and resolution paths leveraged from collaborative scientific studies and exploitation of the Naval Electro-Magnetic Operation (NEMO) trials.

- Other activities cover a broad spectrum of S&T topics of significant military relevance, including: space systems; medicine; cyber; signature management; advanced multi/hyperspectral sensing; autonomy and autonomous systems; artificial intelligence; HW and comprehensive approach; budget constraints; interoperability; and CAX.

FOSTERING CONSULTATION AND PARTNERSHIPS

The STO continued to open its activities to non-NATO Nations – approximately 70% of current activities are open to Partnership for Peace (PfP) Nations and approximately 30% of the activities are open to Mediterranean Dialogue (MD) Nations.

The STB implemented an agreed-upon approach to enhance opportunities in the STO for the Enhanced Opportunities Partner (EOP) Nations (Australia, Finland, and Sweden) under the paradigm "included in the STO unless stated otherwise".

The strategic relationship with the European Union (EU) was reinforced through the NATO-EU joint declaration implementation. The STO has progressed through staff engagements with EU bodies, to include the EC and the European Defence Agency (EDA).

DELIVERING KNOWLEDGE, ANALYSIS, AND ADVICE

The NATO Chief Scientist, who is the senior scientific advisor to NATO leadership, delivered S&T evidence-based advice on a variety of subjects, in the context of supporting informed decision-making. The Chief Scientist's engagements in 2016 addressed such topics as disruptive technologies, innovation, laser weapons, scarcity of rare earth elements, and the future of ASW.

The advice on ASW was developed through expertise from across the Alliance, building on advanced research done within the Nations and the STO's CMRE. The STB fully endorsed the conclusions and approved the recommendations for the ASW way-forward across the DOTMLPFI[2] spectrum. The Military Committee (MC) and the Conference of National Armaments Directors (CNAD) have also received and noted the results of this work.

A select group of national experts conducted a "von Kármán Horizon Scan" on laser weapons, as part of the STB's Strategic S&T Initiative, vKHS[3]. The vKHS Laser Weapons Experts Group, led by an STB member, met twice over three months and rapidly delivered a comprehensive report in 2016, focussed on the development and employment of laser weapons into the next decade. The results of the Horizon Scanning assessment on Directed-Energy Weapons (DEW) were presented to the MC in December.

Working with the CSO and the CMRE, the OCS staff developed questions for the Defence Planning Capability Survey (DPCS), in collaboration with the Allied Nations, to collect S&T-related Nations' data to identify trends that could further improve the way in which the STO supports and facilitates the Nations.

NATO S&T STRATEGIC GUIDANCE AND CO-ORDINATION

The STB issued the 2017 NATO S&T Priorities. These priorities are firmly rooted in military requirements as expressed in the Minimum Capability Requirements (MCRs). The identification of these priorities was driven by two distinct qualities:
1) Broad application to military requirements; and
2) Potential technological disruption.

The STB enhanced efforts for co-ordination of S&T across NATO S&T stakeholders through its STB meetings, STB symposia, initiatives, and a multitude of other activities.

[2] Doctrine, Organisation, Training, Materiel, Leadership, Personnel, Facilities, and Interoperability.

[3] The vKHS Initiative employs the foundational principle of Theodore von Kármán to bring armed forces personnel and scientists together to develop a sound basis for the future, seeking to enhance collective awareness of S&T trends with potential defence relevance, identifying and assessing the defence impact of emerging technologies, and providing evidence-based advice toward military and civilian planning and investments.

Structured relationships with key stakeholders were further implemented:

- The NATO Chief Scientist and the Supreme Allied Commander Transformation (SACT) deepened their strategic partnership through co-operative efforts, to include AFSC capability concept and solutions development, Strategic Foresight Analysis (SFA), and Framework for Future Allied Operations (FFAO). Building on Technology Watch activities within the STO network, at the request of ACT, STO staff started developing a Technology Trends document that will inform ACT's SFA.

- The NATO Chief Scientist and the NATO Parliamentary Assembly (PA)[4] Secretary General reinforced their strategic partnership through targeted engagements on issues important to the STO and the NATO PA. Topics of common interest included: global trends in areas such as demographic and economic shifts; increasingly rapid technological advances and proliferation; pressure on scarce resources; and the changing nature of conflict that portends a complex geopolitical and operational environment for future NATO actions. Enabling the technological edge in Defence and Security is therefore of fundamental importance for the Alliance and its Partner Nations. This strategic partnership between the NATO PA and STO is a key bridge that links S&T knowledge and advice to parliamentarians, their constituencies, and NATO senior leadership.

Relationships with other stakeholders were strengthened at the programme level:

- The STO continued to support the Science for Peace and Security (SPS) programme of Emerging Security Challenges (ESC) through the SPS Independent Scientific Evaluation Group (ISEG), and through collaboration at the PoW level.

- The STO continued to support the further development of NATO's Community of Interest (CoI) in the Operational Research and Analysis (OR&A) domain, primarily composed of analysts from the STO's SAS Panel, the NATO Communications and Information Agency (NCIA), and ACT.

[4] The NATO PA is institutionally independent from NATO.

STO GOVERNANCE

The STB approved the STO Corporate Strategy (see Annex A), which guides the future of NATO's STO. Through this strategy and supporting actions, the STO will continue to nurture and actively advance its collaborative S&T environment and focus efforts to stimulate cross-discipline activities to deliver innovative solutions that meet the rapidly-evolving needs of the Allied Nations and of NATO.

STO OPERATIONS

The STB improved its structure, *modus operandi,* and focus. It also further progressed in defining direction and guidance for the PoW and the management of the various elements of the organisation.

The STCs increased the volume of their CPoW, and improved their responsiveness to Allies' (Nations) and NATO's proposals.

The CSO proactively supported, with the same level of resources, an increasing amount of CPoW activities. Furthermore, it improved the provision of an S&T collaborative environment by initiating the development of a modern business collaboration tool "*Science Connect*" and implementing a videoconferencing workspace, "*WebEx*".

The CMRE continued to deliver its PoW, while decreasing exploitation costs and customer rates. The Centre also managed the impact of a significantly-decreasing order book from their main customer, ACT.

A team of STB members and STO staff have started analysing how the STO's CMRE could continue to deliver a valuable maritime S&T programme for the Allied Nations and NATO within a reduced funding regime.

The OCS executed a smooth transition of leadership with the installation of a new Chief Scientist, focussing their main responsibilities on supporting and advancing the strategic agenda of the STB and its Chairperson, while furthering the impact of S&T at NATO HQ.

STO Executive Body Perspectives

THE OFFICE OF THE CHIEF SCIENTIST

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

Figure 1: 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 effect, 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.

During the AFCS pre-concept stage, the OCS led the AFSC Solutions Working Group, drawing on the STO's wide network of SMEs. In 2016, the Solutions Working Group delivered its final report in time to inform the decision taken at the Warsaw Summit to enter into the AFSC Concept Stage. During this Concept Stage, the STO will remain appropriately engaged to provide S&T advice.

A NATO ASW paper was composed through contributions and consultations from across the Alliance. The presence of the OCS in NATO HQ introduced the relevant political and military context to the S&T content from the STO network and the STO's CMRE in particular. This novel Alliance-wide effort led to support for the paper in the STB, MC, and CNAD.

The year 2016 also saw a change in STO leadership. The tenure of the MGen Albert Husniaux (BEL AF) came to an end. He served as the first NATO Chief Scientist since the STO was established in July 2012. At the Fall STB meeting in September, MGen Husniaux handed the gavel to his successor, Dr. Thomas Killion, who was appointed by the NAC to lead the STO for the next three years.

Dr. Thomas Killion took office as the new NATO Chief Scientist on October 1, 2016 and has focussed the OCS to target opportunities, increase delivery, and enhance the impact of S&T in the Nations and NATO.

THE COLLABORATION SUPPORT OFFICE

The collaborative programme of the STO remains a healthy and vibrant network of some 5,000 scientists, engineers, and analysts across NATO, Member Nations, and Partner Nations. This collaborative model continues to attract the best Defence and Security researchers, providing them with an environment that enables relevant scientific research and technology development that in turn, delivers combat capability for the Nations to the Alliance.

Mr. Alan Shaffer, the Director of the CSO, believes the need to collaborate effectively is increasing as the security challenges facing our Nations continue to grow. From a resurgent and aggressive Russia, to increased pressure from the mass migration, to the continued threat of terrorism, the security challenges facing the Alliance are greater now than in any other period he can remember.

This need is fuelled by many factors including continued austerity in the Nations, and the change in the nature and velocity of technology development. The austerity measures result in continued budget tightening in the Nations. Despite the pledge from National leaders to invest two percent of their Gross Domestic Product (GDP) in Defence upheld at the Warsaw Summit, only five of the 28 NATO Nations meet that pledge, with more than half the Nations at less than 1.5 percent. If the Nations met the pledge, an additional 148 billion Euros would be invested annually (based on 2015 budgets). As Secretary General Stoltenberg has pointed out, several Nations have begun to reverse the funding trends, but these increases are small in comparison to the need.

The change in the nature and velocity of technology development presents an additional security challenge. Simply put, technology development occurs faster than it did 20 or 30 years ago. In addition, advanced military capabilities will likely come from the system engineering and integration of commercial and with military-specific technology.

In essence, the situation is one where there are more requirements, with scarcer resources, and an increased supply of common advanced technologies available to all Nations. In this context, collaboration – or the collective pooling of NATO Members, capabilities, and research – is one of the best paths to take when dealing with this type of complex environment.

Mr. Shaffer's vision for the CSO is to continue to be the organisation that Nations come to for S&T collaboration. In 2016, the CSO supported over 250 formal activities (task groups, symposia, etc.), and will do the same in 2017.

The CSO facilitates an open dialogue that aligns the defence Research and Development (R&D) of the Nations and the capability development elements of the NATO structure. It continues to enhance its information technology "tools" to enable virtual collaboration and meetings; these tools should allow everyone to improve agility and timeliness. The CSO is working hard at shortening the publication process, better communicating their military relevance, and connecting to the operational community – the people who need their products.

Figure 2: CSO staff.

The core of the resulting CPoW remains the seven STCs of the STO – AVT Panel, HFM Panel, IST Panel, NATO M&S Group (NMSG), SAS Panel, SCI Panel, and SET Panel. These STCs are led, on a part-time basis, by voluntary national contributions and supported by full-time military voluntary national contributions and NATO civilian staff from the CSO, all of whom do a great job. The S&T community continues to try to enhance the Panels and Group by bringing in more 'millennials' – the age demographic everyone is building products to support.

The Director believes that the CSO needs to strive to 'lead the future' through activities like Technology Watch, under which they have identified a number of technologies that could change the security landscape, such as hypersonic vehicles, quantum sciences, additive manufacturing, synthetic biology, as well as human performance monitoring and enhancement. He also supports the new 'thematic approach' managed by the STB to strengthen the STO PoW by further aligning it with national priorities and their associated resources.

Mr. Shaffer's view is that it is an exciting time to be part of NATO S&T and he is pleased to have the opportunity to work with the professionals at the CSO and throughout the greater STO network.

THE CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION

NATO'S UNBIASED HUB FOR MULTI-NATIONAL COLLABORATION

In one form or another, CMRE has served NATO for more than 50 years as a hub for multi-national collaboration, where scientists and engineers from across the Alliance have gathered to advance the understanding of the maritime environment and its impact on operational applications. In 2016, the implementation of the business model that sees work funded by discrete sponsors on a project-by-project basis has continued, with multiple topics viewed by the NATO Nations as worthy of collaboration with CMRE from a technical perspective. A Memorandum of Understanding (MoU) has been signed with one Nation (Canada), which provides a structural framework for work to be contracted directly with CMRE.

NRV *ALLIANCE*

At the close of 2015, the Federal Public Flag of Germany was lowered on NRV *Alliance* with the transfer of registration to Italy's Ministry of Defence. Thereafter, a maintenance period included modifications to meet the requirements for Italian Navy operation and the major replacement of systems including a new bow thruster, digital control systems for the winches, and underwater sensors. After a period of crew familiarisation, the Italian Navy flag was hoisted formally on 9 April 2016 and the ship returned to its trials programme. The transition has been a resounding success and reflects the strong relationship with the Italian Navy. NRV *Alliance* has profited from the modifications, and the first scientific deployments with the new crew were considered very successful, both by CMRE and the Italian Navy.

SCIENTIFIC EXPERIMENTATION AT SEA

Of note, the Centre completed a two-month endurance trial – Long-Term Glider Missions for Environmental Characterisation (LOGMEC) – in which oceanographic and acoustic measurements taken by five underwater gliders in the Mediterranean were transferred to NATO and national Command and Control (C2) systems via the Coalition Warrior Interoperability exploration, experimentation and examination eXercise (CWIX) for battlespace prediction for operational forces based at the Joint Force Training Centre (JFTC) in Poland. That and other scientific achievements, including novel and innovative means of submarine detection, are documented later in this report.

OPERATIONAL EXPERIMENTATION

At the 2016 Maritime Expeditionary Conference, the need for operational experimentation in exercises was emphasised by several NATO Commanders. Later, the benefit of involving the private sector was an outcome of the NATO Industry Forum. CMRE opened dialogue where there was interest in pursuing experimentation in an operational context, but greater NATO-wide collaboration will be necessary to ensure that CMRE is funded sufficiently to participate. In addition, the Centre started actively planning for participatation in project TRITON, NATO's replacement Maritime Command and Control Information System (MCCIS).

Figure 3: (From left to right) CO Cdr Ettore Ronco, RAdm (ret) Hank Ort (Director – CMRE), RAdm Enrico Pacioni (Commander – Italian Navy Mine Countermeasures Forces), and CO Cdr Giuseppe Rizzi (picture taken during the last Change of Command).

EUROPEAN COMMISSION

CMRE continued its strong involvement in the EC in 2016, focussing on the Border Security call. In addition to its five active projects, the Centre was awarded a further three projects, which will commence in 2017. They cover data fusion for maritime security applications, autonomous surveillance control systems, and C2 systems for the surveillance of borders in a three-dimensional (3D) environment.

OVERALL ASSESSMENT

2016 has been a pivotal year for CMRE in managing both internal and external change, while developing additional business opportunities and strategic relationships beyond the traditional NATO maritime S&T programme.

NATO STO Programme of Work

ENABLING FUTURE MILITARY CAPABILITIES

Enabling future military capabilities is one of the cornerstones for the Alliance so as to protect and defend its territory and populations against attack, as set out in Article 5 of the Washington Treaty. Against this backdrop, Nations and NATO work closely together over the short, medium, and long term.

The STO supports the Alliance and its Partner Nations in mutually benefitting from collaborative activities to enhance and improve scientific understanding and technological competency in the medium to longer term.

Enabling future military capabilities by investing sufficiently and wisely in S&T is at the heart of NATO's strategy to maintaining the edge in Defence and Security.

To provide a feel for the depth and breadth of the STO PoW, the following pages provide summaries of activities that were completed in 2016:

- Best Practices for Risk Reduction for Overall Space Systems (AVT-257)[5];
- Big Data Analytics for Maritime Traffic Intelligence (STO-CMRE);
- Brillouin Scattering Lidar Demonstration (STO-CMRE);
- Cognitive Radio: Towards Dynamic Spectrum Management (IST-104);
- Considerations for Space and Space-Enabled Capabilities in NATO Coalition Operations (SCI-283);
- Countering Adversarial Cyber Threats Through Predictive Analysis (IST-129);
- Decoupled Collaborative Autonomy (STO-CMRE);
- DMPAR for Enhanced Radar Target Detection (SET-195);
- Eliminating Thermal Limitations Through Validated Design (AVT-226);
- Integrative Medicine Interventions for Military Personnel (HFM-195);
- Long-Term Underwater Glider Deployment for Persistent Marine Environments Predictability Study (STO-CMRE);
- Maritime ISR Glider Networks and Mission Support as a Service (STO-CMRE);
- Methods to Support Decision-Making for Joint Fires (SAS-108);
- Modelling and Simulation for PARC (STO-CMRE);
- Multi-Channel/Multi-Static Radar Imaging of Non-Co-operative Targets (SET-196);
- Persistence in Autonomous Systems (STO-CMRE);
- Research Specialist Team on Hybrid Warfare: Ukraine Case Study (SAS-121);
- Scientific Support to the NATO Naval Armaments Group Above Water Warfare Capability Group (SCI-258);
- Ship Radar Signature Management (SET-203);
- Stochastic Models in Support of AIS/SAR Association and Identity Resolution (STO-CMRE); and
- Store Separation and Trajectory Prediction (SCI-277).

Further documentation of the results of these efforts are available on the STO website: www.sto.nato.int.

[5] The STO numbering convention is the Panel name followed by the activity number, hence 'AVT-257' is Applied Vehicle Technology Panel – Task Group 257.

BEST PRACTICES FOR RISK REDUCTION FOR OVERALL SPACE SYSTEMS (AVT-257)

NATO depends heavily upon space to conduct its missions. Small satellites (Smallsats) offer potential benefits to the warfighter, which include responsive systems for a range of missions at reduced cost. However, proper assessment of risk, reliability, and performance is necessary to maximise those benefits. New techniques and approaches must be developed to achieve potential savings in cost and time.

Dr. David Zimcik, CAN, National Research Council and Prof. Dr. Alim R. Aslan, TUR, Istanbul Technical University

BACKGROUND

NATO is critically dependent upon space capabilities in all its mission areas, including global security, out-of-area peace-keeping, and asymmetric warfare. Operational requirements such as secure point-to-point communications, extended Intelligence, Surveillance, and Reconnaissance (ISR), positioning, navigation, and timing require a responsive and resilient space capability, at an affordable cost. Smallsats are significantly cheaper than large platforms and can potentially be launched more quickly and at a lower cost. Moreover, Smallsats enable the deployment of constellations or formations of space assets that can perform tasks with increased resolution, revisit rates, and performance.

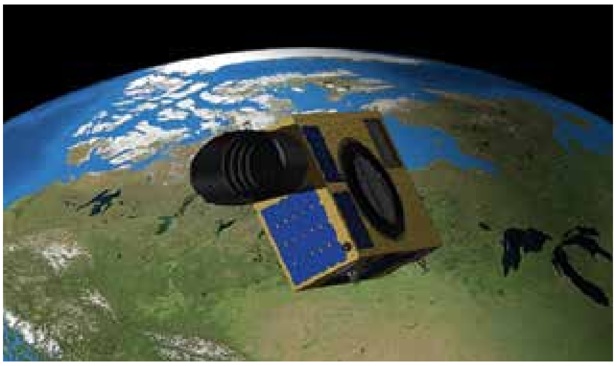

Figure 4: Surveillance Smallsat in orbit.

OBJECTIVE(S)

The objective was to review and assess the state-of-the-art in sub-system compatibility and integration simplification, system implementation opportunities, and verification and validation rationalisation, as well as to identify the gaps in technology, and define the required next steps to enhance the value derivable from Smallsats.

S&T ACHIEVEMENTS

This Specialists' Meeting identified viable new approaches and techniques that were consistent with risk and budget limitations. In order to assess the benefits of Smallsats to the warfighter, the team investigated the most effective means of enhancing the projected Smallsat performance in NATO missions, while achieving cost and schedule savings.

SYNERGIES AND COMPLEMENTARITIES

Smallsats provide platform options for mission concepts under the SCI Panel, as well as space-based platforms for instruments for communications, remote sensing, and ISR under the SET Panel.

