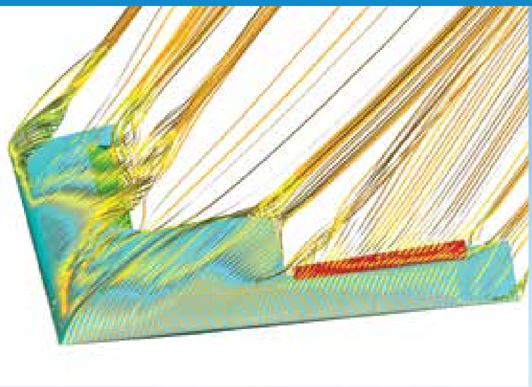
Science and Technology Organization

ANNUAL REPORT 2015


Enabling Defence Innovation through International S&T Collaboration

Foreword

FOREWORD

THE NATO SCIENCE AND TECHNOLOGY ORGANIZATION

"ENABLING DEFENCE INNOVATION THROUGH INTERNATIONAL S&T COLLABORATION"

The year 2015 has clearly been very challenging for NATO: the security challenges facing the Allies have increased, and are likely to remain significant for many years to come.

Nations have expressed their intent to remain at the cutting-edge of Science and Technology (S&T), in order to continue delivering their military capabilities precisely and decisively.

The Science and Technology Organization (STO) has continued to focus on delivering a superb Programme of Work (PoW) to support the objectives of the Allies, their partners and NATO as a whole.

The Collaborative Programme of Work (CPoW), involving a network of more than 4,400 scientists, engineers and experts, continued its growth, with 227 activities.

The Centre for Maritime Research and Experimentation (CMRE) continued to deliver an innovative maritime research and experimentation programme, developing new and cost-effective ways of addressing the operational challenges at sea.

The Science and Technology Board (STB) continued to exercise its governance role of NATO S&T and of the STO. Updated NATO S&T guidance was issued. Co-operation with stakeholders was strengthened, and a well-balanced PoW was developed. NATO reform objectives were met on target and on time.

Lastly, through the involvement of the NATO Chief Scientist (CS) and his office, NATO S&T advice was delivered and used to inform NATO leadership on topics of high relevance, and to support the development of future capabilities, such as the Alliance Future Surveillance and Control (AFSC) effort.

Figure 1: Neeme Väli, MGen (EST AR), NATO IMS P&P Director and S&T Board Co-vice Chair; Albert Husniaux, MGen (BEL AF), NATO Chief Scientist and S&T Board Chair; Ernest J. Herold, NATO DI DASG and S&T Board Co-vice Chair.

As NATO's first CS, I will entrust the STO and NATO S&T into the hands of my successor on 1 October of this year.

I have been inspired by all of the fine professionals with which I have had the privilege to serve in my (almost) two decades of service within the STO and its predecessor, the Research and Technology Organisation (RTO).

I continue to be impressed by the excellence and the dedication of our S&T workforce. I wish you all the best in continuing to support our finest: the military men and women, and civil servants on the ground, in the air, and on the seas who give their utmost to preserve our security.

Major-General (BEL AF) Albert Husniaux
STB Chairman
NATO Chief Scientist

Executive Summary

EXECUTIVE SUMMARY

The 2015 Annual Report of the NATO STO aims at informing the community of NATO S&T stakeholders from a 'demand and provide' point of view. It also aims at reaching out to those demanders and providers across the globe who are interested in benefiting from and participating in NATO S&T.

This report shows the achievements of 2015, including a representative outline of the 2015 STO PoW. The total number of activities in the PoW has grown again covering all relevant and important Defence and Security areas, thereby underlining the importance that NATO S&T stakeholders give to working together in the STO in support of the objectives of the Alliance and Partner Nations.

In the section "Corporate Perspective", the reader is invited to become acquainted with S&T in NATO. The most important functions of the STO are addressed, including the fact that the organisation encompasses a very large network of Defence and Security S&T from all over the world. The section concludes with the 2015 strategic focus and major achievements.

The section "NATO STO Programme of Work" shares a representative set of S&T activities drawn from the extensive STO PoW. Three themes were chosen for this Annual Report: Enabling Future Military Capabilities; Enhancing Interoperability and Affordability; and Mitigating Risk and Threat. The descriptions of the activities presented in this report are detailed in terms of: Achievements in S&T, Synergies and Complementarities, and Exploitation and Impact.

Excellence in S&T is covered as well, through a description of the fine work of those receiving STO awards. The "Annexes" contain a more detailed description of the STO and its functions, including facts and figures, as well as a list of acronyms.

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Corporate Perspective

NATO SCIENCE AND TECHNOLOGY

The role of NATO S&T is to cover basic and applied research broadly in the engineering, physical, information, human, medical and social sciences, and to deliver a range of products and services essential to NATO and NATO Nations. They are:

- Supporting the core tasks of the Alliance as set out in the NATO Strategic Concept;
- Supporting technological and knowledge advantages, thereby being a critical force multiplier;
- Providing the evidence-base to support informed decision-making; and
- Helping to mitigate evolving threats and risks, including supporting public diplomacy.

As a political-military Alliance, NATO's structures and processes are designed to support, inform and facilitate the Alliance's Defence and Security strategic-level decision-making, including defence planning.

NATO S&T thrives on collaboration between its multi-national stakeholders from many different military, organisational and scientific backgrounds. In addition to the NATO and Partner Nations, a large number of NATO bodies and entities are S&T stakeholders, each of which have their own specific mission. The stakeholders can be grouped into three categories:

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

Collaboration in NATO S&T context is voluntary; stakeholders participate according to their capabilities, interests and needs.

Due to the broad range of stakeholders' missions and portfolios, the close co-ordination, co-operation and collaboration between all stakeholders is of vital importance to avoid unnecessary duplication, seek complementarities, and introduce synergies by aligning S&T requirements and activities.

To facilitate generation and exchange of knowledge and technology, and to promote exploitation of S&T results, NATO provides trusted frameworks in which stakeholders capitalise on diverse approaches and perspectives to leverage and augment resources and investments. The majority of S&T efforts in NATO are funded by NATO and Partner Nations.

The nature of S&T activities ranges from ad-hoc and structured information exchange, to jointly planned fostered projects and programmes including Co-operative Demonstrations of Technology (CDTs).

NATO S&T is a strategic force multiplier for the Alliance and its Partners.

NATO SCIENCE AND TECHNOLOGY ORGANIZATION

The NATO 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. The STO welcomes participants and contributors from Allied and Partner Nations, who come 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 SCIENCE AND TECHNOLOGY BOARD

The STO is governed by the STB, which is composed of all relevant NATO S&T stakeholders on a senior level. The STB reports to the North Atlantic Council (NAC) and is instrumental in governing NATO S&T for the interests of all stakeholders, without prejudice to the responsibilities and authority of those stakeholders.

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

THE NATO CHIEF SCIENTIST

Leadership of the STO is exercised by the NATO CS, who chairs the STB and is the scientific advisor to senior NATO leadership. The CS is supported in these functions by the Office of the Chief Scientist (OCS) at NATO Headquarters (HQ) in Brussels, Belgium.

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 for over-arching Alliance objectives.

The delivery of this programme rests on two critical assets for the STO's mission success: a collaborative network; and a dedicated research laboratory.

With some 4,400 active Subject-Matter Experts (SMEs) and 227 activities in 2015, the STO is a very large international network of Defence and Security scientists and engineers. Seven Scientific and Technical Committees (STCs) address all military-relevant aspects of endeavour: Applied Vehicle Technology (AVT); Human Factors and Medicine (HFM); Information Systems Technology (IST); NATO Modelling and Simulation Group (NMSG); Systems Analysis and Studies (SAS); Systems Concepts and Integration (SCI); and Sensors and Electronics Technology (SET).

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

The CMRE is a customer-funded maritime S&T establishment focussed on the underwater domain. By collaborating through the Centre and pooling its infrastructure, Nations can reduce the cost of innovative work.

Using its own capabilities, infrastructure and personnel, the Centre carries out projects and experiments to deliver military relevant, state-of-the-art, validated scientific research and technology results to advance basic understanding and naval capabilities. Key enablers for delivering the CMRE's programme are its research vessels: the NATO Research Vessel (NRV) *Alliance* and Coastal Research Vessel (CRV) *Leonardo*.
The Centre operates out of La Spezia, Italy.

2015 STRATEGIC FOCUS AND MAJOR ACHIEVEMENTS

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

In 2015, the STO continued to deliver a high-quality PoW, well aligned with NATO's, NATO Nations' and Partner Nations' common needs, priorities, and interests.

S&T TO SUPPORT NATIONS' AND NATO'S 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.

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 has continued to grow to 227 activities in 2015, confirming the upward trend observed since 2009 (120 activities); this included a growth in Research Task Groups (RTGs) (the most intense activities) from 102 to 155. This 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 4,400 scientists and engineers.

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 had 25 running projects in 2015, and significantly increased the number of sea-days of its NRV *Alliance* from 113 in 2014 to 168 in 2015, thereby improving efficiency. It further diversified its PoW and customer base by participating in European Commission (EC) funded projects and capturing work from the NATO Maritime Command (MARCOM) and the National Oceanographic and Atmospheric Administration (NOAA) of the United States, with which a five-year framework agreement was signed for the use of the NRV *Alliance*.

- 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 a great 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 importance to knowledge development and technology transfer in the maritime domain.

The STO supported NATO HQ International Staff, Defence Investment (IS-DI) Division, from a methodology and S&T content point of view, in developing roadmaps to implement selected priorities of the Wales Summit Defence Planning Package.

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:

- In spring 2015, the STO responded to a request from IS-DI to lead the Solutions Working Group of the AFSC pre-concept phase. Drawing on more than 150 SMEs and working closely with IS-DI and ACT, the STO rapidly progressed the development of knowledge and concepts concerning a follow-on capability for the NATO Airborne Warning and Control System (AWACS). The conclusions of this work are being drawn together in early 2016 to inform the debate on the most promising options to be considered in a potential concept phase for AFSC. This integrated approach across military, armament, and S&T communities to addressing longer-term capability development proved to be very successful.