EXPLOITATION AND IMPACT

More than 75 representatives from 15 NATO Nations participated in the Specialists' Meeting, which featured 28 technical presentations over four days. The presentations described Smallsat technology advancements and included noteworthy breakthroughs in solar array drive mechanisms, de-orbit concepts, and multiple launch configurations, among others. The report developed from this event was provided to key user groups such as ACT, Allied Command Operations, NATO Industrial Advisory Group (NIAG), and other STO Panels (particularly SCI), in order to solicit advice and recommendations on technology gaps and areas for needed advancement.

> Smallsats offer potential benefit to NATO warfighters through responsive systems supporting a range of NATO missions at reduced cost.

CONCLUSIONS

The team assembled the results of the Specialists' Meeting, available on the STO website, identifying the current technologies and providing recommendations to enhance the value derivable from Smallsats. Applying the given Smallsats recommendations will enhance the accomplishment of NATO's space asset-dependent missions.

BIG DATA ANALYTICS FOR MARITIME TRAFFIC INTELLIGENCE

For Maritime Situational Awareness (MSA), the abundance and availability of data makes more sophisticated analyses possible and actionable insights more timely. However, analysts must rely on summary statistics and representative Patterns of Life (PoLs) to gain an advantage.

Dr. Luca Cazzanti, STO-CMRE

BACKGROUND

Huge amounts of data overwhelm MSA analysts and challenge established workflows. Summary statistics and representative PoLs are relied upon to understand the organic behaviour of maritime traffic, infer trends, and extract key indicators related to safety, security, trade, regulatory compliance, and port operations. Provisioning capabilities for big data analytics in a user-friendly way is essential for informed decision-making.

OBJECTIVE(S)

The objective was to develop a big maritime data analytics platform by adopting state-of-the-art big data, machine learning, and information visualisation techniques. The large historical Automatic Identification System (AIS) vessel database at CMRE would be leveraged by scalable computing frameworks to produce summary statistics of port visits and create PoL maps. The results would be accessible to MSA analysts using the latest cloud-deployed, visual interfaces. Although it is capable of worldwide coverage, initially the analytics platform would only include results for Mediterranean ports.

S&T ACHIEVEMENTS

The Maritime PoL Information Service was developed to process large quantities of AIS data, produce port-visit statistics and traffic density maps, and serve them through a graphical user interface. The scientific challenge of identifying opportunities for applying big data concepts and tools to maritime traffic data was met by adopting leading-edge techniques in the processing pipeline. The information extracted was presented in a user-friendly way by interactive dashboards that exposed key metrics through a cloud service. A multi-disciplinary team of machine-learning and big data experts, maritime security scientists, research software engineers, and end-users adopted agile development practices to ensure a tight iteration loop from idea, to prototype, to user feedback.

SYNERGIES AND COMPLEMENTARITIES

This self-service analytics model can be adopted for other areas relevant to NATO. Large sets of environmental information can be analysed with the same computational tools and disseminated via cloud-deployed dashboards. Throughout the project, NATO Shipping Centre (NSC) staff were the end-users that evaluated the prototypes of the Maritime PoL Information Service. The early and sustained involvement of the NSC ensured that the prototype remained relevant to the operational community.

EXPLOITATION AND IMPACT

As a testament to its exploitation potential, the prototype has been accepted by the NSC, where it is impacting the day-to-day work of maritime traffic analysts.

CONCLUSIONS

The Maritime PoL Information Service provides summary statistics of vessel port visits by leveraging modern technologies and practices, along with the valuable information from the AIS. It exemplifies how data-driven, self-service analytic platforms can address the challenge of extracting easy-to-exploit information for the maritime domain.

Figure 5: Interactive dashboard for exploring vessel traffic in user-selected countries and ports.

BRILLOUIN SCATTERING LIDAR DEMONSTRATION

Passive detection of underwater acoustic signatures using lasers could be possible by harnessing high-order interactions between light and sound.

Dr. Emanuel Coelho and Dr. Charles Trees, STO-CMRE

BACKGROUND

The Brillouin Scattering affecting laser signals is a Doppler shift due to scattering from moving density/pressure fluctuations propagating in all directions at the speed of sound, as a result of photon-phonon interaction.

OBJECTIVE(S)

Background acoustic waves induce Doppler shifts in the scattered light, as determined by the local speed of sound in water, in the so-called Brillouin Scattering phenomena. CMRE aims to develop and test a Brillouin Scattering Lidar (BSL) system to measure sound speed at each bin of a laser path. This solution will also allow the characterisation of objects along the laser path and may allow the measurement of sound waves in the water column (virtual laser hydrophones).

S&T ACHIEVEMENTS

For the first time, a pier-side test measured BSL at sea. The performance was very reliable and actual sound speed (and water temperature) was retrieved concurrently with light extinction along the beam. Object detection and potential use as a virtual laser hydrophone are still under analysis.

SYNERGIES AND COMPLEMENTARITIES

Data are being exploited jointly by CMRE, Canada, and Germany. The information obtained from simultaneous measurements of sound speed, turbidity, and bathymetry delivered by a BSL system can be used with other inputs for the preparation of operational environments and have an indirect impact on planning and conducting ASW, Submarine Operations (SubOps), navigation, Amphibious Operations (AmphibOps), and Mine Counter-Measures (MCM).

EXPLOITATION AND IMPACT

Further to direct object detection/classification and environmental characterisation, the analysis of the BSL signals could also be used to reconstruct the sound pressure, although further studies are still required. This would be game-changing since it would allow both the detection of submerged platforms without traditional transducers and the design of high-sensitivity virtual arrays. It could be ready for testing and validation on a ship or helicopter/aircraft in the near future.

Figure 6: Laser pier test apparatus.

CONCLUSIONS

The detection of an underwater target and the simultaneous retrieval of environmental parameters have been shown to be possible. More measurements with different shapes and surface properties should be considered in the future. In principle, it should be feasible to perform even some form of imaging of the object by scanning the laser beam over an area of interest. The test also proved for the first time that the BSL signal can be used to compute the extinction coefficient in the water column directly without an *a priori* knowledge of the nature of the absorption and scattering properties of the suspended particulates.

COGNITIVE RADIO: TOWARDS DYNAMIC SPECTRUM MANAGEMENT (IST-104)

Cognitive radio is a concept that has been instrumental in re-thinking spectrum management and how it could be improved, leading to the new paradigm of Dynamic Spectrum Management (DSM). The expected benefits will contribute to the mission success of operations by providing Nations with more available and reliable access to the spectrum.

Mr. Christophe Le Martret, FRA, Thales Communications and Security

BACKGROUND

Spectrum unavailability is an issue in the deployment of tactical networks that can jeopardise mission success. DSM is a new paradigm derived from the cognitive radio concept and is expected to mitigate spectrum scarcity.

OBJECTIVE(S)

The IST-104 Research Task Group (RTG) sought to propose DSM solutions that optimise efficiency in spectrum usage. It aimed at defining 'baby steps' to incrementally incorporate dynamicity in military spectrum management.

> "Another one . . . is dynamic sharing. So you can actually put more in a smaller space ... and still have everybody working together as a team and not interfering with each other, because it is an automated system that does that." – *MGen Robert Wheeler, Deputy Chief Information Officer for Command, Control, Communications and Computers (C4) and Information Infrastructure Capabilities, February 2014*

S&T ACHIEVEMENTS

The proposed solutions derived by the RTG were grouped into two levels of technological maturity. The first is a set of procedural adaptations that could be implemented in the near future and have potential for a large impact on operational performance. The second set entails a global allotment approach for systems with Least Restrictive Technical Conditions (LRTC), which produces more accurate planning tools to allow for more efficient spectrum-sharing. This set constitutes a breakthrough by allowing different Nations to share the same bandwidth in both time and place, where sharing/allocation decisions are made based on the local environment. Several spectrum-access models are envisioned that are enabled through common policies shared between Nations.

SYNERGIES AND COMPLEMENTARITIES

IST-104 is complementary to the IST-140 RTG on "Cognitive Networks", elaborating solutions to implement networks of cognitive radios in coalition efforts. It is expected that these solutions will use the spectrum-sharing models developed by the IST-104 Task Group. This work is also complementary to IST Exploratory Team (ET)-091, "Radio Environment Map (REM)" – a useful asset for managing the spectrum.

EXPLOITATION AND IMPACT

With some minor modification, the first set of procedural adaptation solutions proposed by the RTG could be integrated into existing procedures without having to make any changes to the existing International Telecommunication Union (ITU) regulations. The second step may take longer to be accepted and implemented. The impact of this could be very important for interoperability, as more efficient dynamic sharing of the spectrum between Nations will have clear operational enhancements across communication networks.

CONCLUSIONS

The RTG developed a set of DSM solutions to improve existing military spectrum management. A portion of these recommendations can be incorporated into current procedures with only minor revisions required and could be put into operation almost immediately.

Figure 7: "Is there any piece of spectrum left for my system?" (Crowded TV-hill during International Security Assistance Force (ISAF) operation).

CONSIDERATIONS FOR SPACE AND SPACE-ENABLED CAPABILITIES IN NATO COALITION OPERATIONS (SCI-283)

This two-day Symposium on the "Considerations for Space and Space-Enabled Capabilities in NATO Coalition Operations", held in Loughborough, England, saw 91 participants from 20 Nations attend 77 technical presentations and one keynote speech delivered by the Italian Defence General Staff's Chief of Intelligence and Security, MGen Giovanni Fungo.

Dr. Donald Lewis, USA, The Aerospace Corporation

BACKGROUND

NATO is significantly dependent upon services in and from the space domain to address its operational missions and related responsibilities. While NATO does not specifically own or operate any space-based assets, it has an increasing requirement for space domain awareness. This Symposium set out to identify areas for enhancement of the resilience of NATO's use of space to ensure comprehensive mission success.

Figure 8: Phased-array radars like this one in the United States provide space surveillance capabilities to the Alliance.

OBJECTIVE(S)

The Symposium's objective was to share and disseminate information on efforts related to increasing NATO awareness and preparedness in employing space-enabled capabilities in coalition operations. This informed and continued to bridge NATO's operational and S&T communities to ensure a coherent approach for the development and exploitation of space capabilities.

S&T ACHIEVEMENTS

Several core themes emerged from the Symposium. The development of space domain awareness capability was the most discussed theme and participants acknowledged the need and desire for a community approach to this issue. Other themes identified included the role of commercial systems in enhancing planning and execution of NATO missions, S&T support to retaining capabilities in denied or degraded environments, and the challenge of addressing resilience.

SYNERGIES AND COMPLEMENTARITIES

This Symposium made it possible for 20 Nations to share scientific perspectives on space-enabled capabilities in NATO coalition operations. The presentations enabled information sharing among the Nations and the participants left the event with an understanding and agreement on the way ahead.

> The development of space domain awareness was the most discussed theme of the Symposium and the participants acknowledged the need and desire for a community approach to this issue.

EXPLOITATION AND IMPACT

As a result of the Symposium, several topics were identified for future activities. Exploratory Teams have already been established on "Resiliency Concepts to Enhance Preservation of NATO Space Capabilities" and "Collaborative Space Domain Awareness Data Collection and Fusion Experiment". The SCI Panel is also considering additional studies on "Maturity of Concepts for Space-Based Tracking of Moving Objects" and "Opportunities/Implications of Large-Scale Commercial Small Satellite Constellations to NATO Ops". In addition, the SCI space community is now providing scientific support to the NATO Bi-Strategic Command Space Working Group as it plans the next TRIDENT JUNCTURE exercise.

CONCLUSIONS

This Symposium proved very successful in developing new S&T activities within the STO. Four separate activities are anticipated over the next year that will begin to address several of the concerns identified.

COUNTERING ADVERSARIAL CYBER THREATS THROUGH PREDICTIVE ANALYSIS (IST-129)

Traditional approaches for gaining cyber domain situational awareness seldom consider factors associated with the capabilities and behaviours of an adversary. IST-129 intends to show that if these factors are taken into consideration, multiple and co-operative analytic approaches can predict exploitation of known vulnerabilities, even if the attack pattern is previously unknown. Furthermore, such predictions shorten the window of opportunity and provide timely mission impact alerts to operators and Commanders. This approach moves cyber defence from reactive to proactive, and helps maintain NATO and national security.

Dr. Dennis McCallam, USA, Northrop Grumman Corporation

BACKGROUND

Predictive analysis is practiced in many domains, so extending its use to the cyber domain requires an understanding of the state-of-the-art and practice. Future coalition operations require a common concept and approach for predictive analysis of adversarial cyber operations. Highly-scalable, temporally-efficient, and integrated analysis will be needed to anticipate an intelligent adversary's future options of attack vectors and tactics. IST-129 is laying the foundation for those future technologies and approaches, thus enabling cyber defenders to anticipate and effectively counter attack paths of the cyber adversary.

> Effective predictive analysis has the potential to put the cyber-defender inside the attacker's OODA loop.

OBJECTIVE(S)

IST-129 are currently characterising the current research on predictive analysis in the cyber domain to develop a comprehensive roadmap for a set of methodologies, technologies, and tools to defensively counter adversarial cyber operations in real time.

S&T ACHIEVEMENTS

This Task Group is focussing its efforts against cyber threats that compromise systems by creating new exploits for known vulnerabilities. To narrow the potential research space, the RTG will concentrate on enterprise computer networks and not embedded (platform) systems, and they will look at attacker access paths, not attacker intent. Their initial view suggests that a strong solution will fuse predictive, prescriptive, decisive, and descriptive analytics. IST-129 also believes that they will be able to structure a well-defined, cyber-version of Boyd's Observe, Orient, Decide, and Act (OODA) loop in order to provide a framework for characterising adversarial cyber behavior. Their plans include publication of a literature review and a position paper. They will also be holding a Specialists' Meeting in October 2017 in Sibiu, Romania.

SYNERGIES AND COMPLEMENTARITIES

IST-129 members are currently working with or have interfaced with several other NATO groups and fora. Members are contributing to the IST-143 Lecture Series on "Cyber Science and Engineering", the IST-133 Specialists' Meeting, and are part of the IST-153 Workshop.

EXPLOITATION AND IMPACT

The foundational research undertaken by IST-129 will be further exploited to move from on-demand to continuous prediction of adversarial cyber behaviour. Part of the research agenda will be to establish "next steps" and other research areas to operationalise adversarial assessments, as well as to identify the metrics for adversarial features and impacts on threat analysis.

CONCLUSIONS

The interim results seem to indicate that IST-129 will not only add to the thin body of knowledge on adversarial operations, but will also illustrate paths for moving cyber defence from a reactive to a proactive approach. This should lead to a much clearer understanding of contested cyberspace, underscoring the value of predictive analysis.

Figure 9: Predictive analysis has to consider the past and present to properly predict the future.

DECOUPLED COLLABORATIVE AUTONOMY

Recent developments at CMRE on a decoupled, collaborative autonomy framework have enabled multiple phases of MCM to be conducted in parallel, and a decoupled interoperability capability for integrating heterogeneous national platforms in a coalition structure.

Mr. Warren Connors and Dr. Samantha Dugelay, STO-CMRE

BACKGROUND

Whether traditional manned or modern robotic-based systems are employed, conventionally, naval MCM follows a series of phases – detection/classification, re-acquisition/identification, and neutralisation. While an MCM Vessel (MCMV) will execute each of these *in situ*, no single robotic platform can complete the entire process autonomously. In order to fully realise the potential gains of the robotic systems, consideration should be given to the parallel execution of MCM phases using heterogeneous robotic platforms.

OBJECTIVE(S)

The objective of this work is to investigate a flexible, decoupled, multi-vehicle autonomy capability that will leverage the existing capabilities of dissimilar national platforms, and allow for rapid integration of robotic MCM systems for parallel MCM phase execution. This requires a robust framework to ensure effective mission execution in challenging and communication-limited environments. Additionally, this framework must be robust enough to handle failures in individual platforms, ensuring that the overall goals are achieved.

S&T ACHIEVEMENTS

The Decoupled Collaborative Autonomy Framework (D-CAF) was integrated with the CMRE Mine-hunting UUV (Unmanned Underwater Vehicle) for Shallow-water Covert Littoral Expeditions (MUSCLE) and Kongsberg REMUS vehicles during the 2016 Multi-National Autonomous Experiment (MANEX '16) trial to demonstrate a collaborative approach for parallel MCM mission execution. In this experiment, the MUSCLE platform was used for a wide-area search, automatically detecting and classifying mine-like objects on the seafloor. These were communicated to the REMUS vehicle, which selected the most applicable tasks and conducted re-acquisition of the targets at the same time as the MUSCLE survey.

SYNERGIES AND COMPLEMENTARITIES

This effort will investigate the use of highly-decoupled autonomy capabilities that are tolerant to failure in both communications and platforms for NATO MCM. The work will provide input into existing efforts such as SCI-288, "Autonomy in Communications Limited Environments".

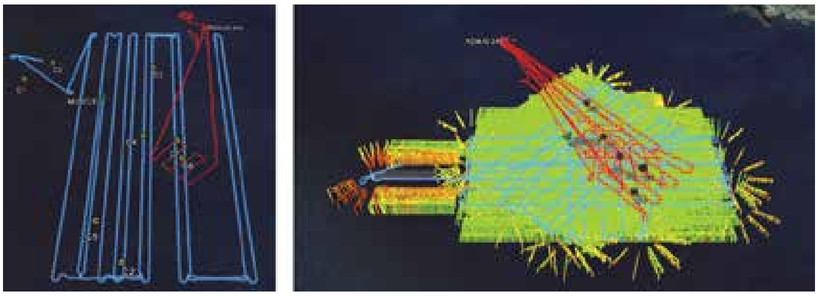

Figure 10: Left: A single parallel re-acquisition by REMUS while MUSCLE conducts an MCM survey; Right: Simultaneous survey and re-acquisition MCM missions by MUSCLE (blue) and REMUS (red) during MANEX '16.

EXPLOITATION AND IMPACT

The outputs of a decoupled collaborative framework will facilitate the integration and interoperability of heterogeneous systems into a multi-phase fleet of national vehicles and the adoption of agreed-upon maritime standards in the MCM domain.

CONCLUSIONS

While still in the early stages, the D-CAF framework has shown potential for further research in collaborative autonomy, leading to a robust capability for parallel, fault-tolerant, robotic MCM in NATO.

DMPAR FOR ENHANCED RADAR TARGET DETECTION (SET-195)

The potential for Deployable Multi-band Passive/Active Radar (DMPAR) as a novel system-of-systems sensor for air defence was demonstrated in a multi-national field trial by networking a prototype, dual-band active radar and a technology demonstrator passive radar system which uses MIMO (Multiple-Input, Multiple-Output) signals and data processing. The results confirm the promise for a near-term upgrade of air defence radar capabilities.

Dipl. Ing. Heiner Kuschel, DEU, Fraunhofer Institute for High Frequency Physics and Radar Techniques

BACKGROUND

Ground-based air defence radar performance is subject to constraints like terrain screening and detection insufficiencies against low-observable targets. In particular, targets with reduced radar cross-section flying at low altitudes pose a considerable threat to state-of-the-art air defence radars. Such coverage gaps and detection range reductions are expected to be alleviated using a DMPAR sensor suite consisting of available active and passive radars.

OBJECTIVE(S)

The intent of this activity was to demonstrate the potential near-term benefits and expected performance improvements of a DMPAR system without awaiting the development of a completely new sensor. The so-called DETOUR (DMPAR Evaluation Trials for Operationally Upgraded Radar) trials took place in Hradec Kralove, Czech Republic, in the Fall of 2014, to demonstrate the expected DMPAR capability enhancements in realistic field conditions.

S&T ACHIEVEMENTS

Comparing the results of the trials with simulated results produced by SET-152 allowed for verification of the performance benefit obtained from applying this new processing scheme to a mix of networked passive and active multi-band sensors. Adding one or two low-cost passive radar sensors to a modern dual-band active radar with sophisticated common DMPAR processing will close detection gaps and enhance detection range at a cost considerably lower than fielding a second active radar with enhanced system survivability.