- The STO contributed to the Connected Forces Initiative (CFI): Global Navigation Satellite Systems (GNSS), Harbour Protection (HP), and Federated Mission Network (FMN). These activities were used to inform a report of IS-DI for the Conference of National Armaments Directors (CNAD) on identification and assessment of emerging technologies to contribute to and enable the CFI.

- Building on the technological maturity achieved in and demonstrated by the STO through several years of research in which government and industry participated, a new Smart Defence project was launched, based on Integrated Munitions' Health Management (IMHM) work started in the CNAD Ammunition Safety Group (CASG). IMHM has the potential to dramatically improve logistics and resources management of ammunition stocks, while improving the safety, reliability and performance of very costly munitions, such as precision-guided weapons.

- Other activities addressed: protecting seas, borders and ports; the affordability of force structures; munitions-related contamination; cyber; urban combat training; advanced sensing; and Modelling and Simulation (M&S).

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 approach to enhanced 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 further developed. The NATO CS briefed the European Defence Agency (EDA) Steering Board (SB) in Research and Technology (R&T) Directors' format, and the EDA Chief Executive has been invited to brief the STB in March 2016.

DELIVERING KNOWLEDGE, ANALYSIS AND ADVICE

The NATO CS, who is the senior scientific advisor to NATO leadership, delivered S&T evidence-based advise on a variety of subjects, including M&S, maritime security and the scarcity of materials (e.g., rare earths), in the context of supporting informed decision-making.

Advice was provided to support enhancement of the NATO Defence Planning Process (NDPP) across all steps, as well as the development of the Minimum Capability Requirements (MCRs) (long-term aspects), and the development of roadmaps for selected Defence Planning Priorities.

NATO S&T GUIDANCE AND CO-ORDINATION

The STB exercises NATO S&T governance which encompasses strategic guidance and co-ordination across NATO S&T.

NATO S&T STRATEGIC GUIDANCE

The STB issued the 2016 NATO S&T Priorities. These priorities are firmly rooted in military requirements as expressed in the MCRs. The identification of these priorities was driven by two distinct qualities: broad applications to military requirements; and potential technological disruption.

The STB implemented its Strategic S&T Initiatives to promote collaboration on topics of strategic importance across NATO S&T stakeholders. The current initiatives are on Maritime Security and von Kármán Horizon Scanning[1], with a first project on Directed Energy Weapons.

NATO S&T CO-ORDINATION

The STB continued to fulfil its role as the focal point for co-ordination of S&T across NATO S&T stakeholders.

The STB further improved its *modus operandi* by introducing a "Plans and Programmes Event" facilitating the development of a balanced STO PoW, taking into account the requirements of the Nations and NATO.

Structured relationships with major stakeholders were formalised:

- The NATO CS and the Supreme Allied Commander Transformation (SACT) signed a structured partnership agreement between the STO and ACT; and
- The NATO CS and the NATO Parliamentary Assembly (PA)[2] Secretary General signed a Letter of Intent (LoI) pledging to develop a more structured partnership between the STO and the NATO PA.

Relationships with stakeholders were strengthened at the programme level, some examples of note are:

- 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 of STO's SAS Panel, the NATO Communications and Information Agency (NCIA) and ACT.
- The STO and the Energy Security Section (ESS) of the Emerging Security Challenges (ESC) division, which develops NATO's role in energy security, mutually supported their PoWs. The co-operation during the "Capable Logistician 2015" exercise ("Smart Energy"), and the STO activities on "Enhancing Strategic Awareness of Energy Security – A Holistic Approach" and on "Energy and Defence: Reducing Dependencies and Vulnerabilities, Enhancing Efficiency", merit particular mention.
- The STO continued to support the Science for Peace and Security (SPS) programme of ESC through the SPS Independent Scientific Evaluation Group (ISEG) and through collaboration at the PoW level. The project "Towards the Monitoring of Dumped Munitions Threat (MODUM)", involving STO's CMRE deserves particular attention.
- The NATO CS and his office continued to engage with the NATO PA Staff as appropriate. Plans for 2016 include collaboration on Intelligence, Surveillance, and Reconnaissance (ISR) as well as emerging to disruptive technologies. The NATO PA is an essential bridge linking parliamentarians, their constituencies, and NATO leadership. The role of S&T in maintaining transatlantic security has been a central function of the Assembly since its founding in 1955.

STO GOVERNANCE

The STB exercises STO governance, which encompasses guidance and direction to its STCs and its executive bodies.

STO STRUCTURE

The STO is composed of the STB, STCs and three executive bodies:

- *The STB*, in which all NATO S&T stakeholders are represented, is the highest authority in the STO and is chaired by the NATO CS. The STB exercises governance on behalf of the NAC and reports to the NAC through the Military Committee (MC) and the CNAD.

[1] von Kármán Horizon Scanning employs a 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.

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

- *The STCs* are responsible for the planning and execution of the STO's CPoW. They are composed of national defence S&T managers and SMEs from all stakeholders, i.e., government, academia, institutes and industry.

- *The CSO* (Neuilly-sur-Seine, France) provides a collaborative environment, and executive and administrative support to the S&T activities conducted through the STCs and their working groups.

- *The CMRE* (La Spezia, Italy) organises and carries out projects and experiments to deliver military relevant, state-of-the-art S&T in the maritime domain, and particularly in the undersea environment.