SYNERGIES AND COMPLEMENTARITIES

With the participation of passive radar demonstrators from institutes, universities, and industries, and a dual-band active radar prototype from Poland, a one-week trial with multiple sorties of different military and civilian targets was performed. The trial was an example of international institutional co-operation under the NATO STO umbrella.

DMPAR processing of active and passive radar will cover detection gaps and enhance detection range at a cost considerably lower than fielding another active radar.

EXPLOITATION AND IMPACT

Gap filling, asset protection, and coastal surveillance are scenarios, among others, where the application of a DMPAR system and processing schemes will provide enhanced radar performance against critical targets like low-flying, low-observable, and highly-manoeuvrable aircraft, and results of up to a 50% increase in detection probability and range.

CONCLUSIONS

The multi-national, co-operative DETOUR trials demonstrated and quantified the potential performance upgrade for air defence radar systems that apply the DMPAR principle. Coastal surveillance, gap filling, and asset protection tasks can benefit considerably in the near term from the proposed DMPAR principle applied to a system of state-of-the-art active and passive radar systems.

Figure 11: Passive Coherent Location (PCL) demonstrator by ERA (left) and dual-band radar prototype by PIT-RADWAR (right).

ELIMINATING THERMAL LIMITATIONS THROUGH VALIDATED DESIGN (AVT-226)

Consideration of thermal management for military platforms typically occurs late in the development cycle and is often based on invalidated component and sub-system models, resulting in under-performing thermal systems. Thermal design must occur early in the development cycle, using validated tools, in order to ensure full operational capability, optimise platform efficiency, and avoid costly fixes.

Dr. Mark Spector, USA, Office of Naval Research and Ir. Bart Eussen, NLD, National Aerospace Laboratory

BACKGROUND

Increasing thermal loads are found to be an operationally-limiting constraint for military air, land, and sea vehicles. Electrical power levels have continued to grow exponentially, with nearly 70% of the power eventually dissipated in the form of waste heat. Thermal problems often surface only after a new system has been fielded, and will tend to force restrictions on the platform's operational capabilities.

> Validated thermal models are needed to ensure platforms operate according to their design specifications.

OBJECTIVE(S)

The objective was to assess thermal model validation methodologies in order to strengthen design practices for future military platforms. The goal was to understand and quantify the uncertainty in thermal models through experimental validation of a representative thermal management system.

S&T ACHIEVEMENTS

AVT-226 designed and fabricated a common test bed, which circulated among national laboratories for experimental characterisation. The test bed is a single-phase fluid loop that represents a commonly-occurring design application for power amplifier liquid cold plates. Various thermal models of the test bed were formulated, and comparisons between models and measured performance led to improved understanding and quantification of uncertainty as it influences the validation process.

SYNERGIES AND COMPLEMENTARITIES

The RTG brought together 21 experts in thermal system design and modelling from six NATO Nations. Three test beds and four modelling approaches were implemented independently in academic institutions, government laboratories, and private companies. By comparing the approaches of these organisations, the team developed standards for best practices in thermal design and validation.

EXPLOITATION AND IMPACT

This work led to validated thermal models, which are needed to ensure operational platforms meet their design specifications once fielded. Early consideration of thermal design helps to avoid the imposition of operational restrictions based on poorly-understood thermal limits and enhances platform efficiency. Dissemination of the results of this effort educates practitioners and decision-makers on the best practices for the validation of thermal analysis tools.

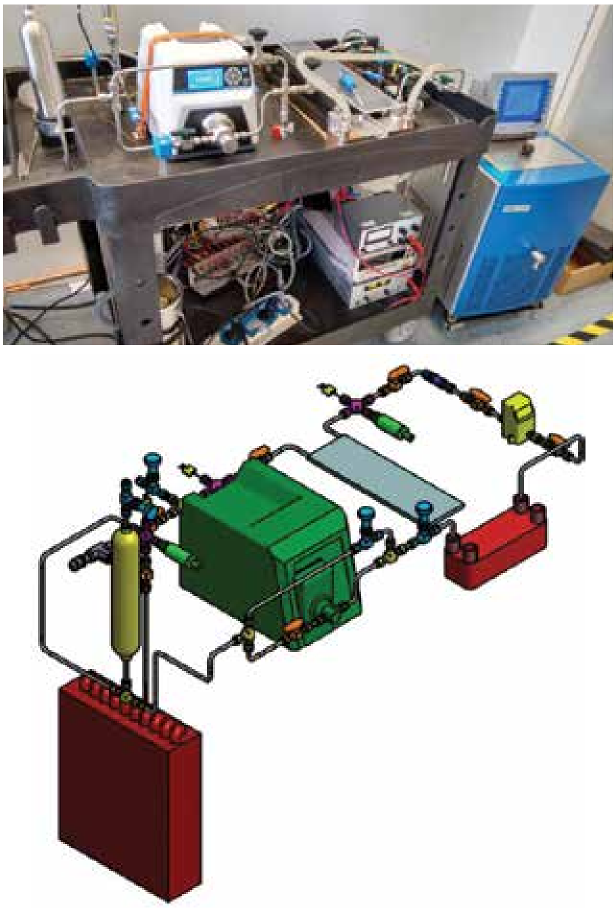

Figure 12: AVT-226 test bed schematic and picture.

CONCLUSIONS

A statistically-based experimental design methodology for thermal model validation has been developed and is being implemented using a common test bed. A Workshop is planned for Fall 2017 (AVT-270) to share the results and formulate recommendations for follow-on activities.

INTEGRATIVE MEDICINE INTERVENTIONS FOR MILITARY PERSONNEL (HFM-195)

HFM-195 was a research team formed to evaluate the status of Integrative Health and Healing (IH2) within NATO healthcare systems. IH2 offers a model of holistic care that has potential benefits and provides a new perspective on healthcare delivery. The findings indicate that implementation of selected IH2 practices, development of education programmes, and reviews of clinical outcomes and best practices can provide immediate benefit.

COL Richard P. Petri, Jr. (MD), USA, William Beaumont Army Medical Center

BACKGROUND

The field of IH2 is emerging from the dark recesses of "voodoo" into the light as a much needed healthcare paradigm. There is an emerging consensus that current healthcare systems are unsustainable and ineffective – healthcare must evolve and adapt to the needs of the provider, patient, and system. IH2 offers new perspectives using traditional wisdom and practices combined with modern medical advances.

> IH2 focusses on quality of life through individual patient responsibility and empowerment.

Figure 13: Integrative medicine interventions.

OBJECTIVE(S)

The objectives were to establish a baseline of current IH2 practices for NATO Nations and their Partners. Recommendations on initial steps for implementation of practices, educational requirements, and potential research opportunities were to be explored.

S&T ACHIEVEMENTS

HFM-195 explored, evaluated, and recommended possible IH2 modalities and healthcare paradigms. Acupuncture, meditation/mindfulness, and movement/yoga programmes were identified as modalities for near-term implementation, based on continuing analyses of efficacy, cost-effectiveness, suitability, and acceptability. The RTG found that cross-cultural initiatives and research partnerships are needed to expand the perspectives and understanding of the potential benefits and impacts of integrative medicine on NATO and Partner Nations' healthcare systems, as well as those of the rest of the world.

SYNERGIES AND COMPLEMENTARITIES

Current programmes and projects from six countries were evaluated in the areas of pain management, stress-related conditions, as well as health and well-being. A review of the utilisation patterns, terminology, best practices, co-ordination of efforts, partnerships, and strategic planning showed significant variation between countries. This RTG effort provides an initial harmonisation of some of these variations in terms and practices.

EXPLOITATION AND IMPACT

HFM-195 was the preliminary step in the evaluation of IH2 practices as a possible new paradigm for healthcare systems. IH2 offers possibilities for new options for military healthcare – in international military systems, IH2 will ultimately benefit the readiness of troops, improve performance of military personnel, and support financial stability of military organisations.

CONCLUSIONS

The use of IH2 practices is increasing in civilian and military populations. HFM-195 evaluated the current status of IH2 practices within NATO Nations and found that it will improve health status and military readiness, while decreasing the cost of current healthcare systems. The RTG also found that multi-national and multi-cultural partnerships benefit clinical practices, educational, and research opportunities.

LONG-TERM UNDERWATER GLIDER DEPLOYMENT FOR PERSISTENT MARINE ENVIRONMENTS PREDICTABILITY STUDY

CMRE has carried out long-term glider deployments to support the development of capabilities for persistent preparation and prediction of ocean environments for maritime ISR in Anti-Access and Area Denial (A2/AD) regions.

Dr. Yong-Min Jiang, Dr. Emanuel Coelho, and Dr. Reiner Onken, STO-CMRE

BACKGROUND

CMRE has been conducting R&D on underwater glider sensor/network technology and data assimilation to improve modelling of ocean ambient noise and oceanographic environments. Multi-disciplinary smart sensing has been integrated via long-endurance autonomous underwater platforms. During LOGMEC'16, a persistent environmental characterisation mission was achieved.

OBJECTIVE(S)

Major objectives of the R&D included: collecting data for a closed-loop study of the variability and predictability of marine acoustical and oceanographic characteristics; the feasibility of synchronising glider tracks with the footprints of spaceborne altimeters so that satellite altimetry data can be assimilated for estimating sub-surface ocean states; and the benefit of assimilating glider observations in ocean circulation models for acoustic prediction.

> CMRE conducts long-term underwater glider deployments for studying persistent battlespace preparation techniques for maritime ISR in high-risk domains.

S&T ACHIEVEMENTS

To demonstrate the capability of long-term data collection using underwater gliders, five Teledyne Webb Research Slocum gliders with acoustical and oceanographic sensors were deployed in the Ligurian Sea. The active time of two vehicles was 55.35 and 36.01 consecutive days at sea. CRV *Leonardo* supported the operation and collected the acoustic data. Preliminary analysis suggested a surprising temperature increase at around 200 m between Corsica and the Italian coast, compared to measurements taken between 1970 and 2014.

SYNERGIES AND COMPLEMENTARITIES

Fourteen external partners from three NATO Nations actively participated. During the sea trial, the raw glider data were downloaded and sent to the French data service centre CORIOLIS and made available via the Copernicus-Marine-Environment Monitoring Service. In addition, for the first time during CWIX 2016, the positions, tracks, intended tracks, and observations acquired by the gliders were forwarded in near-real-time to NATO and national C2 and Common Operational Picture (COP) systems.

EXPLOITATION AND IMPACT

Persistent preparation and prediction of ocean acoustic and oceanographic environments is a key capability for future NATO ISR operations in A2/AD regions. Based on the data collected during LOGMEC'16, a closed-loop tool for underwater ambient noise prediction that integrates the dynamic ocean modelling capability was developed. A study on glider safety in high-traffic shipping areas and associated mission planning was also initiated.

CONCLUSIONS

The LOGMEC'16 sea trial demonstrated the capabilities of a persistent environmental characterisation using a fleet of underwater gliders. It also provided a comprehensive dataset for assimilating multi-disciplinary field observations to develop, improve, evaluate, and validate ocean acoustic and oceanographic modelling skills for the benefit of all NATO Nations.

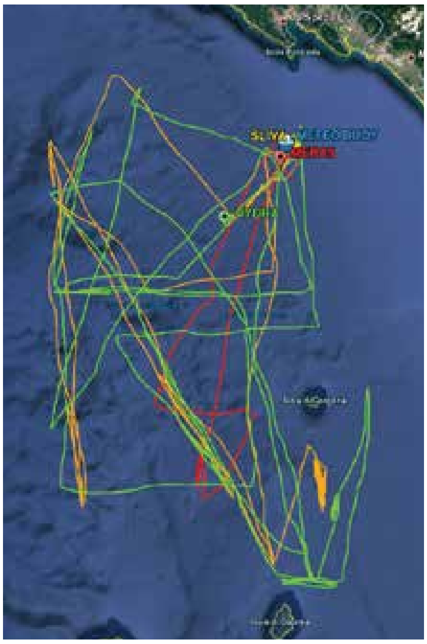

Figure 14: Glider tracks and moorings during LOGMEC'16.

MARITIME ISR GLIDER NETWORKS AND MISSION SUPPORT AS A SERVICE

Robotic underwater networks can provide cost-effective and long-endurance solutions for a secure Initial Preparation of Operating Environments (IPOE) and for Indication and Warning (I&W) of features of interest within the underwater battlespace.

Dr. Emanuel Coelho, Mr. Aniello Russo, and Dr. Paolo Oddo, STO-CMRE

BACKGROUND

CMRE has been conducting research towards developing an autonomous capability to deliver persistent IPOE and I&W for underwater ISR in high-risk and asymmetric domains.

OBJECTIVE(S)

CMRE has two major objectives: 1) Research a maritime ISR robotic network with scalable sensor payloads; and 2) Design a reach-back mission support as a service solution, combining multiple layers of information (from observations and modelling, to knowledge).

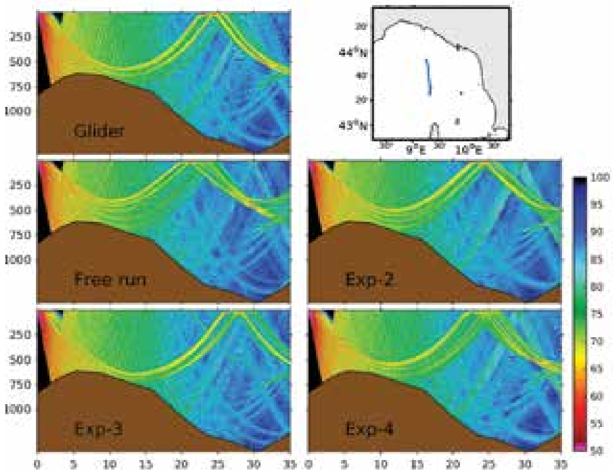

Figure 15: Prediction of TL as a function of depth and distance along a glider track.

S&T ACHIEVEMENTS

In sea trials, CMRE produced a persistent (two-month long) environmental characterisation, combining observations made by satellites and local robotic networks (sea gliders). Local ocean-acoustic observations were integrated, evaluated, and interpreted to deliver knowledge and information at different tier levels, with a major focus on underwater sound speed characterisation. Water masses with strong signatures not included in the climatology databases were observed. These anomalies had a major impact on sound propagation. In Figure 15, the top-left panel shows Transmission Loss (TL) relative to a geometry assuming a shallow sound source and using the glider observations of sound speed along the cross-section. The middle-left plot shows the TL based on a 24-hour forecast not constrained by local observations, the middle-right plot shows results using the 24-hour forecast assimilating only satellite observations, and the bottom-left plot shows the ocean forecast using only the glider's past observations. The bottom-right panel displays the optimal results, combining previous glider and satellite observations to correct the 24-hour forecast. The latter shows a closer match with the results estimated by the actual observations.

SYNERGIES AND COMPLEMENTARITIES

This work will allow for the production of high-fidelity prediction maps of operating environments that can be leveraged and complement maritime ISR systems and NATO C2 – Decision Systems (C2-DS). These results will be suited for both operational and tactical planning.

EXPLOITATION AND IMPACT

These improved TL-prediction skills support new passive acoustic capabilities for unmanned underwater ISR. Future exploitation will develop ambient noise sensing and prediction modalities that will provide cost-effective and long-endurance solutions for IPOE and I&W in the underwater battlespace by means of robotic passive acoustic sensing.

CONCLUSIONS

CMRE modelling and data assimilation solutions were able to incorporate *in-situ* observations to correct high-resolution sound speed predictions. The trial proved that glider platforms can perform multi-tier integrated ocean characterisation and acoustic monitoring missions over long periods and provide environmental intelligence.

METHODS TO SUPPORT DECISION-MAKING FOR JOINT FIRES (SAS-108)

Informed decisions for Joint Fires[6] must be made during force planning, system procurement, pre-deployment planning, and in-theatre-operations. To do this requires trade-offs between effectiveness and operational risks, and between effectiveness and cost. SAS-108's results will provide a framework and common set of definitions to help Nations support decision-making and develop strategies regarding Joint Fires.

Mr. Marcel Smit, NLD, Netherlands Organisation for Applied Scientific Research

BACKGROUND

Due to the increasing relevance of Joint Fires, there is a need to identify the most cost- and risk-effective combination of weapons, munitions, and platforms available (Joint Fires) in a variety of scenarios. Many Nations are interested in Joint Fires and are developing initiatives in these areas.

OBJECTIVE(S)

SAS-108 sought to develop methods to quantify and balance the operational risks, effectiveness, and costs of Joint Fires for given scenarios.

S&T ACHIEVEMENTS

To help find the most cost-effective force mix while also minimising risk, the activity investigated current models and methods, determined analytic tool requirements, and developed a new analytic framework that included definitions, scope, and boundaries. This new framework uses a common set of definitions, methods, and models on effectiveness, cost, and risk quantification drawn from the participating Nations. Gaps in these models related to the framework have been identified.

Using a number of case studies, the framework proved to be appropriate for decision-making with different types of Joint Fires. It can also be used with a range of analytical techniques, from judgmental methods to simulation.

> There is a need to identify the most cost- and risk-effective joint combination of weapons, munitions, and platforms available.

SYNERGIES AND COMPLEMENTARITIES

SAS-108 brought together members from other NATO agencies and the five participating Nations; together they surveyed current NCIA models (mainly on strategic defence planning). The RTG was also made up of members from the

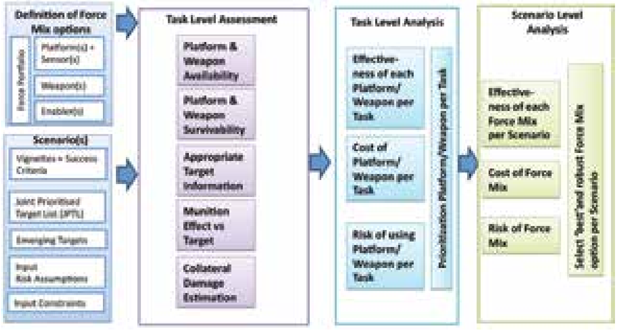

Figure 16: Framework developed by SAS-108 to weigh risks, cost, and effects of Joint Fires.

NATO Army Armaments Group (NAAG) Indirect Capability Group Indirect Fire Sub-Group 2 (SG/2), which has a programme to develop software focussing on weapon system effectiveness – the SG/2 Shareable Software Suite (S4). The software part of S4 was also considered by SAS-108.

EXPLOITATION AND IMPACT

This framework could be used to support national force mix planning and acquisition, pre-deployment and in-theatre planning, as well as elements of the Joint Targeting Cycle of the NATO Defence Planning Process (NDPP). Joint Force and Component Commands may also wish to consider how to use the framework to support Joint Fires decision-making. The framework should be tested for 'fitness of purpose' before application, to provide familiarity with the approach and determine appropriateness.

CONCLUSIONS

The framework developed by SAS-108 will enable informed decision-making for Joint Fires during force planning, procurement programmes, pre-deployment planning, and in-theatre operations. It will also provide input for the NDPP. Moreover, it provides common definitions related to Joint Fires to enable a better understanding of the Joint Fires context.

[6] 'Joint Fires' are fires produced during the employment of forces from two or more components in co-ordinated action toward a common objective.

MODELLING AND SIMULATION FOR PARC

CMRE showcased the M&S of two different Autonomous Underwater Vehicles (AUVs) collaborating persistently in a port-protection scenario, as well as the logistics of recharging underwater vehicles.

Dr. Alberto Tremori, Dr. Amau Carrera, Dr. Maria Caamaño, and Mr. Robert Bee, STO-CMRE

BACKGROUND

Activities for CMRE's project entitled "Persistent Autonomous Reconfigurable Capability (PARC)" addressed the interoperability and security aspects of multi-domain unmanned systems, while focussing on technology demonstrations, both in the field of M&S and unmanned system energy persistence.

OBJECTIVE(S)

The primary objective was to develop a maritime autonomy virtual test-bed capability, both at the mission and physics level, to design, implement, and use a hardware- and software-in-the-loop simulation capability – i.e., a modular (federation-based) capability that can simulate heterogeneous unmanned system missions such as the port-protection use-case. The M&S activity also looks into physics-based scenarios, such as the autonomous docking of underwater vehicles – this serves as a de-risking exercise prior to (costly) full-scale at-sea experiments.

S&T ACHIEVEMENTS

The modules (or federates) of the High-Level Architecture (HLA) for an M&S standard and a Robotic Operating System (ROS) standard have been populated. A first scenario with two different vehicles was demonstrated at the Modelling and Simulation of Autonomous Systems (MESAS) conference. A physics-based simulation demonstration involved an AUV and a mid-water docking station. Again, the interoperable/ standardised M&S framework was used, allowing for both hardware- and software-in-the-loop simulation. The latter included software-in-the-loop to demonstrate the ability to test the AUV's control system in docking operations that were either autonomous or operator-driven.

SYNERGIES AND COMPLEMENTARITIES

The development of a dedicated M&S network architecture has started, which will enable distributed experiments over the internet, thereby allowing partners to join standardised assets for future M&S Concept Development and Experimentation (CD&E) activities. Links with external partners, such as the NMSG, have been strengthened.

EXPLOITATION AND IMPACT

An extended, multi-vehicle port-protection scenario simulation was demonstrated. In this scenario, one AUV (real hardware) 'hunts' for mines attached to ship hulls, using a simulated, advanced side-scan sonar, and communicates detections to the second vehicle (simulated) that can do (video) identification of detections made by the first AUV.

CONCLUSIONS

The quest has started for 'over-the-internet' concept development and experimentation – an important tool for de-risking multi-partner, expensive sea trials. This will provide, as an example application, a capability for the assessment of unmanned system counter-measure scenarios.

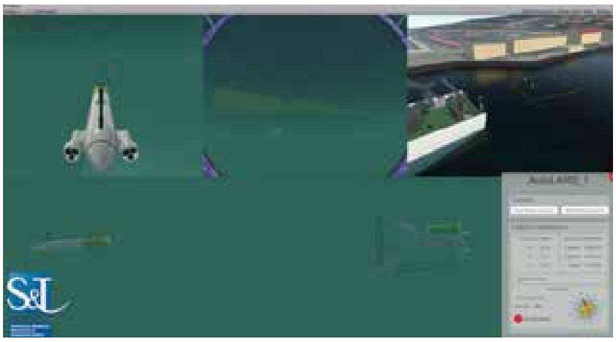

Figure 17: Screenshot from the simulated automated docking demonstration.

MULTI-CHANNEL/MULTI-STATIC RADAR IMAGING OF NON-CO-OPERATIVE TARGETS (SET-196)

Multiple channels and multi-static configurations have the ability to significantly improve radar image quality and, consequently, Non-Co-operative Target Identification (NCTI). This activity focusses on the development of system concepts and algorithms for enabling effective multi-channel and multi-static radar imaging of non-co-operative targets to improve target identification.

Prof. Martco Martorella, ITA, University of Pisa

BACKGROUND

ISR operations benefit from Automatic Target Recognition (ATR) systems, which have to be effective in providing information accurately and robustly. Single sensor / single channel radar imaging systems are often not able to satisfy such requirements as they cannot produce accurate and easily-interpretable images in a consistent manner.

OBJECTIVE(S)

The main objectives of this activity are to: define a multi-channel/multi-static radar framework and two-dimensional/three-dimensional (2D/3D) image formation techniques for non-co-operative target imaging; identify existing multi-channel/multi-static radar imaging systems and use them to collect data via joint trials; and test algorithms and systems to make recommendations to NATO Nations regarding the benefits and costs of multi-channel/multi-static systems.

S&T ACHIEVEMENTS

During its tenure, the RTG demonstrated: system feasibility by means of a major field trial conducted in Livorno, Italy, with the deployment of nine radar systems arranged as a multi-channel/multi-static radar imaging system; multi-static 3D imaging of ships and aircraft with multi-channel/interferometric Inverse Synthetic Aperture Radar (ISAR) systems; multi-bistatic radar imaging using satellite illuminators and ground-based receivers; and the effectiveness of multi-channel/multi-static radar imaging systems compared to single sensor / single channel systems.

In addition, a number of novel algorithms were developed in the areas of multi-static and multi-channel radar imaging.

SYNERGIES AND COMPLEMENTARITIES

Academic, industry, and government institutions collaborated with and complemented each other, as was broadly demonstrated during the Livorno trials. There was close collaboration with SET-163 and its follow-on RTG SET-215 for consistent exchange of data and information, and three SET RTGs (SET-180, SET-196, and SET-215) collaborated to organise an STO Specialists' Meeting, namely SET-228, on "Radar Imaging for Target Identification".

The days of monocular imaging are over – collecting and combining data from different directions is the future for a wide range of military tasks.

EXPLOITATION AND IMPACT

SET-196 findings can be applied to ISR operations, where a more accurate and robust Non-Co-operative Target Recognition (NCTR)/NCTI will be provided by multi-static and multi-channel radar imaging systems. Multi-channel/multi-static radar imaging also has the potential to defeat target low observability, therefore enabling stealthy target imaging.

CONCLUSIONS

SET-196 has made significant progress in establishing multi-channel/multi-static radar imaging as a solution to the current limitations of single-channel radar-based NCTR/NCTI. The results achieved through this effort strongly encourage continued work to take this technology to a higher Technology Readiness Level (TRL) and eventually transform demonstrators into operational systems.

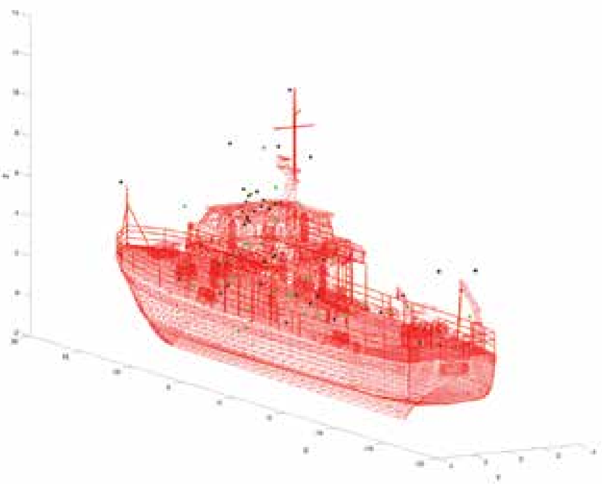

Figure 18: 3D point target reconstruction using Interferometric Inverse Synthetic Aperture Radar (In-ISAR) techniques and a multi-static/multi-channel radar system with Computer-Aided Design (CAD) model superposed.

PERSISTENCE IN AUTONOMOUS SYSTEMS

Technology demonstrations for interoperability and security aspects of multi-domain unmanned systems have included M&S and energy persistence.

Dr. Vittorio Grandi, Mr. Alessandro Carta, Mr. Alberto Grati, and Mr. Robert Been, STO-CMRE

BACKGROUND

In 2015, the design and implementation of a Wireless Power Transfer (WPT) unit was developed for a 21-inch diameter AUV. Since the system was designed to be scalable (hardware interoperable), the unit could also be fitted into a smaller AUV, the *eFolaga*.

OBJECTIVE(S)

The primary objectives were to demonstrate the possibility of acoustically driving a small AUV into a capture mechanism, securing it, and performing battery recharging via a contactless energy transfer device. Simultaneously, high-speed underwater data hand-off would take place to better inform the operator of the results of the mission. This is in support of the long-term objective of increasing AUV endurance and autonomy.

Figure 19: AutoLARS with primary WPT module.

S&T ACHIEVEMENTS

Equipped with a WPT module, the *eFolaga* was tank-tested with the primary WPT module of the docking station. The test consisted of fully recharging a completely depleted set of battery packs. The charging took three hours, with an efficiency of 90%. Temperatures, charging voltages, and currents were monitored to ensure they remained within acceptable limits. As expected, the recharging curves were in accordance with the batteries' chemistry. Autonomous docking and un-docking, underwater recharging, and data hand-off were also demonstrated successfully at sea.

SYNERGIES AND COMPLEMENTARITIES

The project collaborated with the Autonomous Naval Mine Counter-Measures (ANMCM) programme, and interacted (at the architectural level) with a project that CMRE conducted for the UK's Defence Science and Technology Laboratory (Dstl) in 2016. The latter aimed at making the CMRE MUSCLE capability interoperable with MCM vehicles in The Technical Collaboration Programme (TTCP) involving Australia, Canada, New Zealand, the United Kingdom, and the United States.

EXPLOITATION AND IMPACT

These activities implement specific aspects of broader concepts generated for generic unmanned systems, providing important insights and opportunities for exploitation. In 2017, autonomous docking will be demonstrated as part of a realistic port-protection scenario. Starting in 2018, the development of mid-water vehicle docking may be considered (the equivalent of in-flight re-fuelling). This is important for the future application of persistent AUVs deployed from, and fuelled by, unmanned surface vehicles or ships.

CONCLUSIONS

The feasibility of an ad-hoc modified Autonomous Launch and Recovery System (AutoLARS) as a static docking station for small AUVs, providing vehicle navigation assistance to homing, contactless battery recharging, and a high-speed underwater data link, was demonstrated. These three research objectives were achieved as demonstrated by the several successful homing runs carried out by the *eFolaga*. Such achievements facilitate application to more operational activities such as a 'port inspection' demonstration.

Figure 20: *eFolaga* with secondary WPT module and battery charger section.

RESEARCH SPECIALIST TEAM ON HYBRID WARFARE: UKRAINE CASE STUDY (SAS-121)

Analysis of HW and Russia's actions in Ukraine has led to a significant body of work, almost none of which accounts for the first-hand experiences and expertise of Ukrainian military and government personnel. SAS-121 examines the war in Ukraine as a case study to build upon the existing definition of HW, by specifically focussing on the capture and analysis of relevant strategic-, operational-, and tactical-level events as experienced by the Ukrainians.

Mr. Neil Chuka, CAN, Defence Research and Development Canada

BACKGROUND

Russia has applied a mix of traditional and novel means to further its policy goals in its border regions, particularly in Ukraine, as evidenced by the annexation of Crimea and the war in Eastern Ukraine. Colloquially known as HW, these methods created specific challenges for Ukraine and, more broadly, for NATO. Over the past few years, analysis of HW and Russia's actions in Ukraine has led to a significant body of work, most of which does not account for the first-hand experiences and expertise of the Ukrainians.

Figure 21: The annexation of Crimea and the war in Eastern Ukraine has seen Russia apply a mix of traditional and novel means to further its policy goals.

OBJECTIVE(S)

The objective of SAS-121 was to build on the existing definition of HW by examining the war in Ukraine as a case study to provide a deeper understanding of HW to further inform Ukrainian and NATO decision-makers.

S&T ACHIEVEMENTS

SAS-121 enhanced existing definitions of HW by examining the war in Ukraine as a case study, specifically focussing on the capture and analysis of relevant strategic-, operational-, and tactical-level events as experienced by Ukrainian personnel. Additionally, this was the first strategic analysis partnership between Ukraine and NATO, which introduced additional leadership challenges in generating trust, and participative and consultative engagement with Ukrainian partners.

> Hybrid warfare methods have created challenges for Ukraine and NATO.

SYNERGIES AND COMPLEMENTARITIES

SAS-121 provided the venue for NATO and Partner Nations to work directly with Ukraine in a joint effort to learn about HW through the lens of those that experienced it first-hand. This work would not have been possible without the strong support and participation of Ukraine.

EXPLOITATION AND IMPACT

The results provide valuable insights and have informed the Ukraine-NATO Defence Investment Group in their drafting of the "The NATO-Ukrainian Platform for Identifying Key Lessons-Learned from Hybrid Warfare" under the NATO-Ukraine Joint Working Group on Defence Reform at the NATO Warsaw Summit. SAS-121 also increased practical ties between NATO and Ukraine.

CONCLUSIONS

SAS-121 provided a unique contribution to the body of HW literature, and when cautiously employed in concert with other analysis, generates a greater understanding of HW in support of Ukrainian and NATO decision-makers.

SCIENTIFIC SUPPORT TO THE NATO NAVAL ARMAMENTS GROUP ABOVE WATER WARFARE CAPABILITY GROUP (SCI-258)

SCI-258 added an essential scientific drive to the AWWCG exercise planning business process by helping it to plan for the correct equipment, facilities, doctrine, and training needed for the NEMO trial series.

Mr. Henricus Muehren, NLD, Netherlands Organisation for Applied Scientific Research

BACKGROUND

Control and exploitation of the electromagnetic spectrum has become as much a part of modern warfare as air superiority or dominance of the sea lanes. EW is the mission area responsible for establishing and maintaining a favourable 'position' for Alliance military assets in the electromagnetic domain; a domain in which the number of applications and systems utilising it are increasing with accelerating speed.

Figure 22: A representative example of an IR signature from a target asset.

OBJECTIVE(S)

The objective of this activity was to consult and contribute to the AWWCG EW Syndicate's mission by providing scientific support that will improve the effectiveness, reliability, and responsiveness of NATO EW assets. Specifically, the activity provided an assessment of EW capabilities, shortfalls, and resolution paths, leveraged from collaborative scientific study and exploitation of the NEMO trial series.

S&T ACHIEVEMENTS

This activity informed the AWWCG of its options for enhancing the contributions of EW to military advantage, both today and in the future. Robust controls are now established that ensure the conduct of future NEMO trials – using the scientific method – will add to the assessment of EW maturity as expressed by the NEMO Objective List (a document maintained by SCI-258 on behalf of the AWWCG). Collaborative activity across SCI-258 produced fruitful joint analyses between the Radio Frequency (RF) and Infra-Red (IR) domains – helping to share the research burden and broaden the common understanding of EW capabilities across Partner Nations.

SYNERGIES AND COMPLEMENTARITIES

This effort permits Nations to compare and contrast maritime EW research efforts. Many examples exist where the outcome of a national initiative has been shared with other Nations. The NEMO trial itself was a major opportunity for Nations to freely share in the joint resources made available; often ships had free use of measurement facilities and also had the chance to evaluate EW systems not normally available elsewhere.

EXPLOITATION AND IMPACT

SCI-258 enables a greater understanding of current and emergent EW capabilities and requirements by sponsoring the evaluation of new technologies and facilitating industrial demonstrations, rather than simply evaluating current tactics. As a result, the AWWCG is better able to prioritise future study needs, orient its relationship with industry, and plan future NEMO trials.

CONCLUSIONS

SCI-258 adds significant weight to the scientific drive behind the understanding of current and future EW needs. When aligned with the operational and acquisition arenas, this greatly improves the quality of NATO's EW business.

This activity provides a visible assessment of EW capabilities, shortfalls, and resolution paths, leveraged from collaborative scientific study and exploitation of the NEMO trial series.

SHIP RADAR SIGNATURE MANAGEMENT (SET-203)

Awareness of how a ship appears to a threat radar allows the susceptibility of that ship to be assessed. The work of this RTG will raise awareness of the ship's signature as seen by the threat, leading to better-informed tactical advice. It will also feed into the ship procurement process. Validation of propagation and signature prediction codes will increase the confidence level in the advice given.

Dr. Frances Talbot, GBR, Defence Science Technology Laboratory

BACKGROUND

The radar signature of a ship is not a single value – it depends on the ship configuration, the parameters of the radar addressing it, and the propagation conditions. The signature of the ship, as seen by the threat, is a key factor in determining the susceptibility of the ship.

OBJECTIVE(S)

The objective was to provide improved tactical advice to ship operators and national tacticians to improve ship survivability and provide advice to the procurement and materiel organisations on procedures for the optimisation of ship signatures during the design phase.

Figure 23: NEMO 2016 corner reflector at 24 km range (courtesy of QinetiQ).

S&T ACHIEVEMENTS

Traditional propagation codes were written to match data, primarily at frequencies up to 18 GHz. At higher frequencies, for example 35 GHz, there has been much less validation of the codes; the Task Group provided suggested changes to the codes, where required.

The RTG's work has raised the awareness of the significance of ship signatures. Knowledge of the signature data currently available onboard ships will be used to suggest how the ship best estimates the propagation conditions to improve its situational awareness and vulnerability assessments.

> The signature of a ship, as seen by the threat in the existing environment, is a key factor in determining the survivability of the ship.

SYNERGIES AND COMPLEMENTARITIES

The sharing of data from trials and predictions is a valuable exercise that increases confidence in the models. Through participation in the NEMO 2016 trial, SET-203 participants gathered a more comprehensive set of data than would have been possible by a single Nation. In addition, during the analysis phase, the Nations were able to share different analysis techniques.

EXPLOITATION AND IMPACT

The work conducted here will be exploited through delivery of improved tactical advice for surface ships. The propagation knowledge gained will be included in susceptibility modelling, and the studies and trials reported by SET-203 will lead to greater confidence in the modelling. The work conducted by this RTG has led to advice being given to the organisers of the NEMO trials to allow them to better interpret anti-ship missile defence activities. A common approach has been followed for analysing and presenting the data.

CONCLUSIONS

The RTG demonstrated excellent co-operation in sharing modelling and trial information, which has led to improvements in understanding to how to improve surface ship survivability. Ideally, these results will be further developed in future NATO and national work.

Figure 24: NEMO 2016 instrumentation radars (courtesy of QinetiQ).

STOCHASTIC MODELS IN SUPPORT OF AIS/SAR ASSOCIATION AND IDENTITY RESOLUTION

Association of detections from heterogeneous sensors and cued reconnaissance of ships at sea can be improved by a novel motion model that enhances the accuracy of long-term position predictions.

Mr. Leonardo Millefiori, Dr. Paolo Braca, and Dr. Gemine Vivone, STO-CMRE

BACKGROUND

Vessels in open seas are seldom continuously observed. Advances in ship-motion modelling based on mean-reverting stochastic processes have proven capable of predicting future ship positions with an accuracy that is orders-of-magnitude better than that obtained with traditional motion models. The ability to predict the future position of a ship accurately in the long term (dozens of hours) provides the capability to associate detections – and therefore resolves unknown vessel identities – from highly-unsynchronised sensors, such as AIS and SAR.

OBJECTIVE(S)

The objective was to evaluate the potential of stochastic mean-reverting ship motion models to deliver long-term predictions of future ship positions that could be used for association and cued reconnaissance of vessels observed from heterogeneous and asynchronous sensors, such as AIS and SAR.

S&T ACHIEVEMENTS

The proposed stochastic ship motion modelling was verified extensively against real-world commercial maritime traffic, with suitable metrics developed to compare its performance with that of traditional motion models. The developed technique was proven to be better-suited than traditional methods for the association of AIS with SAR data, achieving the same misdetection rate, with a strong reduction of the association uncertainty.

> Vessels in open seas are seldom continuously observed, and the resulting coverage gaps represent a high risk in terms of safety at sea.

SYNERGIES AND COMPLEMENTARITIES

CMRE is collaborating with Defence Research and Development Canada (DRDC) on a joint research project on PoL model parameterisation for exploitation in C2 systems to integrate new algorithmic approaches into national and NATO tools, and to develop capabilities that extend the state-of-the-art for sparse data management.