- *The OCS* (NATO HQ, Brussels, Belgium) supports the STB and the NATO CS in their role as Chairperson of the STB and scientific advisor to senior NATO leadership.

STO TRANSITION

The last major STO transition objectives (related to the Agencies Reform) have been met, on target and on time:

- The final solution for the future of NRVs was approved by the NAC in December 2015. In this solution, Italy provides a military flag and military crews for both the NRV *Alliance* and the CRV *Leonardo* from 1 January 2016, with the custody of the vessels under the STO (CMRE). The related Memorandum of Understanding (MoU) between Italy and the CMRE was signed in December 2015. Synergies achieved through the Host Nation will allow increased utilisation while reducing the operating costs of both vessels.

- The benefits and risks of a potential geographical consolidation of the three STO executive bodies (CMRE, CSO and OCS) were investigated by an STB-led team. The STB endorsed the team's recommendation to maintain the *status quo* in the three locations, and agreed to submit the report to the Defence Planning and Policy Committee (Reinforced) (DPPC(R)).

STO STEADY-STATE OPERATIONS

The STB continued to improve 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.

The OCS continued to support the STB and its Chairperson in their main responsibilities while further integrating into NATO HQ processes.

The STB launched the development of a STO corporate plan as strategic direction and guidance, further enhancing the delivery of S&T to the Nations and NATO.

NATO STO Programme of Work

THE COLLABORATION SUPPORT OFFICE

The CSO saw a change of leadership in 2015 as I replaced Mr. René Larose on 1 July 2015. René left a well-functioning organisation and healthy collaborative network of some 4,400 scientists, engineers, and analysts across NATO, NATO Member and Partner Nations. The CSO continues to operate a collaborative model: our job is to support the ability of NATO Nations to work together to conduct military and security relevant scientific research and technology development, delivering combat capability for the Nations to the Alliance. I am pleased to have the opportunity to work with the professionals in the CSO office and the greater network.

> The growth in complexity of technology based security challenges is reflected in a growth of the collaborative programme, and in the tools and methods CSO is fielding to support the programme.

I contend there is a greater need to collaborate today than at any time since the dissolution of the Warsaw Pact Alliance. The combined effect of a resurgent Russia and security pressures from radical extremists, together with ongoing national austerity measures, presents new and growing security challenges for the NATO Alliance. This situation of new challenges, with the emergence of new warfare tools such as cyber capabilities and greatly enhanced Electronic Warfare (EW) capabilities, enabled by rapid advances in Nations' ability to process information, means the security environment is more complex than in the past. Two additional elements that add complexity to capability development are the rise of commercial products and capabilities, and the shortening of the technological maturation cycle, both of which change the security environment for most Nations. The ability to harness commercial opportunity in a military capability is critical for future security. This greater complexity, in the context of the rise of a potential near-peer, coupled with a challenged resource pool, leaves us all in a situation where more, not less, collaboration is needed.

My vision for the STO is to continue to be the organisation Nations rely on for collaboration. In 2015, the CSO supported 227 formal activities (Task Groups, Symposia, etc.), and we are on track to increase this output in 2016. 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. We are pushing to enhance the information technology "tools" to enable dramatically enhanced virtual collaboration and meetings; these tools should allow us all to increase our agility and timeliness. We are working hard at shortening the publication process, and at underscoring our military relevance. We are also making more of an effort to better connect to the operational and requirements community – the people who need our products – and as a result, I see the NATO STO increasing field trials and demonstrating more mature technology.

The core of the resulting CPoW remains the seven Level II Technical Committees of the STO (AVT, HFM, IST, NMSG, SAS, SCI and SET). These seven Committees 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. We look forward to enhancing the Panels and Groups by bringing in more "millennials", the age demographic we are all building products to support.

Figure 2: CSO Staff.

I believe we need to strive to "lead the future" through activities like Technology Watch, under which the CSO has identified a number of technologies that could change the security landscape. These include (but are not limited to): hypersonic vehicles; quantum sciences; additive manufacturing; synthetic biology; and human performance monitoring and enhancement.

It is an exciting time to be part of the STO, and even with the challenges facing them, I am confident that the CSO team and Panels and Task Groups are ready to respond.

Alan Shaffer
Director, STO-CSO

THE CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION

MARITIME SCIENCE IS A FORCE MULTIPLIER

DEDICATED RESEARCH LABORATORY

The CMRE was formerly the NATO Undersea Research Centre (NURC) until June 2012, and known as SACLANTCEN (SACLANT Undersea Research Centre) prior to 1993. For more than 50 years, CMRE has served as the place in NATO where scientists and engineers from the Alliance gather to conduct collaborative research projects that advance the understanding of the maritime environment and develop the naval capabilities needed to operate effectively and efficiently in the maritime domain.

Figure 3: RAdm (ret.) Hank Ort, Director, STO-CMRE (Center) on the Bridge of NRV *Alliance* with VAdm Stefano Dotti, Italian Navy (Left), and RAdm Shoshana Chatfield, United States Navy of the International Military Staff (Right).