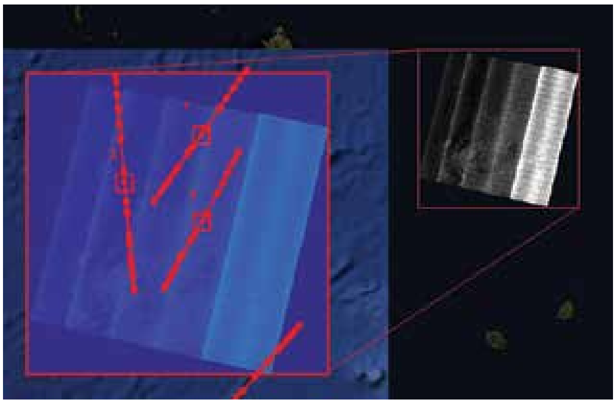

Figure 25: European Space Agency (ESA) SAR image showing AIS trajectories (overlaid in red) that enable identity resolution by association.

EXPLOITATION AND IMPACT

This methodology allows for more accurate predictions of future ship positions – and many applications in maritime surveillance and situational awareness can benefit from it. The reduction of uncertainty leads directly to a reduction of the association ambiguity of observations from heterogeneous sensors. At the same time, a smaller uncertainty reduces the probability of missing a vessel of interest in an optical or high-resolution SAR acquisition that has to be scheduled several hours in advance. This methodology will be evaluated together with DRDC in a collaborative research project, creating a loop that allows for continuous and informed improvement of research products.

CONCLUSIONS

CMRE is developing and testing methodologies that enable effective long-term prediction and association capabilities, with the expectation that they can be leveraged by the Alliance and individual Nations to enhance existing systems and capabilities.

STORE SEPARATION AND TRAJECTORY PREDICTION (SCI-277)

The SCI-277 Lecture Series (LS) on “Store Separation and Trajectory Prediction” was held at Pratica di Mare AFB, Rome (ITA), in Ankara (TUR), and at Eglin AFB (USA). The team of lecturers, Dr. Alex Cenko (USA), Dr. Wolfgang Luber (DEU), Dr. Joseph Nichols (USA), and Prof. Dr. Nafiz Alemdaroğlu (TUR), executed an event that was extremely well received.

Prof. Dr. Nafiz Alemdaroğlu, TUR, Atilim University

BACKGROUND

Store separation predicts the trajectory of a store from its position at carriage until it is cleared of the aircraft. The store’s mass properties, aerodynamic forces acting on it, and the ejector forces determine the trajectory of the store after its release from the aircraft. Understanding the complex nature of this phenomenon is essential for the safety of flight. As new munitions are developed, their safe deployment becomes a critical issue.

Figure 26: Mirage F1 with full weapons load and test munitions onboard.

OBJECTIVE(S)

The objective of this LS was to share and disseminate the experiences and the lessons learned from store separation and trajectory prediction studies among the NATO Nations. This will help all NATO Nations to improve, reduce the time required for and the risks involved in flight testing of stores, and to predict their trajectories following their release from the aircraft.

S&T ACHIEVEMENTS

The information presented at this LS was given to over 150 attendees from 10 different Nations, which made this LS among the most successful in STO history.

SYNERGIES AND COMPLEMENTARITIES

Lecture topics included: effects of stores carriage on aircraft performance and flying qualities; effects of stores on aircraft structures; store separation overview; structural dynamics flutter; computational fluid dynamics applications in store separation; and store separation, lessons learned.

EXPLOITATION AND IMPACT

The team of experts leading this LS imparted their expertise on a broad community and contributed to the future capabilities of NATO. The lectures and discussions improved the understanding of technologies and engineering techniques necessary for safe store separation and flight clearances for new aircraft and stores.

CONCLUSIONS

The SCI-277 was a successful venture that brought together 150 experts in aircraft stores separation and flight testing community from Australia, Canada, France, Germany, Italy, Netherlands, Poland Turkey, the United Kingdom, and the United States.

Its substantial participation made this Lecture Series among the most successful in STO history.

ENHANCING INTEROPERABILITY AND AFFORDABILITY

The Alliance and its Partner Nations collectively work together to achieve and maintain peace, security, safety, and stability. Working together in complex environments, while performing difficult tasks and operations within a multi-national coalition, requires a vast set of skills, knowledge, and technology, including connected and interoperable forces.

In times of economic downturn and austerity, coupled with the trend that military solutions tend to become ever-more expensive, affordability is all the more important.

The STO supports providing solutions for enhancing interoperability and affordability.

To provide a feel for the depth and breadth of the STO PoW, the following pages provide summaries of activities that were completed in 2016:

- A Risk Game for Cognitive Assistance (STO-CMRE);
- Building Effective Collaboration in a Comprehensive Approach (HFM-227);
- Clearing the Fog Around Variations in M&S Terminology (MSG-120);
- Future Defence Budget Constraints: Challenges and Opportunities (SAS-113);
- Improving Integration Between HQ and Tactical Levels by Making SOA Applicable on the Battlefield (IST-118);
- Innovative Underwater Communications (STO-CMRE);
- Interoperability in Unmanned Systems (STO-CMRE);
- ISR Underwater Glider Integration into NATO C2-DS (STO-CMRE);
- Joint Exercise on Infra-Red Signature Prediction (AVT-232); and
- M&S Resource Discovery and Access (MSG-100).

Further documentation of the results of these efforts are available on the STO website: www.sto.nato.int.

A RISK GAME FOR COGNITIVE ASSISTANCE

To improve the design of information systems for cognitive tasks for MSA, CMRE has developed a methodology to elicit and better understand an expert's abilities in reasoning and decision-making under uncertainty, when facing several, possibly conflicting, sources of information.

Dr. Anne-Laure Jousselme, STO-CMRE

BACKGROUND

Acknowledging the need to consider the human in the design of MSA solutions, the 'Risk Game' is one of the three games developed by CMRE and run as a Table-Top eXercise (TTX) that emphasises the human's double-role as a source and decision-maker. This generic approach has now been adapted to several purposes, supporting the design of MSA solutions in particular.

OBJECTIVE(S)

The objectives were to: understand how SMEs make decisions based on information in risk-based environments; provide a better understanding of information needs; show a relationship between information quality and the ability to adequately assess threat; and determine where the S&T community should focus its effort.

S&T ACHIEVEMENTS

The 'Risk Game' provides a generic framework for analysing information, processing from both human and machine while supporting the development of corresponding automated fusion solutions. The analysis of data gathered highlighted the impact of weak information quality and context on belief assessment and decision-making, as well as the discrepancy between perceived and effective information relevance.

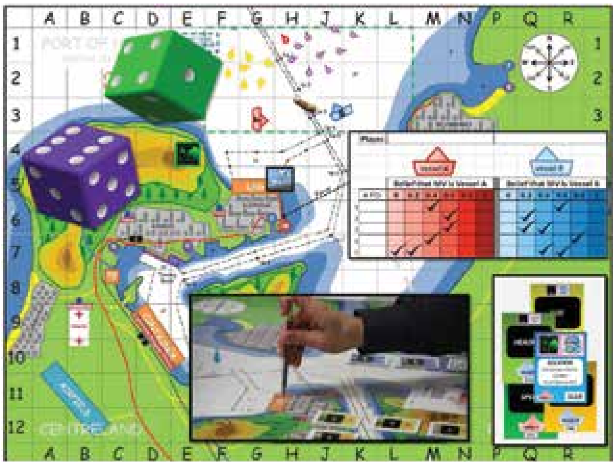

Figure 27: Board of the TTX game from a specific scenario. Dice, cards, and paper forms enable the abstraction of information and belief assessment.

SYNERGIES AND COMPLEMENTARITIES

The 'Risk Game' involved nine Nations. The work is strongly aligned with SAS-114 (RTG-053) on "Assessment and Communication of Risk and Uncertainty to Support Decision-Making", which studies the standard scales for information credibility, source reliability, and confidence (or uncertainty).

EXPLOITATION AND IMPACT

This generic framework is being used as a blueprint for the design of future information service prototypes for maritime anomaly detection, with the intent to improve interoperability toward maritime information superiority. The methodology will be reused through the TTX on MSA following the STB initiative on 'Maritime Security', with a focus on value of information assessment. Coupled with automatic, structured data gathering, and analysis methods, the 'Risk Game' is a powerful tool for simultaneously eliciting experts' knowledge and performing associated research on the design of solutions supporting reasoning under uncertainty, thus building a bridge between the operational and scientific communities.

CONCLUSIONS

CMRE validated the 'Risk Game' as both an entertaining elicitation method and an efficient means of gathering data that links the different aspects of information quality and decision-making. Running games in parallel to research and algorithmic developments is expected to improve synergy with the human operator.

BUILDING EFFECTIVE COLLABORATION IN A COMPREHENSIVE APPROACH (HFM-227)

HFM-227 provides Commanders and leaders with innovative training concepts and a Quality of Interaction Assessment (QIA) framework to better prepare their people for improved interaction and collaboration for a comprehensive approach in operational practice. Application in practice demonstrates the value of this effort.

Dr. Peter Essens, NLD, Netherlands Organisation for Applied Scientific Research and Dr. Megan Thompson, CAN, Defence Research and Development Canada

BACKGROUND

Complexity is the hallmark of contemporary crises. The challenges of effective interaction and collaboration in such complex and challenging settings are often under-estimated. A comprehensive approach is therefore necessary, where international actors work in concert, applying a wide spectrum of civil and military instruments. Relatively little work has been devoted to the uniquely human aspects of the comprehensive approach.

OBJECTIVE(S)

HFM-227 aimed to provide Commanders and leaders with insights on training practice and relevant theory for a comprehensive approach, and to provide an initial assessment framework as a feedback tool to improve collaboration in practice.

S&T ACHIEVEMENTS

HFM-227 built upon previous activities to provide a detailed description of lessons learned in preparing for a comprehensive approach. The four essential requirements for effectively engaging with people and organisations are: deepened knowledge about the other parties; social networks built with a basic level of trust; developed social competencies; and supported organisational arrangements. Policies and training concepts addressing these requirements will increase the likelihood of achieving a comprehensive approach in operational practice. Finally, HFM-227 developed an initial QIA framework based on two over-arching concepts: organisational and interpersonal readiness.

Figure 28: Picture of the international civil-military Exercise "Common Effort", The Hague, NLD, June 2016.

> As Commander 1 (GE/NL) Corps, I was impressed with how civilians and military together promoted and institutionalised 'a comprehensive approach' to deal with a contemporary crisis. (October, 12, 2016, reflecting on the international civil-military Exercise "Common Effort", The Hague, June 2016) – *Lieutenant General Michiel van der Laan*

SYNERGIES AND COMPLEMENTARITIES

HFM-227 leveraged inter-organisational trust theory and practical training experiences from Canada, training concepts and exercise experiences from the Netherlands, whole of government approaches from Estonia, and organisational and interpersonal readiness concepts from the United States. The result was an enriched approach for developing the comprehensive approach in Alliance Nations.

EXPLOITATION AND IMPACT

The results are currently being applied by the 1(GE/NL) Corps (1GNC), one of NATO's multi-national military headquarters, in their organisational and training innovations aimed at achieving a comprehensive approach. Their efforts, coupled with broad representation from governmental and non-governmental organisations, in continually practicing a comprehensive approach, have been shown to significantly benefit their operational readiness.

CONCLUSIONS

A next step in the development of the effective application of a comprehensive approach in operational practice is needed. HFM-227 provides theory, an innovative training concept, as well as a focussed assessment framework to help build this approach between NATO and its civil partners.

CLEARING THE FOG AROUND VARIATIONS IN M&S TERMINOLOGY (MSG-120)

Continuing work on the maintenance of the NATO M&S Standards Profile and other work in the M&S domain reveals that there is a clear lack of coherence and co-ordination with regards to the terminology used across NATO M&S, which in turn hampers interoperability and drives the need for a NATO M&S Glossary.

Mr. Grant Bailey, GBR, Ministry of Defence

BACKGROUND

NATO has long recognised the need for its Members and Partners to be able to communicate clearly and unambiguously, as misunderstandings in NATO's political and military activities can lead to inefficiency or more serious consequences.

The NATO Terminology Programme (NTP) provides the framework for the terminology activities of all NATO's senior committees. The terminology approved through the NTP sets the standard for terminology used in NATO documents and communications of all kinds.

OBJECTIVE(S)

The initial intention of MSG-120 was that the NATO M&S Glossary of Terms would become a NATO Allied Standard product covered by a NATO Standardisation Agreement (STANAG). In 2015, two years after the group started their work, the NATO Standardisation Office (NSO) merged all unclassified NATO glossaries from all specialist domains into a single database called "NATOTerm" – consequently, the M&S Glossary terms were fed into NATOTerm.

> "England and America are two countries separated by a common language."
> – *George Bernard Shaw*

S&T ACHIEVEMENTS

The M&S terminology developed by MSG-120 has been incorporated into the NATOTerm database, which currently contains more than 10,000 definitions. NATOTerm is helping to promote a common understanding, and is available on the NSO website (https://nso.nato.int/nso/).

SYNERGIES AND COMPLEMENTARITIES

There are many other NATO non-M&S glossaries – it is important for the MSG-120 Glossary to adopt a similar 'look and feel', and it is beneficial to learn from the experience of others. Care must be taken to ensure that terms are not duplicated in other glossaries to avoid confusion, therefore content was restricted to fundamental M&S-specific terms only. Where necessary and appropriate, reference is made to definitions listed elsewhere, such as those held by recognised organisations that develop standards.

Figure 29: Do we really understand each other when we use M&S terminology?

EXPLOITATION AND IMPACT

The Glossary is expected to be used when any collaborative or joint M&S-related work is conducted, allowing each participant to understand the other. The M&S Standards Sub-Group (MS3) of the NMSG is the custodian of the M&S Terminology developed by MSG-120, and a process for adding new terms, proposing amendments, etc., has also been established.

CONCLUSIONS

The M&S terminology will provide a valuable aid to interoperability. It will allow individual Nations to communicate using a common language in the M&S domain through the use of specific technical terms and will be a living document that continues to evolve as technology develops and progresses.

FUTURE DEFENCE BUDGET CONSTRAINTS: CHALLENGES AND OPPORTUNITIES (SAS-113)

SAS-113 identified and evaluated defence resource management practices implemented by Member Nations facing financial stress and developed a common analytical framework to promote better use of resources. The study found that most practices focussed on reactive resourcing strategies versus proactive planning, and also discovered that there is no generally-accepted NATO-wide analytical framework to assist Nations with identifying, organising, and sharing defence resource management practices.

Dr. Todd Calhoun, USA, US Marine Corps Headquarters

BACKGROUND

In the years following the Great Recession, the average defence spending by NATO Nations, as a percentage of GDP, declined from 1.72% in 2009 to 1.46% in 2013. This decline and the likelihood of continued fiscal austerity increases the need for NATO to respond. This response must include a widespread application of effective and efficient defence resource management practices.

Figure 30: *"… this is not just about how much money we spend on defence. It's also about what we spend that money on… and how we spend it."* – Secretary Jens Stoltenberg (Keynote address, 60th Plenary Session of the NATO Parliament – 2014).

OBJECTIVE(S)

The objectives of the RTG were to identify and evaluate resource management strategies implemented by Member Nations to mitigate the negative impacts of reduced defence spending, and identify valuable practices in defence resource management when responding to budget constraints that have broad applicability within the Alliance.

S&T ACHIEVEMENTS

SAS-113 developed an analytical framework that organised 'exemplar' country defence resource management practices. The framework is based on four key components: 1) Rationalise capabilities and programmes; 2) Improve transparency and accountability of the resource management process; 3) Generate operating efficiencies; and 4) Promote assessment mechanisms. These components closely correspond to the logic of planning, programming, budgeting, execution, and assessment reflected in financial management systems used within the Alliance. The framework provided a common foundation to organise national practices, and allowed SAS-113 to assess where Nations focus their efforts when responding to defence resource management challenges.

SYNERGIES AND COMPLEMENTARITIES

SAS-113's recommendation to develop a collaborative process to identify and share defence resource management practices aligns with NATO initiatives designed to mitigate budgetary risks such as Smart Defence, Connected Forces Initiative, and Framework Nations Concept. These efforts encourage multi-national co-operation, interoperability, and defence capabilities development through prioritisation, specialisation, and co-operation.

> SAS-113's framework provides a common foundation to help improve defence resource management.

EXPLOITATION AND IMPACT

Study results will be presented to NATO boards and committees, such as the Defence Policy and Planning Committee, the CNAD, and the Resource Policy and Planning Board, for review and future action. The target audiences are budgeting authorities within national defence ministries that are challenged with maximising the value of scarce resources.

CONCLUSIONS

Currently, there is no generally-accepted NATO-wide analytical framework to assist Member Nations with identifying, organising, and sharing defence resource management practices. The adoption of SAS-113's proposed analytical framework will provide a common foundation to help improve defence resource management.

IMPROVING INTEGRATION BETWEEN HQ AND TACTICAL LEVELS BY MAKING SOA APPLICABLE ON THE BATTLEFIELD (IST-118)

IST-118 provided concrete recommendations for the application at the tactical level of a sub-set of the Service-Oriented Architecture (SOA)-based HQ-level core services from the NATO Command, Control, Communications (C3) taxonomy, based on systematic testing and evaluation, which will positively influence training, materiel, and interoperability.

Mr. Peter-Paul Meiler, NLD, Netherlands Organisation for Applied Scientific Research

BACKGROUND

The NC3B uses the SOA paradigm as the method to achieve interoperability at the information infrastructure level. Current technologies used to implement SOA (web services, Data Distribution Service (DDS), and others) have not been specifically designed to handle the conditions found at the tactical level (disadvantaged grids). This remains a major impediment to achieving interoperability among the Nations in the battlespace. The possibility to extend this SOA-based information interoperability from the HQ level to the tactical level would be an essential capability improvement.

OBJECTIVE(S)

The objective was to investigate the application of core SOA services in the tactical domain and provide recommendations for their deployment based on experiences and experiments. These recommendations would support the development of SOA at the tactical level, and improve integration between tactical and HQ levels.

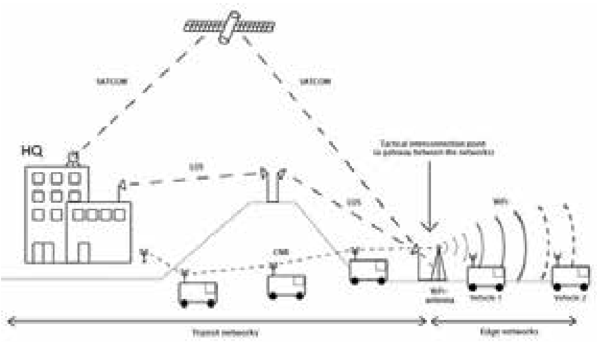

Figure 31: Different network technologies between HQ and the battlefield, used as either a transit or edge network.

S&T ACHIEVEMENTS

The recommendations enable application of existing SOA technology at the tactical level, which is a major advancement. IST-118 showed the advantage of cross-layer middleware, enabling adaptation of the services' communication behaviour to the special needs of tactical networks, and enabling parameterisation of the network to fulfil the services' communication requirements. IST-118 also pursued video- and text-based services, contributing to their use on the battlefield. Technology demonstration events showed a TRL of 4 (i.e., validation of the technology in a laboratory environment) and a TRL of nearly 5 (i.e., validation of the technology when integrated with supporting systems in a simulated operational environment). Additionally, the team produced 15 publications, nine presentations, and four workshops/demonstrations.

> Making existing HQ-level SOA applicable at the tactical level enables integration between these levels and reduces cost for the entire life-cycle of tactical SOA capabilities.

SYNERGIES AND COMPLEMENTARITIES

By integrating network emulation, physical radios, cross-layer middleware, communication services, etc., provided by different national stakeholders, IST-118 efficiently and effectively integrated a large network of contributions to benefit the Alliance. The work was also carried out in synergy with ongoing national projects and with NATO efforts such as Network-Enabled Capability and the Federated Mission Network.