2015 – YEAR OF LANDMARK AGREEMENTS

CMRE signed two landmark long-term agreements in 2015. The first was a five-year framework agreement with the NOAA in the United States for the use of the NRV *Alliance*. The first 30-day research trial under this agreement was conducted in December 2015. The next trial, scheduled for December 2016, is already in the early planning stages.

The second agreement signed was with its Host Nation Italy that will provide the "Steady-State Solution" for the NRVs directed by the 2012 NATO Agencies Reform. The agreement will shift custody from ACT to CMRE and provide an Italian flag and crew for the NRV *Alliance* and the CRV *Leonardo* for the remainder of their service lives (up to 25 years). Synergies with its Host Nation will allow increased utilisation while reducing the operating costs of both vessels.

OPERATIONALISING THE FUTURE

The Centre has stepped up its participation in NATO and national exercises to introduce emerging technologies into operational exercises. With exposure to new technology comes the development of Experimental Tactics (EXTACs) and Standard NATO Agreements (STANAGs) that change the way NATO navies fight and insure interoperability from inception. In the fall of 2016, for example, the NRV *Alliance* will participate in UNMANNED WARRIOR, the adjunct autonomous vehicle exercise to JOINT WARRIOR 2-16. NRV *Alliance* will be the mothership for the testing of a fleet of different autonomous vehicles from the industries of several NATO Nations.

LOOKING TOWARD THE FUTURE

In 2015, CMRE continued to operate successfully as a customer-funded entity. Although ACT remains the principal customer, the focus of the Centre's PoW and the overall customer portfolio is expanding.

Recent work with NOAA, the EC and the NATO MARCOM, and possible work with the Office of Naval Research (ONR), the US Coast Guard Research and Development Center (USCG RDC) and the Global Foundation for Ocean Exploration (GFOE) highlight the exciting possibilities on the horizon. The GFOE work is especially exciting since it will take CMRE into the realm of collaborative ocean exploration for the first time.

Hank Ort
Director, STO-CMRE

ENABLING FUTURE MILITARY CAPABILITIES

Enabling future military capabilities is a complex process in which the Nations and NATO work closely together over the long, medium and short term. Many elements come into play to finally arrive at superior military capabilities at the right moment; human brainpower, scientific understanding and technological competency are critical requirements. Enabling future military capabilities by investing sufficiently and wisely in S&T is at the heart of NATO's strategy for keeping people safe by deterrence.

NATO Deputy Secretary General Alexander Vershbow remarked at the Snow Meeting: "The goal of deterrence is to convince potential adversaries that the costs of any form of attack would be disproportionately high, and that such action would be a serious mistake. But the security environment has changed, and so strengthening and modernising NATO's deterrence posture for the 21st century is, in my view, the most important challenge we must meet between now and the Warsaw Summit."
(21st Century Deterrence, Trakai, Lithuania, 15 January 2016)

The outline of STO PoW activities below enables the development of future military capabilities:

- System Design Considerations for High Tempo Operations in Degraded Visual Environments (SCI-206);
- Flight Testing of Unmanned Aerial Systems (UAS) (SCI-269);
- Extended Assessment of Stability and Control Prediction Methods for NATO Air Vehicles (AVT-201);
- Low-Power and Easily Deployable Radar Sensor Network (STO-CMRE);
- Maritime Radar Surface Surveillance Techniques and the High Grazing Angle Challenge (SET-185);
- Evaluating the Effectiveness of Co-ordination Methods for Distributed Mobile Sensors (SET-199);
- Potential of Autonomous Networks for Submarine Detection (STO-CMRE);
- Towards New Active Sonar in the Littoral Battlespace (STO-CMRE);
- Advancing Autonomy for Naval Mine Counter-Measures (STO-CMRE);
- Towards Unmanned Autonomous Passive Acoustic ISR Solutions (STO-CMRE);
- CORSAR – A Relocatable Ocean Prediction System (STO-CMRE);
- Phenomenology and Exploitation of Thermal Hyperspectral Sensing (SET-190); and
- Assessment of Mission Impact Due to Cyber-Attacks (IST-128).

SYSTEM DESIGN CONSIDERATIONS FOR HIGH TEMPO OPERATIONS IN DEGRADED VISUAL ENVIRONMENTS (SCI-206)

Current conflicts show that NATO forces are required to conduct high tempo operations 24/7. Characterised by short planning phases, precise execution timing, multiple aircraft, high aircrew stress and safety risk, high tempo operations pose considerable challenges when conducted in Degraded Visual Environments (DVEs). Current aircraft systems are incapable of providing adequate information for a complete picture of the battlespace within shortened timelines.

Mr. John Ostgaard, USA, US Air Force Research Laboratory

BACKGROUND

The solutions for operating in high tempo DVEs varies between platforms and missions. Key technologies include: sensors which can see through degraded environments; databases containing *a priori* knowledge and symbologies/cues; digital communications tied to an on-board situational awareness processor to receive real-time updates from off-board sources; and integration and automation to present a single integrated picture to the aircrew.

Figure 4: Helicopter operating in a DVE.

OBJECTIVE(S)

The objectives were to identify technology considerations in system design that could improve high tempo operations in DVEs, and respond to airborne DVE requirements, including system concepts, technology components and solution sets that can provide enhanced safety and effectiveness during high tempo operations in DVEs across a range of mission areas.

S&T ACHIEVEMENTS

The analysis determined that hardware currently on the market can support a development programme towards DVE solutions for NATO platforms; however, a single integrated system that accounts for specific high tempo aspects (atmospheric/spectrum, special, terrain and the tactical situation) currently does not exist.

A DVE is the cause of many military helicopter mishaps. Current ground avoidance systems are not ready for operational employment, but are ready for system engineering development.

SYNERGIES AND COMPLEMENTARITIES

Six Nations worked in concert to assess new and emerging technologies and the state-of-the-art for existing technologies. Each of the participating Nations held meetings to showcase technology developments and testing facilities.

EXPLOITATION AND IMPACT

The rate of technology development in the areas of sensors, communication systems and data fusion will influence the definition of next-generation system architectures to enhance high tempo operations. This activity notes the current direction in technological advancement, and areas where more development is required to produce the next generation of sensors, displays and system solutions. The advent of augmented reality and supporting display technologies, together with sensor management and fusion techniques, multi-platform/multi-sensor data gathering and exploitation, will become the prime architecture for complex system automation and improve our ability to conduct high tempo DVE operations.

CONCLUSIONS

High tempo NATO air operations in degraded environments can lead to loss of aircrew situation awareness because of limited visibility and degraded input from conventional sensors. This is compounded by the resulting reduced action-reaction timeframes and disparate information from multiple sensors, databases, and communications. The solution is to assemble relevant data into an integrated picture, allowing the aircrew to rapidly understand the situation without missing key data or relationships, leading to effective, timely decisions for safe and successful mission accomplishment.

FLIGHT TESTING OF UNMANNED AERIAL SYSTEMS (UAS) (SCI-269)

UAS play an ever-expanding role in modern military operations. In recognition of this expansion, the Flight Test Technical Team (FT-3) hosted the "Flight Testing Unmanned Aerial Systems" Symposium to address the question of whether the flight-testing of UAS is fundamentally different from the testing of manned platforms.

Mr. Wilson R. Lowry, USA, US Naval Test Pilot School

BACKGROUND

UAS are becoming more widely used by NATO in major conflict areas around the world. They are being used for ISR, suppression of enemy air defence, decoys and kinetic attacks. As a result, their design and application vary greatly. Individual Nations now recognise the value of sharing lessons learned in this complex and rapidly growing technology.

OBJECTIVE(S)

The objective was not only to provide a forum for presentations on NATO Nations' achievements in UAS flight testing, but also to establish a basis for future collaboration on the development of appropriate flight-test techniques and accepted practices for UAS procurement projects.

S&T ACHIEVEMENTS

Starting in 2012, the FT-3 team began to assemble a comprehensive assortment of UAS presentations from six NATO Nations that covered a wide range of UAS topics, including: high altitude extended duration vehicles; multi-rotor helicopters for medical missions; and the use of manned UAS surrogate aircraft for system development and testing. The Symposium brought together national experts and provided the opportunity for open discussion on the challenges facing this expanding technical field.

> The impact of SCI-269 will enhance the safe operations of manned and unmanned aircraft in the same airspace.

SYNERGIES AND COMPLEMENTARITIES

The Symposium provided 21 technical presentations and two keynote speeches giving 95 participants from 15 NATO and Partner Nations the opportunity to share UAS flight-test information and experiences. The high-quality technical presentations generated continued discussions on topics raised, often revealing similar lessons learned from other UAS efforts, and demonstrating that NATO and Partner Nations face some common UAS flight-test issues. This reinforced the value of Symposia for the technical community.

EXPLOITATION AND IMPACT

Most of the Symposium presentations were cleared for public release and, along with the Technical Evaluation Report, are available for download from the NATO/STO website. This expands the availability of the information beyond Symposium attendees and provides the opportunity for future growth and collaboration. The value of the Symposium extends beyond the participants to future NATO Nations' flight-test organisations as they research the topic and develop new UAS flight-test practices.

CONCLUSIONS

This Symposium successfully presented a sampling of UAS flight-test efforts from a broad spectrum of technical interests, with one underlying theme emerging: Nations agreed on the need to develop processes and technologies to safely enable the integration of UAS operations into NATO Nations' airspace while preserving safe skies for manned flight.

Figure 5: An example of a low, slow and small UAS.

EXTENDED ASSESSMENT OF STABILITY AND CONTROL PREDICTION METHODS FOR NATO AIR VEHICLES (AVT-201)

Current projections for future military Unmanned Combat Aerial Vehicle (UCAV) systems in missions such as the suppression of enemy air defences indicate they must be low, observable and agile, and will require both high survivability and assertiveness. The designs resulting from these criteria typically have non-linear flow field characteristics and Stability and Control (S&C) properties.

Dr. Russell M. Cummings, USA, USAF Academy and Dr.-Ing. Andreas Schütte, DEU, German Aerospace Centre

BACKGROUND

The ability to predict air vehicle stability characteristics accurately using Computational Fluid Dynamics (CFD) could revolutionise the military air vehicle design process. A validated CFD capability would significantly reduce the number of ground tests required to verify vehicle concepts and could eliminate costly "repair" campaigns required to fix performance anomalies.