EXPLOITATION AND IMPACT

Making existing HQ-level SOA applicable at the tactical level improves integration between tactical and HQ levels. This increases defence capabilities and (partly) removes the need to develop and implement separate HQ and tactical versions of the same functionalities, thus reducing costs over the entire life-cycle of tactical SOA capabilities.

CONCLUSIONS

IST-118 generated NATO-specific core service recommendations, enabling HQ to tactical level integration, and reducing costs. IST-118 achieved significant synergy within this large effort. Co-operation was achieved with other (non-) NATO and (inter)national entities. IST-118 shared acquired knowledge and experience through demonstrations, workshops, publications, and presentations.

INNOVATIVE UNDERWATER COMMUNICATIONS

As the first underwater digital communications standard, JANUS is a 'game-changer' in terms of communication interoperability in the underwater domain.

Mr. Joao Alves, STO-CMRE

BACKGROUND

Underwater communication capabilities are currently manufacturer-specific, using proprietary digital coding technologies with no interoperable capability between modems from different manufacturers. Obsolescence, procurement, and management risks prevent scalable and ad-hoc underwater networking from being practicable.

OBJECTIVE(S)

To fill this gap, CMRE has developed JANUS, an underwater digital communications standard currently in the final stages of acceptance as a STANAG. JANUS is a modulation and coding scheme, with additional mechanisms to render it practical. It is a standard with a common format for announcing a presence, exchanging low volumes of data, and creating an ad-hoc network.

S&T ACHIEVEMENTS

Following scientific trials, CMRE has exercised JANUS from the perspective of real end-users through connections in the operational community. Services include the so-called "Underwater AIS" and "Underwater METOC (Meteorological and Oceanographic)", developed and implemented with the support of the Portuguese Navy and their submarines. Prototype hardware for JANUS transmission and reception was installed in a modern diesel-electric submarine during an experiment in Portuguese waters. These capabilities delivered information vital to mission safety to a submerged submarine that is usually not available beyond periscope depth.

SYNERGIES AND COMPLEMENTARITIES

NATO relies heavily on interoperability. For connected forces, it is crucial that the forces from different Nations be able to work together. The Portuguese Navy committed high-value resources, including a modern diesel-electric submarine for the validation and testing of JANUS in operational-relevant scenarios. Germany provided equipment and scientists for the 2014 trial, which was also conducted with the Portuguese Navy. CMRE advocated JANUS to EC-funded projects in order to align the objectives of its partners with a standard for digital underwater communications. A NIAG study reported on JANUS application scenarios, future revisions, and definitions for compliance of JANUS equipment. A total of

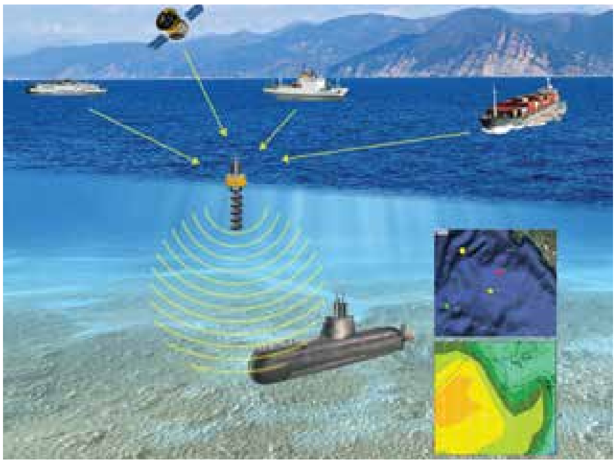

Figure 32: AIS and METOC information being delivered to underwater assets using JANUS acoustic communication.

29 experts from nine NATO Nations provided valuable feedback on the next steps of JANUS.

EXPLOITATION AND IMPACT

The challenges faced by underwater communications are immense (the low speed of sound propagation when compared to electromagnetic waves in air, and the physical ocean phenomena that affect propagation and disperse the signals both in time and frequency), and the requirements for underwater data exchange are increasing. The increased need for cost-effective underwater surveillance requires a communications capability where equipment from different manufacturers is able to work together to establish networks – JANUS is able, for the first time, to provide such a solution. This breakthrough can be used to deliver new underwater capabilities and de-risk the Nation's procurement programmes by reducing the dependence on individual manufacturers.

CONCLUSIONS

CMRE has developed, tested, validated, and promoted the first-ever, widely-adopted, digital underwater communications standard. The path to interoperability does not end in the promulgation of an accepted standard, but serves as a first step in demonstrating the possibility of a real roadmap for underwater communications standards. The CoI must continue its collaborative work and critically engage in the adoption of JANUS.

INTEROPERABILITY IN UNMANNED SYSTEMS

A focus on interoperability and security aspects of multi-domain unmanned systems has included technology demonstrations – both in the field of M&S and unmanned system energy persistence.

Dr. Stefano Fioravanti, Dr. Francesco Baralli, and Mr. Robert Been, STO-CMRE

BACKGROUND

There is a growing requirement for the co-operative operation of assets across multiple domains through a single control station in order to promote interoperability via component re-use, and to reduce manning, the equipment footprint, integration time, and cost.

OBJECTIVE(S)

The primary objective of the PARC project is to engage in NATO activities relative to unmanned system standards in order to ensure the interoperability of future NATO maritime unmanned systems.

S&T ACHIEVEMENTS

To develop a standardised, autonomous/ unmanned system software payload architecture, the application of an advanced side-scan sonar scenario for MCM was used as an example, with emphasis on a service-oriented approach. The results and the lessons learned in a sea trial using the new software have been captured in a technical memorandum. At an SCI-288 meeting, attempts to unify/align a proposed US generic framework for standardised autonomy architectures/frameworks with the Multi-Domain Control Station (MDCS) / UK's Maritime Autonomy Framework (MAF) met with some success. CMRE's involvement will continue if close alignment between the RTG's ideas on architecture and the direction taken by the MDCS group can be ensured.

SYNERGIES AND COMPLEMENTARITIES

The project team is involved in many NATO initiatives. The NNAG is considering using the NIAG Study-Group 202 (MDCS development) output for a future STANAG. An activity for a standardised approach to risk assessment, entitled "Security Challenges Related to Multi-Domain Autonomous and Unmanned C4ISR Systems" has been approved as Exploratory Team ET-099. CMRE is also active in the SCI-288 RTG on "Autonomy in Communications-Limited Environments", and in the Joint Industry Project on "Launch and Recovery of Autonomous Systems (JIP-LAURA)". The team is exploring the possibility of co-operating with JIP-LAURA in 2018.

EXPLOITATION AND IMPACT

Interoperability of Unmanned Maritime Systems (UMSs) is key to the success of future maritime operations, and CMRE is going to take a lead role in the development of future standards in this domain.

CMRE will be involved in setting up a multi-year, multi-national, government, and industry project on the creation of a STANAG for an MDCS. The development of a standardised, autonomous/ unmanned system software payload architecture will continue in 2017, building on the completed NIAG SG-202 report. CMRE also expects to participate in future RTGs on standards for unmanned system risk assessment, mission characterisation using architectures, M&S for verification and validation, and unmanned system counter-measures.

CONCLUSIONS

PARC has expanded its activities in the interoperability, standards, and unmanned system security field. CMRE's role as a NATO hub for collaborative S&T, development, and experimentation, fosters joint efforts towards NATO standards and multi-domain unmanned system interoperability.

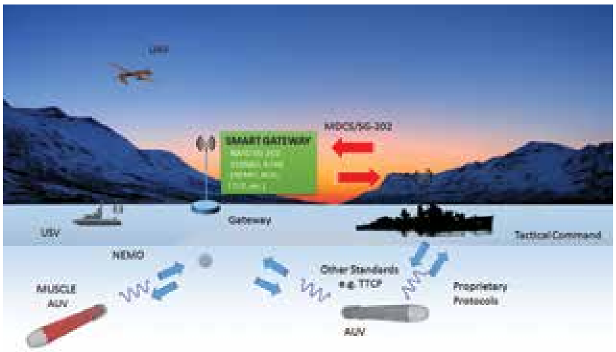

Figure 33: Interoperability in a MCM mission between UMSs.

ISR UNDERWATER GLIDER INTEGRATION INTO NATO C2-DS

At CWIX 2016, live information acquired by underwater gliders was provided in near-real-time to NATO and national C2 and COP systems using NATO standards. Two gliders were deployed 2,000 km from the site. For the first time, data were provided at the NATO SECRET (NS) level, working in coalition with NATO and national systems.

Dr. Raúl Vicen and Dr. Emanuel Coelho, STO-CMRE

BACKGROUND

CMRE has been working for several years on the provision of autonomously-collected maritime ISR information that has been successfully tested in several scientific experiments at sea.

OBJECTIVE(S)

The objective was to develop a solution consisting of a maritime ISR robotic network with scalable sensor payloads and a reach-back mission support service that can combine multiple layers of information from observations and modelling to create knowledge. High-fidelity observations of operating environments were delivered for integration and exploitation in NATO and national C2 and COP capabilities. Geographic, Meteorological, and Oceanographic (GEOMETOC) products need to be suited for operational and tactical planning.

S&T ACHIEVEMENTS

The concept tested during CWIX 2016 in association with the LOGMEC'16 sea trial is summarised in Figure 34. Two autonomous underwater gliders were deployed for two consecutive months, 24/7, controlled from the CMRE GliderC2 capability. NATO UNCLASSIFIED glider contacts/positions and tracks (past and intended) and the acquired oceanographic information were pushed to a NS network and provided to NATO and national C2 and COP capabilities using NATO-accepted standards. Data were provided in near-real-time to the operational site at the JFTC, over a distance of 2,000 km. Data from gliders were successfully provided using Open Geospatial Consortium (OGC) standards, interoperable within the NATO Allies.

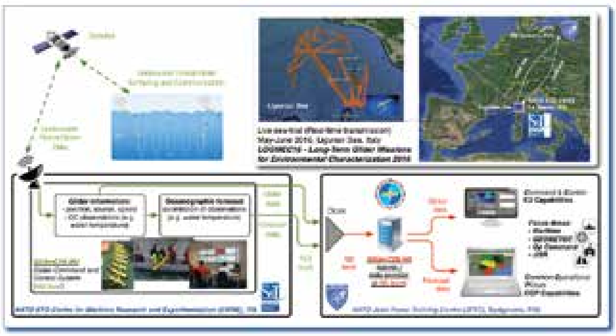

Figure 34: Live data provision of the CMRE GliderC2 capability in NATO Exercise CWIX 2016.

SYNERGIES AND COMPLEMENTARITIES

NATO and national capabilities were able to access live data from unmanned ISR assets, such as underwater gliders, during this demonstration of the CMRE GliderC2 capability in a NATO exercise. GEOMETOC, C2, and COP capabilities were able to test communication protocols and standards to communicate with the GliderC2 capability for the first time, accessing live data in near-real-time.

EXPLOITATION AND IMPACT

This was the first time underwater gliders provided live data in an operational context to NATO and national C2 and COP capabilities at the NS level in near-real-time. This allowed NATO and the Nations to test their own capabilities using this cutting-edge technology, providing ISR data autonomously and automatically to the end-users and decision-makers without exposing Alliance forces in high-risk areas.

CONCLUSIONS

CMRE has been working on an ISR unmanned underwater capability with a fleet of gliders with different payloads for several years. The exercise of this capability in the NATO Exercise CWIX 2016 was another step towards making it operational.

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

Infra-Red (IR) signature model accuracy directly impacts EW self-protection, intelligence threat assessment, as well as signature management specifications and design. This activity provides a means to validate methods and understand the propagation of uncertainty from models and inputs through to operational decision-making.

Dr. Nigel Smith, AUS, Defence Science and Technology Group and Dr. Martin Fair, GBR, Defence Science and Technology Laboratory

BACKGROUND

Vehicles and weapons are sources of IR radiation; IR signatures are routinely used to detect, track, and identify these systems. Accurate understanding and modelling of IR signatures is essential to the militaries of NATO and Partner Nations in meeting operational requirements for stealth, surveillance, and EW survivability. This exercise sought to establish the current state of validation and verification of IR signature prediction tools, and identify capability gaps and uncertainties.

OBJECTIVE(S)

The objective was to investigate key technical aspects of IR signature prediction for aerospace systems, with the primary focus being 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 NATO and Partner Nations, with corresponding blind predictions, were employed to examine each element both individually and collectively, and to articulate a validation methodology and signature prediction framework. Together, these concepts allowed 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

Prior to this activity, no single NATO or Partner Nation had access to all the requisite test-case data necessary to make a full assessment – for this effort, different Nations provided test cases specific to different model elements. The synergy achieved by combining the test cases and the national SMEs provided a rare opportunity to definitively assess the state-of-the-art of IR signature prediction and its impact on the military user. To further enhance the value of AVT-232, the RTG established links with the NATO Air Capability Group – Threat Warning Tech Team, SET-211 on "Naval Platform Protection in the Electro-Optical (EO)/IR Domain", and AVT-251 on "Multi-Disciplinary Design and Performance Assessment of Effective, Agile NATO Air Vehicles".

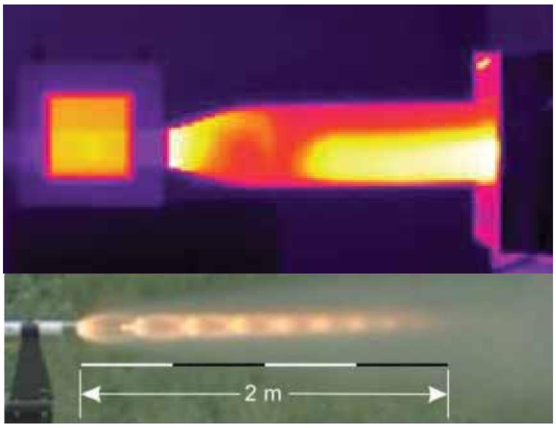

Figure 35: Experimental test cases used in the quantitative validation of plume structure and radiance tools as a part of IR signature prediction.

EXPLOITATION AND IMPACT

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

CONCLUSIONS

The test cases have been completed and compared, and the follow-on activity (AVT-281) will adhere to a cross-domain approach as the next step in IR signature prediction.

M&S RESOURCE DISCOVERY AND ACCESS (MSG-100)

NATO Nations require enhanced M&S capabilities in order to meet the challenges of reduced funding for data development and systems acquisition declines. One solution is to develop an improved capability to discover and reuse existing M&S resources to meet increasing demand.

Mr. John Moore, USA, Navy Modelling and Simulation Office

BACKGROUND

The NATO M&S Master Plan (NMSMP) defines the NATO M&S vision, guiding principles, and primary application areas. One of the objectives of the NMSMP is to establish a common technical framework to advance and promote interoperability and reuse. A central catalogue is essential in achieving this objective.

OBJECTIVE(S)

The objective was to improve M&S resource discovery and reuse, increase interoperability, and enable sharing between Nations via a common taxonomy and interface specification.

S&T ACHIEVEMENTS

A proof of concept demonstrated the processes and procedures necessary to add, edit, discover, and remove M&S metadata from existing catalogues. The demonstration showed two things: 1) How to accomplish these functions within the Data Services Environment and the US Department of Defense (DoD) Enterprise Catalogue; and 2) How an individual Nation could perform similar procedures using a different catalogue system to satisfy a training requirement.

This proof of concept used an existing Unstructured Information Management Architecture (UIMA) technology to analyse large volumes of information to discover the information sought by an end-user. The UIMA core was extended to apply specifically to M&S metadata via a Local Inventory Metadata Engine (LIME). LIME has additional capabilities to update metadata holdings after back-up data sets are created and to harvest metadata from updated M&S training systems upon the conclusion of training exercises.

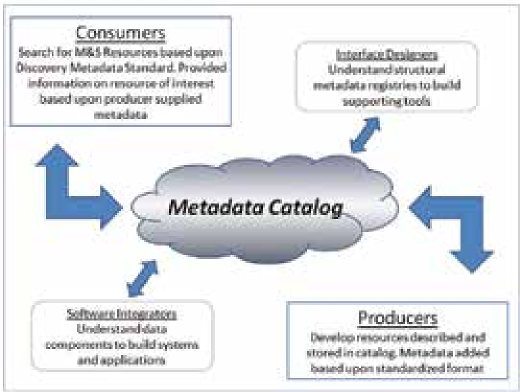

Figure 36: Relating consumers and producers via metadata.

> Establish a common technical framework to foster interoperability and reuse.

SYNERGIES AND COMPLEMENTARITIES

Increased adoption of stable Discovery Metadata Specification (DMS) will allow more user interfaces, automated population tools, and automatic output reporting algorithms. Each will significantly reduce the level of effort required to discover recyclable resources, thus improving software reuse. There will be more assets to choose from, and so it is more likely that the capability need and the resource previously developed will match.

EXPLOITATION AND IMPACT

The report recommends techniques to improve how M&S resources are discovered and made available for reuse, increase interoperability, and enable sharing between Nations. These recommendations apply to discovery and structural metadata, as well as to asset repositories.

CONCLUSIONS

While it is unlikely that a single technical solution will satisfy all the needs of each NATO Nation, it is evident that a technical solution is achievable. Equally important are the non-technical aspects of advancing NATO M&S interoperability, including the business and governance processes. MSG-100 provides a set of applicable M&S resource and access recommendations to promote the adoption of an M&S discovery metadata standard, update NATO's M&S DMS, develop and employ business models to promote M&S reuse, and enhance the NATO Simulation Resource Library (NSRL).

EXCELLENCE IN NATO SCIENCE AND TECHNOLOGY

Every year, during their Fall meeting, the NATO STB acknowledges excellence in S&T by awarding a von Kármán medal in recognition of either a complete STO œuvre or a single outstanding achievement, and awarding significant STO activities for their scientific achievements.

In 2016, Mr. Daniel Chaumette was awarded the von Kármán medal, and the following six STO activities received awards for scientific achievement:

- Economics for Evaluating Fleet Replacement (SAS-099);
- Enhanced CAX Architecture, Design and Methodology – SPHINX (MSG-106);
- Integrated Munitions Health Management: The Consequences of Not Knowing (AVT-212);
- Mid-Infra-Red Fibre Lasers (SET-170);
- NATO's Critical Role in Biological Defence: The Long-Term Challenges of Medical Countermeasures Development (HFM-186); and
- Radio Frequency Directed-Energy Weapons in Tactical Scenarios (SCI-250).

Further documentation of the results of these efforts are available on the STO website: www.sto.nato.int.

EXCELLENCE IN NATO SCIENCE AND TECHNOLOGY

NATO's STB recognises the value of S&T excellence within the Alliance. The quality of S&T, the breadth and depth of the collaboration within NATO, and the potential impact and exploitation are the key elements for displaying its recognition.

Every Fall, the 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 presents the achievements to the successful candidates during the STB meeting in the Fall.

The von Kármán Medal is the most prestigious scientific and technological award; it is a personal prize that recognises either the whole STO œuvre or a single outstanding STO achievement of the laureate. Exemplary service and significant contribution to the enhancement of progress in S&T collaboration among NATO, Member Nations, and Partners within the STO are key. The medal is presented together with an accompanying citation, signed by the STB Chair.

An SAA recognises exceptional accomplishments in STO S&T activities. The emphasis is on recently-completed work that has significant impact for NATO, the Nations and the technical community. It can be granted to individuals or to teams. The SAA consists of a certificate and an accompanying citation, signed by the STB Chair.

In 2016, during the Fall meeting in Rome, Italy, the STB awarded one von Kármán Medal and six SAAs, which are summarised on the following pages.