OBJECTIVE(S)

The objective was to develop an integrated experimental and numerical approach for predicting S&C characteristics and for designing and estimating control device effectiveness for highly swept, low observable UCAV configurations.

S&T ACHIEVEMENTS

AVT-201 conducted experimental tests for a wide range of flight conditions using advanced wind tunnel facilities. The resulting data set was used to validate the computational methods, develop a flight mechanics model, and train using several reduced-order model approaches. AVT-201 began an evaluation process to determine the performance of CFD and enhanced computational methods in predicting performance under model- and real-scale conditions. Finally, AVT-201 developed recommendations and conclusions regarding numerical approaches, performance and future technology requirements.

> It is almost certain that we will see the results of AVT-201 fly in a future UCAV system.

SYNERGIES AND COMPLEMENTARITIES

The participating Nations pooled resources to achieve greater research value from both experimental and numerical design methods for future combat air vehicles. AVT-201 built and tested four wind tunnel models using four different facilities in three NATO Nations. In all, 13 Nations used nine different CFD methods to provide a significant benchmark and validation process. The work produced more than 30 scientific publications and the Chairs received the 2015 American Institute of Aeronautics and Astronautics (AIAA) International Co-operation Award.

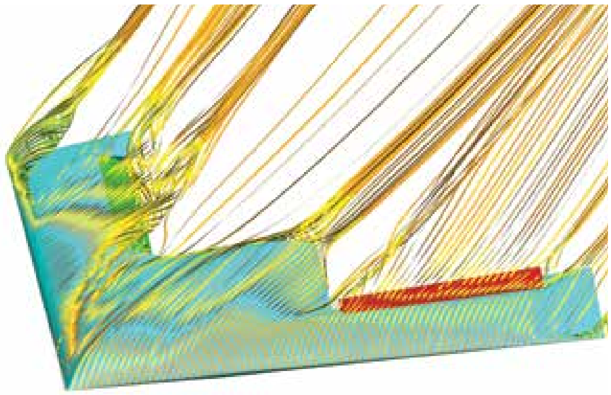

Figure 6: Vortex-dominated flow field around the AVT-201 UCAV configuration.

EXPLOITATION AND IMPACT

AVT-251 will apply the results of AVT-201 to re-design a flyable UCAV. The design process enhancements for predicting non-linear aerodynamics to determine flight characteristics could potentially improve the aircraft design process through early definition of challenging flight characteristics, and by including those characteristics in the development of aerodynamic models, flight control systems, and flight simulators. The potential for significant cost savings in vehicle development is substantial, and the ability to understand the flight behaviour of non-traditional configurations before construction is greatly enhanced.

CONCLUSIONS

AVT-201 is one element in a continuous research programme evaluating the aerodynamic performance of military air vehicles. This body of work comprises essential fundamental research topics as well as the assessment of fully equipped military aircraft. The material benefit of AVT-201 is a set of tools to enhance UCAV design based on the application of state-of-the-art computational methods.

LOW-POWER AND EASILY DEPLOYABLE RADAR SENSOR NETWORK (STO-CMRE)

Coastal surveillance can be improved by low-power, easily deployable, high-resolution radar systems. These advancements are possible through novel signal processing techniques combined with currently available radar systems.

Dr. Gemine Vivone, Dr. Paolo Braca and Dr. Borja Errasti-Alcala, STO-CMRE

BACKGROUND

Advances in low-power, low-cost, networked sensing technologies are revolutionising sensing capabilities by moving from systems which can simply detect targets, to systems that also have the capability to classify targets. The ability of high-resolution radar systems to determine target dimensions, combined with proper algorithms, provides the capability to classify surface targets, even at an extended range.

OBJECTIVE(S)

The objective was to evaluate the possibility of determining both the kinematics and dimensions of a surface target. Furthermore, the ability to fuse information acquired by both of the Radar Sensor Network (RSN) nodes (Fig. 7) was investigated.

> Advances in low-power, low-cost, networked sensing technologies are revolutionising sensing capabilities to be systems that can also classify targets.

S&T ACHIEVEMENTS

An extensive amount of data has been collected by CMRE's RSN in La Spezia, Italy. Additionally, a recent trial acquired a data set with a small co-operative target. Using several signal processing approaches that CMRE developed, the team was able to exploit data acquired by both the Marine Radar Node (MRN) and Inverse Synthetic Aperture Radar Node (ISARN) (Fig. 8) in order to track targets effectively and determine both kinematics and target dimensions.

SYNERGIES AND COMPLEMENTARITIES

Several members of the Alliance are interested in this technology, as expressed at a SET Specialists' Meeting on "Radar Imaging and Target Identification", held in October 2015.

EXPLOITATION AND IMPACT

The continuous wave technology allows for low-power, compact, and easily deployable systems. Several Nations plan to install networks of high-resolution continuous wave radars for coastal surveillance purposes; partnering with the CMRE can accelerate these national programmes by providing knowledge of the state-of-the-art for low-power compact systems, concepts for their employment, and algorithms accelerating the use of these systems. The developed algorithms can leverage this infrastructure for surveillance without requiring additional equipment expenses, thereby multiplying the impact of NATO's investment in scientific research.