THE 2016 VON KÁRMÁN MEDAL

Mr. Daniel Chaumette is a globally-recognised expert in high-performance structures and materials, focussed on fatigue life prediction, integrated design analysis and optimisation of aircraft structures, and the development of new composite materials. Throughout his extraordinary career, he has exemplified the best of collaborative S&T, and has masterfully driven the implementation of cutting-edge research results to high-profile aviation platforms, directly impacting the safety and airworthiness of state-of-the-art combat aircraft, space vehicles, and airliners.

In the 1970s, Mr. Chaumette developed fatigue and damage tolerance tools and methodologies that have become standard procedure in industry today. He dramatically advanced the metallic thermal protection systems of the Space Shuttle through innovative brazing methods, a field in which he holds several patents. He was instrumental in the development and establishment of airworthiness regulations for airliners, which are employed by all European countries today. His vast work in carbon-fibre composites led to several pioneering designs in aviation and fast, efficient marine vessels – yet another field in which Mr. Chaumette holds a patent.

Figure 37: Mr. Daniel Chaumette receives the 2016 von Kármán medal from the former NATO Chief Scientist, MGen Albert Husniaux (BEL AF).

For more than 40 years Mr. Chaumette has been dedicated to the highest level of scientific and technical work in NATO and has demonstrated exemplary leadership, catalysing exceptional collaborative work to advance vehicle technology in the NRV *Alliance*. Mr. Chaumette embodies the values that Dr. von Kármán held dearly for collaborative research, and has effectively bridged the gap between academia, industry, and the military throughout his career.

As a gifted speaker and true educator, Mr. Chaumette has passionately shared his breadth of knowledge with a generation of scientists and engineers. For nearly 20 years, he has taught a course in composite structures and materials at École Nationale Supérieure de Techniques Avancées, one of the most prestigious and selective French engineering universities. He has also transferred his knowledge of composite structures to the electro-nuclear industry and his expertise in bonded structures to the automotive industry, resulting in significant safety improvements in both fields.

For his steadfast dedication and leadership within NATO S&T, and his remarkable contributions to the S&T Community, the STB hereby recognises Mr. Chaumette for his exemplary work by presenting him with the 2016 von Kármán Medal.

ECONOMICS FOR EVALUATING FLEET REPLACEMENT (SAS-099)

This work provides a modelling tool to assist military decision-makers in determining optimum fleet replacement times. The Greenfield-Persselin real options fleet replacement model was extended, yielding a statistically-determined time window for an optimal replacement or a 'reset-the-clock' overhaul. Using three different aircraft fleets as case studies, the decision-making tool was demonstrated.

Mr. David Maybury (Task Group Chair – on behalf of the RTG), CAN, Defence Research and Development Canada

BACKGROUND

Military fleet replacement decisions represent an example of investing under uncertainty. As vehicles age, it is expected that operation and maintenance costs will eventually reach a prohibitive level. Timing the fleet replacement decision presents the decision-maker with a trade-off between learning more about the fleet's cost performance in an uncertain environment, and minimising the total fleet ownership cost. In light of NATO's aging fleets, understanding the value of delay will feature centrally in optimal replacement decisions.

OBJECTIVE(S)

The objective was to provide a methodology for determining and standardising the economics for evaluating fleet replacement decisions.

S&T ACHIEVEMENTS

A method that expands on the real options literature for evaluating fleet replacement decisions was delivered. Instead of relying on central fits to set the replacement decision, the focus was placed on the statistical inference methods for qualification. In particular, it was found that the extended Greenfield-Persselin real option model yields new opportunities for evaluating fleet or equipment replacement decisions.

> Once the military makes the irreversible investment, it no longer has the opportunity to learn more about its current fleet – surrendering the opportunity to learn forms part of the total acquisition cost. [SAS-099 final report]

SYNERGIES AND COMPLEMENTARITIES

The model was illustrated using both Bayesian and Frequentist methods, with three case studies: the Royal Canadian Air Force CF-18; the United States Army AH-64; and the Swedish Air Force C-130. The case studies leveraged the collateral efforts of the US-Canada Army Operational Research Symposium.

EXPLOITATION AND IMPACT

In three cases, Canada's Department of National Defence (DND) used the methods of SAS-099 in support of major acquisition decisions. The fleets involved were under the CP-140 Modernisation Programme, the Logistics Vehicle Replacement Programme (multiple fleets), and the CH-149 Programme. The models showed decision-makers how to incorporate measures of military utility into the economic analysis, and emphasised the importance of information in an uncertain costing environment. By using a real options approach and exploiting the outputs of SAS-099, the Alliance can better understand the drivers of a fleet replacement decision.

Photo Credit: Sgt Gaétan Racine, Canadian Forces Combat Camera

Figure 38: Maintenance of Canada's CC-177 Globemaster.

CONCLUSIONS

SAS-099 built upon the real options model of Greenfield and Persselin and promoted the model to a practical fleet replacement decision-making tool by focussing on a first passage time approach. The RTG explicitly showed the decision-maker how trade-offs in uncertainty affect the fleet replacement timing decision. The results showed how decision-makers can use real option techniques to support real-world replacement decisions.

ENHANCED CAX ARCHITECTURE, DESIGN AND METHODOLOGY – SPHINX (MSG-106)

Distributed exercises require more intensive use of simulation, which implies they are more complicated to organise. This RTG provided a complete response with a conceptual model called SPHINX that describes a CAX and presents several guidelines for customers, users, and suppliers, resulting in best practices for their use by the exercise community.

COL Laurent Tard (Task Group Chair – on behalf of the RTG), FRA, Joint Defence Staff

BACKGROUND

Motivated in part by budget pressure, NATO Nations joined together to develop new M&S capabilities. One example is MSG-096 on "Consequence/Incident Management for Coalition Tactical Operations", which developed initial technical solutions enabling Distributed CAX. Here, 'distributed' means multiple trainees at multiple training centres using multiple tools. The resulting Distributed CAX is more complex to organise. In response, NATO developed the Collective Training and Exercise Directive (Bi-SC 75-3), which is a reference document for organising exercises in support of the officer conducting the exercise.

OBJECTIVE(S)

The objectives were to: provide guidelines for exercise control and simulation control cells in performing CAX; use tested technical solutions to improve and extend the Federation Architecture and Federation Object Model (FOM); design a reference document; and provide products and recommendations for standardisation, quality assurance, co-ordination, and risk management.

Distributed exercises require more intensive use of simulation.

S&T ACHIEVEMENTS

The Task Group produced a set of reference documents for CAX use in the Nations: M&S Standard Profile for NATO and Multi-National CAX with Distributed Simulation (AMSP-03); NATO Education and Training Network (NETN) Federation Architecture and FOM Design (AMSP-04); Handbook for CAX Best Practices (AMSP-05); and A Conceptual Model Supported by an Experimental Tool (SPHINX).

SYNERGIES AND COMPLEMENTARITIES

Twenty Nations, seven NATO bodies and more than 100 people worked together to deliver these documents. As a capstone event, MSG-106 conducted a limited demonstration at I/ITSEC (Interservice/Industry Training, Simulation, and Education Conference) in December 2014 to illustrate the SPHINX concept.

EXPLOITATION AND IMPACT

The results of MSG-106 support M&S interoperability during the preparation, execution, and exploitation of CAX. The SPHINX conceptual model provides CAX leaders/organisers with a clearer mutual understanding of virtual and constructive exercises which decreases risks and increases potential for success in exercise execution. Additionally, the harmonisation and standardisation enabled by the SPHINX model increases interoperability and re-use to achieve cost-effective M&S to support CAX. Experiences gained during the planning of exercises such as the VIKING EXERCISES (SWE) and NetOpFueEXER (DEU) supported the process in feeding and evaluating this theoretical approach with real-life exercise planning.

CONCLUSIONS

MSG-106 was an extremely large RTG delivering three Allied M&S publications, focussed not only on technical matters (NETN architecture and FOM design), but also on organisation and operational issues (Handbook for CAX). The SPHINX conceptual model has been developed and tested to provide a mutual understanding among all stakeholders.

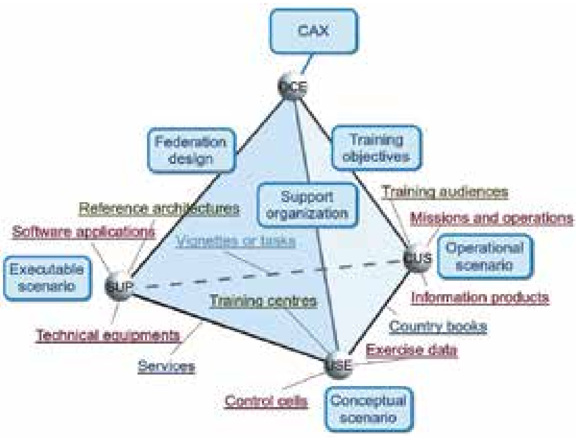

Figure 39: Conceptual model SPHINX describing a CAX.

INTEGRATED MUNITIONS HEALTH MANAGEMENT: THE CONSEQUENCES OF NOT KNOWING (AVT-212)

Integrated Munitions Health Management (IMHM) is a NATO initiative that will revolutionise the way health and safety of munitions is monitored, analysed, predicted, and managed. IMHM aligns technology with a number disciplines and organisations, and is structured towards a common goal. The output provides compelling benefits with transversal impact on safety, cost, and performance.

Dr. Robert A. Mueller, (Task Group Co-Chair – on behalf of the RTG), USA, Micron Instruments and Dr. Steven Wagstaff, (Task Group Co-Chair – on behalf of the RTG), GBR, Fraser-Nash Consultancy

BACKGROUND

The service life of munitions is currently estimated using conservative assumptions with little or no knowledge of an individual munition's condition. The actual remaining safe service life may vary positively or negatively through exposure to benign environments or exceptional events. Costs and impacts from not knowing the actual status of a munition item include: loss of life; loss of capability; loss of use; and unnecessary disposal.

Figure 40: MINERVE missile demonstrator with an implemented sensor system to measure the condition of the missile.

OBJECTIVE(S)

IMHM seeks to: increase safety for aged assets; understand individual munition life; facilitate flexible stockpile management including in-service support; and enable asset and cost sharing by NATO Nations.

S&T ACHIEVEMENTS

AVT-212 conducted the first Co-operative Demonstration of Technology (CDT) at NATO HQ, in Brussels, Belgium. Keynote speakers included: the former NATO Chief Scientist, MGen Albert Husniaux; the Deputy Assistant Secretary General for Defence Investment, Mr. Ernest J. Herold; and the Deputy Director of the Logistics and Resources Division of the International Military Staff, Brigadier General Bo Engelbreth. The team demonstrated the objectives and benefits of IMHM and showed that it is ready for immediate deployment.

SYNERGIES AND COMPLEMENTARITIES

The IMHM CDT demonstrated the advancement of a NATO-common approach developed through the S&T framework, enabling collaboration between government, industry, and academia. The core ethos of IMHM is the linking of capability and the co-operation of Nations. The approach supports a 'Linked Force Capability' that encompasses infrastructure, personal, logistics, and assets.

EXPLOITATION AND IMPACT

IMHM technologies are available and ready today, and are already being used to improve safety and reliability of a current munition programme. The IMHM CDT was the driving force that led to successful ratification of a NATO IMHM Smart Defence Initiative, with seven Member Nations already participating.

CONCLUSIONS

The CDT successfully demonstrated key benefits: Safety – technology and in-service surveillance to inform safety decisions; Cost – the deferral of asset disposal; Performance – greater understanding of current condition and ability to perform mission objectives; Reliability – improved knowledge of both current operational status and the safe remaining service life of individual munitions; and Interoperability – supports collaboration within and across NATO Nations and enables the creation of a shared capability stockpile.

IMHM is an approach to enhance the way munitions are managed in NATO. It is structured towards understanding relative risk and providing associated benefits which have impact on reducing cost, and improving safety and performance.
– MGen Albert Husniaux, former NATO Chief Scientist and STB Chairman

MID-INFRA-RED FIBRE LASERS (SET-170)

Fibre lasers have distinct advantages for IR counter-measures and remote sensing, but have been limited in practice due to rare and fragile materials, and high optical losses. SET-170 addressed these shortfalls by advancing direct lasing in rare-earth-doped fibres, supercontinuum generation, and pump sources for bulk frequency conversion devices.

Dr. Rita Peterson (Task Group Chair – on behalf of the RTG), USA, Air Force Research Laboratory

BACKGROUND

NATO aircraft are increasingly threatened by heat-seeking missiles in spectral bands where effective counter-measures do not exist. New laser technology is required to defeat these lethal threats.

OBJECTIVE(S)

The objective was to develop new fibre laser sources in the critical mid-IR region that can be practically inserted into airborne counter-measure systems.

Figure 41: SET-170 advanced laser technology to defend NATO pilots from heat-seeking missiles, increase military target identification range, and enhance surveillance of terrorists and insurgents.

S&T ACHIEVEMENTS

The team evaluated rare-earth ions and identified those most promising for mid-IR lasers. They also identified crystalline host materials in which to place these ions and developed techniques to optimise the combined performance of the optimal host/ion combinations. To improve supercontinuum mid-IR laser sources, the team increased the power output provided by both fluoride-doped and chacogenide-doped fibres, studied the efficacy of various input power coupling techniques, and identified several parasitic factors limiting low-frequency light generation. The team also developed techniques to efficiently provide input power to the mid-IR sources, studied several input sources fabricated from multiple materials, and evaluated the efficacy of these materials fabricated in device geometries. These achievements provide the scientific foundation upon which new laser sources extending counter-measures and remote-sensing capabilities can be developed.

SYNERGIES AND COMPLEMENTARITIES

SET-170 addressed key technology problems, needs, and capabilities within NATO by bringing 11 scientists from eight NATO Nations into a tightly-coupled theoretical and experimental project. The RTG reached out to other NATO sub-groups to harmonise its foundational research with systems developers. The team actively supported a workshop that reviewed the state-of-the-art in mid-IR fibre lasers and put forth key recommendations for addressing issues confronting further progress, and a Specialists' Meeting on "Mid-IR Laser Technology" that co-ordinated this important technology with the NATO user community and experts in alternative laser technology.

EXPLOITATION AND IMPACT

Generating laser energy at the frequencies used by aircraft missile guidance systems is a technology that is critical in protecting NATO aircraft from these threats. By leveraging high-intensity broadband lasers sources, this work also enhances remote-sensing missions for combat identification, counter-terrorism, and counter-insurgency.

NATO aircraft are increasingly threatened by heat-seeking missiles in spectral bands where effective counter-measures do not exist.

CONCLUSIONS

The SET-170 team provided relevant technology to improve mid-IR laser sources for both aircraft protection and advanced remote-sensing applications. The team's multi-disciplinary approach to material design, fabrication, and testing was critical to demonstrating this key technology. The vital technological advances from this team will be transferred to NATO's industrial partners and end-users.

NATO'S CRITICAL ROLE IN BIOLOGICAL DEFENCE: THE LONG-TERM CHALLENGES OF MEDICAL COUNTER-MEASURES DEVELOPMENT (HFM-186)

What will the next outbreak be? For the first time ever, HFM-186 examined NATO Nations' R&D on medical diagnostics and counter-measures against biological agents or related highly-contagious infectious diseases. Both are key to military medical readiness and a Nations' ability to respond to and counter these threats.

Dr. Leonard Smith (Task Group Chair – on behalf of the RTG), USA, Army Medical Research Institute of Infectious Diseases

BACKGROUND

NATO and PfP Nations figure prominently as first responders, international co-ordinators, and occasionally as impacted Nations in the face of disease outbreaks. NATO R&D on medical diagnostics and counter-measures against biological agents are essential to both military medical readiness and a Nations' public health response. During the Ebola Virus Disease outbreak of 2014/15, many NATO Nations responded with medical capabilities enabled by the knowledge represented by this RTG.

Vaccination, when available, is preferable for many diseases, but may be impracticable for a number of agents. The incubation time following exposure offers the possibility for intervention, but many counter-measures have not been tested and approved, and their effectiveness against new or emerging diseases is currently unknown.

OBJECTIVE(S)

HFM-186 sought to conduct a broad study of the mechanisms of biological agent-related infectious diseases, prophylaxis, and therapy in Chemical, Biological, Radiological and Nuclear (CBRN) defence.

S&T ACHIEVEMENTS

This RTG produced the first-ever compilation of NATO and PfP Nations' R&D perspectives on militarily-relevant infectious diseases and medical biological defence. It addressed the ramifications of recent advances in microbiology, molecular biology, and genomics, with an eye towards operational relevance. The final report serves as a science-based guide for both operational and medical Commanders.

SYNERGIES AND COMPLEMENTARITIES

This Task Group was fully integrated into the activities of NATO's Committee of the Chiefs of Military Medical Services / Biological Medical Panel (COMEDS/BioMedAC). While focussing on infectious disease S&T, it was constantly mindful of the challenges and requirements associated with the fielding and use of the counter-measure products being developed and investigated.

Figure 42: Success in the laboratory has direct application to NATO's understanding of how to cope with exotic diseases in real-world settings.

EXPLOITATION AND IMPACT

This RTG generated renewed interest and overall medical preparedness across NATO. It emphasised the need for rapid identification of broad-spectrum bacterial and viral threats. The RTG included participants from Nations which have not historically had medical biological defence research programmes, allowing them to leverage over 500 million USD in NATO-wide Research Development Test and Evaluation (RDT&E) efforts.

HFM-186 was the basis for a NATO Symposium (HFM-239) on "Medical Counter-Measures", which was attended by scientists from approximately one-third of the NATO Member Nations.

CONCLUSIONS

The biological threat is more diffuse and less-well understood than during the Cold War; this has caused a shift from vaccines to diagnostics and therapies as a focus for future efforts. The value and importance of global collaborations in research, development, and testing was also noted.

RADIO FREQUENCY DIRECTED-ENERGY WEAPONS IN TACTICAL SCENARIOS (SCI-250)

The team investigated applications and aspects of RFDEW in order in order to improve future material solutions and facility design. The RTG conducted a technology demonstration trial – the first of its kind – with a well-attended Visitors' Day.

Dr. Ernst Krogager (Task Group Chair – on behalf of the RTG), DNK, Danish Defence Acquisition and Logistics Organisation

BACKGROUND

Since 1990, technical teams under the former NATO Defence Research Group (DRG), and most recently the STO, have conducted studies related to the threat of High-Power Microwave (HPM) systems to electronic systems. From initial generic studies, the PoWs have progressed into recent programmes of testing tactical network equipment. Radio Frequency Weapons (RFW) have the potential to support NATO activities with low collateral damage and non-lethal weapon capabilities.

OBJECTIVE(S)

SCI-250 addressed the use of HPM and RFW against military infrastructure and electronic equipment. The specific objectives included: evaluating RFW effects on electronic systems; military value and tactical implications; concepts for use and constraints; a tactical demonstration of technology; and RFW as a non-lethal weapon.

Figure 43: An HPM source used during the trial.

S&T ACHIEVEMENTS

Preparatory laboratory tests were carried out before a demo trial called Trial DEAR (Directed Energy At Radio frequencies) was held in Norway. The synergy of bringing together different systems and approaches provided valuable knowledge for further research and development efforts.

SYNERGIES AND COMPLEMENTARITIES

A Lecture Series, SCI-249 on "Radio Frequency Directed Energy Weapons", was organised in parallel to the effort at venues in France, Slovakia, Turkey, and the United States. An automated data acquisition system was borrowed from the Trial MACE Team under the NATO Air Force Armaments Group (NAFAG). Counter Improvised Explosive Device (C-IED) applications were included in the trial, supported by NATO C-IED Funding. The work was presented at a Symposium "Innovation for C-IED", held by the S&T Board in Vilnius, Lithuania. The SCI-250 Chairman gave briefings to NAFAG and was a member of three other activities: SAS-094 "Analytical Support to the Development and Experimentation of NLW Concepts of Operation and Employment"; SCI-256 "Route Threat Detection and Clearance Technologies"; and SET-161 "Leading Body for the C-IED LTCR".

EXPLOITATION AND IMPACT

A Visitors' Day was held with more than 30 distinguished attendees, notably the former NATO Chief Scientist, the NCIA Chief of Staff, and the CSO Executive Officer to the Director. The trial was covered by NATO TV in the form of a video published on the NATO YouTube site, "*Suicide bombers – and how to beat them*" (see: https://www.youtube.com/watch?v=56veH8-KbEM). An alternative RF car stopper was demonstrated by E2V on the BBC (British Broadcasting Corporation) News. This system will be involved in a follow-on group that will also carry on with studies of RFW against Unmanned Aerial Systems (UAS).

> RFW have the potential to support NATO activities.

CONCLUSIONS

The field trial resulted in a substantial amount of common data and reached a wide audience through a well-attended Visitors' Day and a video published by NATO TV.

Annexes

ANNEX A – STO CORPORATE STRATEGY

We are the NATO Science & Technology Organization…

- We deliver innovation, advice, and scientific and technical solutions to meet the Alliance's needs.
- We are the world's largest collaborative research forum in defence and security, composed of world-class expertise.
- We cherish a collaborative international environment that is both challenging and stimulating.
- We foster high-impact S&T to maintain cutting-edge capabilities for the Nations and NATO.

This Corporate Strategy guides the future of NATO's Science & Technology Organization. Through this Strategy and our supporting actions, we will continue to nurture and actively advance our collaborative S&T environment and focus efforts to stimulate cross-discipline activities to deliver innovative solutions that meet the rapidly evolving needs of our Nations and of NATO.

The NATO Science and Technology Organization's shared **vision** is to …

> ***Catalyse and leverage the Nations' and NATO's S&T investments to push the boundaries of knowledge to create science and technology-based capability advantages for the defence and security of the Alliance and its Partner Nations.***

We share a common **mission** to …

> ***Generate and exploit a leading-edge S&T programme of work, delivering timely results and advice that advance the defence capabilities of NATO Nations, Partner Nations, and NATO in support of collective defence, crisis management, and cooperative security.***

The STO achieves its mission by nurturing a vibrant collaboration network of over 5,000 actively engaged scientists and engineers; this network draws upon the expertise of over 200,000 scientists and engineers in their Nations. The knowledge network delivers timely S&T results and supports the generation and delivery of advice to Nations and NATO.

The STO brings new science and new technologies from the global innovation system to create and advance capabilities that support Alliance mission success.

THE NATO SCIENCE & TECHNOLOGY ORGANIZATION (STO)

The STO plans and delivers a programme of work (PoW) that covers a broad spectrum of defence and security related S&T. The PoW contributes to capability development, supports threat mitigation, and provides advice to decision makers. The STO welcomes participants and contributors from Allied and Partner Nations, coming from government, industry, or academia. In pursuing this mission, the STO positions S&T to the strategic advantage of Nations and NATO, thereby supporting the core tasks of the Alliance.

The STO is governed by the Science & Technology Board which comprises of senior national defence S&T leaders. The STB is responsible for developing and maintaining the strategic guidance for S&T in NATO, promoting synergies across stakeholders while respecting their individual responsibilities and authorities. The STB oversees policies and management and guides, directs and supports the STO PoW. The NATO Chief Scientist chairs the STB and serves as the scientific advisor to senior NATO leadership. The NATO Chief Scientist is supported by the *Office of the Chief Scientist* (OCS) at NATO HQ in Brussels, Belgium.

The Multinational Collaboration delivers the largest S&T PoW within the NATO framework. It promotes multinational collaboration that augments each contributor's resources by leveraging the knowledge, skills, and investments made available by all contributors. It is predominantly funded by participating Nations in line with their individual objectives; to a lesser extent, it is funded by NATO directly in support to overarching Alliance objectives. The delivery of this programme rests on two pillars that are critical assets for the STO's mission success: a network of subject matter experts and dedicated research facilities.

… IN A NETWORK

With nearly 5,000 active participants per year, the STO is home to the world's largest international network of defence and security scientists and engineers. This network embraces a broad spectrum of scientific fields and is designed to address defence relevant aspects. Cross-domain activities are launched whenever appropriate. 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 200 such activities. NATO provides executive support to this network and its PoW through the *Collaboration Support Office* (CSO), located in Neuilly-sur-Seine, France.

… IN DEDICATED RESEARCH FACILITIES

The *Centre for Maritime Research and Experimentation* (CMRE) is a maritime S&T establishment with research and experimentation facilities focused on the maritime domain. The Centre carries out projects and experiments for its customers to deliver military-relevant, state-of-the-art, scientific research and technology development. The CMRE advances the basic understanding and naval capabilities needed to operate effectively and efficiently in the maritime domain, and facilitates interoperability in future naval systems. The key enablers for delivering the CMRE's programme are its 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.

STO STRATEGIC GOALS

1. The STO leads and conducts a defence-focussed programme of work by leveraging and cooperatively combining science, technology and innovation capabilities of Nations and NATO and catalysing collaborations to deliver relevant and timely S&T products for procurement, policy and military decision makers. The STO accesses knowledge, advances capabilities and uses analytical expertise to provide advice and deliver solutions to National and NATO challenges.

2. The STO facilitates access for Nations to unique S&T facilities to enable and inspire experts to develop, test, demonstrate and evaluate innovative capabilities and concepts for collective defence and security of the Nations.

3. The STO provides trusted, timely and S&T-based advice and solutions for collective defence and security for NATO and the Nations' decision makers. The STO generates evidence-based advice linking S&T knowledge and current and future military capabilities of the Alliance and of the Nations.

4. Under the direction of the STB, the STO manages its program of work with lean, efficient and effective governance. The STB governs the STO with clear direction and guidance, and provides unifying vision and guidance to the entire NATO S&T community, ensuring responsiveness to National and NATO needs.

Goal 1: The STO leads and conducts a defence-focussed programme of work by leveraging and cooperatively combining science, technology and innovation capabilities of Nations and NATO and catalysing collaborations to deliver relevant and timely S&T products for procurement, policy and military decision makers. The STO accesses knowledge, advances capabilities and uses analytical expertise to provide advice and deliver solutions to National and NATO challenges.

OBJECTIVES:

1. The STO Programme of Work (PoW) yields technical reports, advice and other knowledge products in a timely fashion to the Nations and NATO to support decision-making.

2. The STO S&T experts "lead the future" through the conduct of research and experimentation activities and the demonstration of technology with potential military relevance at the forefront of science.

3. STO staff facilitate collaboration among scientists and engineers and support the distribution and utilization of S&T results, using advanced Information and knowledge management tools.

4. The STO S&T experts maintain a common picture of emerging technologies dynamically assessed for relevance to defence and security.

5. The STO and the Nations continually fuel a vibrant innovation network of scientists, engineers and military operators to deliver S&T-based results and solutions.

The STO PoW contains all scientific and technical work planned, executed and delivered by the STO; this PoW is focused on the delivery of S&T results with high impact to the Alliance.

The Scientific and Technical Committees and the Centre for Maritime Research and Experimentation (CMRE) plan, execute and deliver the STO PoW. The CSO facilitates collaboration and manages the collaborative program of research and experimentation across Nations. The CMRE delivers a PoW where activities are led by the CMRE, with collaboration with and contributions from Nations and other international bodies.

Goal 2: The STO facilitates access for Nations to unique S&T facilities to enable and inspire experts to develop, test, demonstrate and evaluate innovative capabilities and concepts for collective defence and security of the Nations.

OBJECTIVES:

1. The STO catalyses the development and use of collaborative laboratory facilities at the cutting-edge for addressing the Alliance needs.

2. The STO facilitates access to unique combinations of expertise, knowledge base and services to reduce risk in S&T through test and evaluation of developmental capabilities, as well as concept development for implementation of innovative solutions.

3. Access to a network of unique S&T facilities in the Alliance, both national assets and NATO assets, is facilitated and coordinated through the STO to support S&T activities for collective defence and security.

The STO supports unique S&T facilities and expert groups. The STO provides unbiased expertise to support Allies' and NATO's acquisitions through independent research, development, field trials, and test and evaluation of defence capabilities. STO-supported facilities also develop standards and interoperability, thereby augmenting national programmes and facilities.

Goal 3: The STO provides trusted, timely and S&T-based advice and solutions for collective defence and security for Nations' and NATO decision makers. The STO generates evidence-based advice linking S&T knowledge and current and future military capabilities of both Nations and NATO.

OBJECTIVES:

1. The STO provides timely responses to questions directed at STO by National and NATO decision makers and policy developers.

2. The STO systematically uses its knowledge base and S&T network to analyse questions in context and synthesize the findings into a response appropriate for Nations' and NATO's decision makers and policy developers.

3. The STO continuously nurtures, expands and monitors its knowledge base and innovation networks to facilitate subject matter expert contributions and to proactively identify and generate S&T advice on defence and security issues to Nations' and NATO's decision makers.

Evidence-based advice and solutions are derived from S&T knowledge applied to defence and security questions or challenges. It is tailored to a specific audience to ensure effective delivery of the decision support and it is traceable, auditable, and defensible.

The collective activities of the STO contribute to increasing S&T knowledge base and defence and security capabilities. That knowledge base, and its underpinning network of S&T practitioners, form the foundation for evidence-based advice. Both the knowledge base and the scientific network are available across the community. The CSO and CMRE provide support to the NATO Chief Scientist with S&T results and advice that enable him to capitalize on the entire STO PoW to provide NATO with timely, authoritative and comprehensive information and evidence-based advice.

Goal 4: Under the direction of the STB, the STO manages its program of work with lean, efficient and effective governance. The STB governs the STO with clear direction and guidance, and provides unifying vision and guidance to the NATO S&T community, ensuring responsiveness to National and NATO needs.

OBJECTIVES:

1. The STB provides strategic guidance, direction and expectations to the STO Executive Bodies and Scientific and Technical Committees.

2. The Chairs of Scientific and Technical Committees and STO Heads of Executive Bodies strive, within their areas of responsibility, to increase agility and responsiveness to address the Nations' and NATO's needs in a timely manner.

3. The STO Heads of Executive Bodies are accountable to the STB, the Nations and NATO to operate with efficiency and effectiveness principles so that S&T results are delivered to generate impact for the Nations and NATO.

4. The STO focusses its corporate communications, under the leadership of the NATO Chief Scientist, to maximize the exploitation of S&T results, enhancing military capabilities as well as S&T capacities of the Nations and NATO.

The STB is accountable to NATO and the Nations for resources used for the delivery of STO PoW. The STB is also accountable to provide clear direction and expectations to the STO, its Executive Bodies and Chairs of Scientific and Technical Committees. The STB entrusts the NATO Chief Scientist, as the STB Chairman, to supervise the implementation of STB guidance and direction.

The Chairs of Scientific and Technical Committees and the STO Heads of Executive Bodies are accountable to the STB for developing plans that are aligned with the guidance and requirements defined by the STB. They provide regular updates to the STB and the NATO Chief Scientist, in his capacity as the STB Chairman, on their plans, objectives and results in a timely manner.

The STB relies on the NATO Chief Scientist to serve as the STO's principal interface with senior leadership at NATO HQ and across NATO, supported by the STO Heads of Executive Bodies and Chairs of Scientific and Technical Committees.

ANNEX B – STO PoW ACTIVITIES/DISTRIBUTION

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

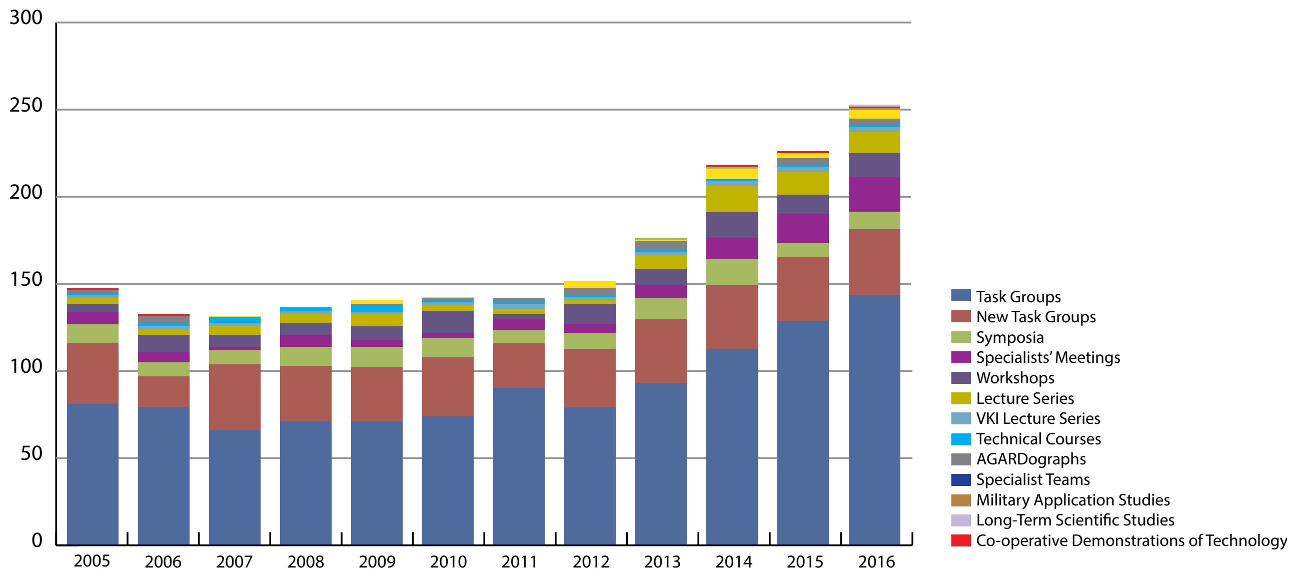

Figure 44: 2016 Trends in STO CPoW.

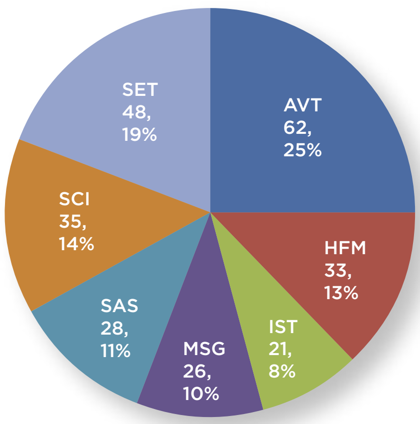

Figure 45: 2016 Distribution of STO CPoW activities per STC, where activities include all task groups, workshops, lecture series, etc.

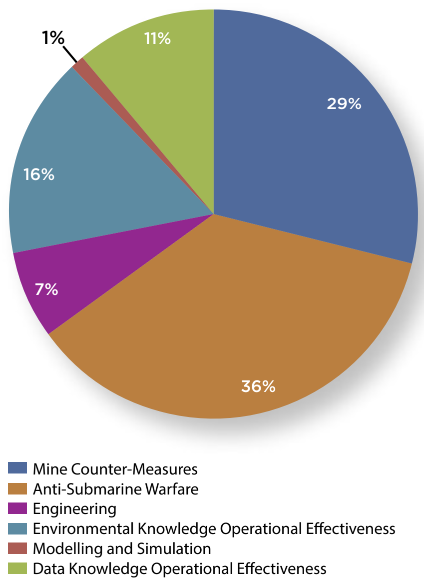

Figure 46: 2016 Distribution of activities over the STO CMRE PoW.

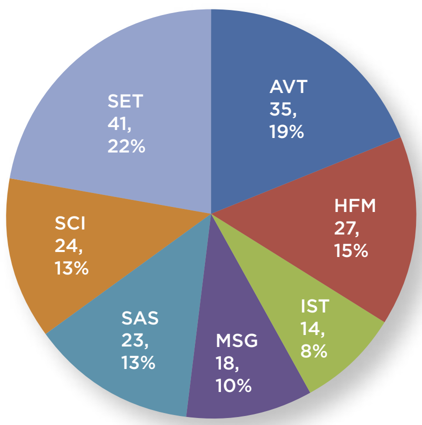

Figure 47: 2016 Number of STO CPoW RTGs per STC.

ANNEX C – LIST OF ACRONYMS

24/7	24 hours a day / 7 days a week
2D	Two-Dimensional
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
AIS	Automatic Identification System
AmphibOps	Amphibious Operations
AMSP	Allied Modelling and Simulation Publication
ANMCM	Autonomous Naval Mine Counter-Measures
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)
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
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
COP	Common Operational Picture
CPoW	Collaborative Programme of Work
CRV	Coastal Research Vessel
CSO	Collaboration Support Office
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
DMPAR	Deployable Multi-band Passive/Active Radar
DMS	Discovery Metadata Specification
DND	Department of National Defence (CAN)
DNK	Denmark
DoD	Department of Defense (USA)

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
DSM	Dynamic Spectrum Management
Dstl	Defence Science and Technology Laboratory
EC	European Commission
EDA	European Defence Agency
EO	Electro-Optical
EOP	Enhanced Opportunities Partner
ESA	European Space Agency
ESC	Emerging Security Challenges
ET	Exploratory Team
EU	European Union
EW	Electronic Warfare
FFAO	Framework for Future Allied Operations
FL	Florida (USA)
FOM	Federation Object Model
FRA	France
GBR	Great Britain
GDP	Gross Domestic Product
GE/NL	Germany/Netherlands
Gen	General
GEOMETOC	Geographic, Meteorological, and Oceanographic
GHz	Gigahertz
GNC	German/Dutch Corps
HFM	Human Factors and Medicine
HLA	High-Level Architecture
HPM	High-Power Microwave
HQ	Headquarters
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)
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)
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
MANEX	Multi-national Autonomous Experiment
MARCOM	Maritime Command
MC	Military Committee
MCCIS	Maritime Command and Control Information System
MCM	Mine Counter-Measure
MCMV	Mine Counter-Measure Vessel
MCR	Minimum Capability Requirement
MD	Medical Doctor
MD	Mediterranean Dialogue
MDCS	Multi-Domain Control Station
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
MUSCLE	Mine-hunting UUV for Shallow-water Covert Littoral Expeditions
NAAG	NATO Army Armaments Group
NAC	North Atlantic Council
NAFAG	NATO Air Force Armaments Group
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
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
NNAG	NATO Naval Armaments Group
NOAA	National Oceanographic and Atmospheric Administration
NRV	NATO Research Vessel
NS	NATO SECRET
NSC	NATO Shipping Centre
NSO	NATO Standardisation Office
NSRL	NATO Simulation Resource Library
NTP	NATO Terminology Programme
OCS	Office of the Chief Scientist
OGC	Open Geospatial Consortium
OODA	Observe, Orient, Decide, and Act
Ops	Operations
OR&A	Operational Research and Analysis
PA	Parliamentary Assembly
PARC	Persistent Autonomous Reconfigurable Capability
PCL	Passive Coherent Location
PfP	Partnership for Peace
PoL	Pattern of Life
PoW	Programme of Work
QIA	Quality of Interaction Assessment
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
ROS	Robotic Operating System
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
SET	Sensors and Electronics Technology
SFA	Strategic Foresight Analysis
SG/2	Sub-Group 2
Smallsat	Small satellite
SME	Subject-Matter Expert
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
TL	Transmission Loss
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
vKHS	von Kármán Horizon Scanning
WPT	Wireless Power Transfer

www.sto.nato.int

organization
CMRE

organization
CSO

organization
OCS

Published March 2017