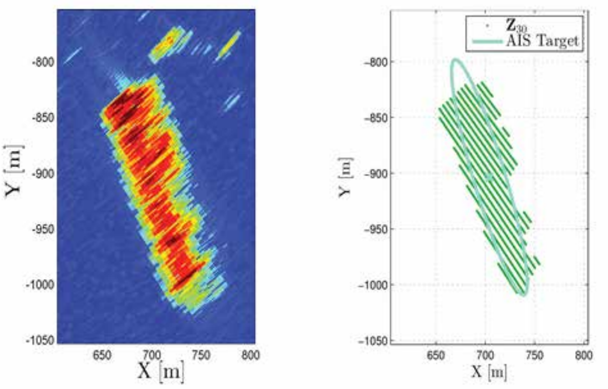

Figure 7: Amplitude of marine radar data and detections with Automatic Identification System (AIS) information.

CONCLUSIONS

CMRE has successfully developed and tested the signal processing necessary for effective target tracking, with expectations that the Alliance can leverage existing RSN infrastructure and enhance capabilities with an easily deployable coastal surveillance system.

Figure 8: The ISARN and the MRN fields of view depicted in yellow and red, respectively.

MARITIME RADAR SURFACE SURVEILLANCE TECHNIQUES AND THE HIGH GRAZING ANGLE CHALLENGE (SET-185)

Significant progress was made in characterising, modelling and simulating coherent multi-channel data from the High Grazing Angle (HGA) maritime clutter regime. These outcomes supported the assessment of coherent detection schemes and highlighted shortcomings in Constant False Alarm Rate (CFAR) control.

Dr. Michael K. McDonald, CAN, Defence Research and Development Canada

BACKGROUND

Modern maritime surveillance aircraft fly at high altitude for aerodynamic efficiency. One consequence is significantly higher grazing angles, which substantially increases sea clutter and changes its nature, possibly hiding small targets of interest. New processing methods are therefore needed to detect small targets from high altitude.

OBJECTIVE(S)

The objective was to study the heretofore poorly understood HGA clutter regime to reduce CFAR.

S&T ACHIEVEMENTS

Substantial progress was made towards understanding the HGA clutter regime phenomenology. New statistical models, such as Pareto and K+Rayleigh, provided accurate closed form fits to real data. Statistical models allowed practical evaluation of detection settings in real-world systems. Additionally, new coherent models identified and exploited the contribution of underlying clutter components arising from Bragg and fast-scatter mechanisms. The results enhanced the Task Group's understanding of a clutter mechanisms' impact on observed spectra and support development of data-simulation approaches which accurately capture clutter statistics versus Doppler frequency. These results underpinned the Group's assessment and development of coherent detection approaches. The root causes for departures from CFAR performance were identified and clear guidance was provided on suggested future development using multi-component clutter models.

SYNERGIES AND COMPLEMENTARITIES

The Task Group comprised 22 members from 10 countries (nine of which supplied data) belonging to academia, industry and government. The mix provided a broad range of expertise, ensuring that the work remained focussed and practically relevant. Leveraging of work and data permitted a breadth of investigation that would have been prohibitively expensive for any single country.

EXPLOITATION AND IMPACT

The outcomes directly inform NATO Nations of the operational implications and trade-offs implicit in HGA maritime radar surveillance capabilities. Potential technical exploitation routes for results include the ongoing development of robust detectors to provide near-optimal detection and CFAR performance with minimal operator intervention. Equally important, the results allow the characteristics of the HGA regime to be quantitatively specified. This is critical to equipment specification development and compliance testing strategies and underpins the development of national procurement programmes and schema. The performance evaluations undertaken provide practical inputs to current and future military operational planning.

CONCLUSIONS

The investigations provide crucial information to guide Tactics, Techniques and Procedures (TTPs) for small target detection from high-altitude maritime surveillance aircraft. Modelling and performance studies inform the development of procurement specification and compliance testing strategies for airborne maritime surveillance radars. As well, technical results highlight current performance shortfalls and provide clear guidance on required future research needed to resolve these shortfalls.

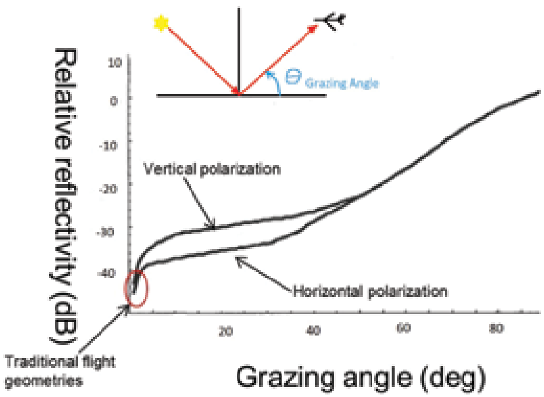

Figure 9: The HGA problem in a nutshell. Backscatter grows rapidly past a few degrees grazing angle.

EVALUATING THE EFFECTIVENESS OF CO-ORDINATION METHODS FOR DISTRIBUTED MOBILE SENSORS (SET-199)

Co-ordination enables co-operation, and teamwork is the goal of co-operative mobile sensors. Achieving Smart Defence requires a fundamental understanding of how the co-ordination of individual contributions leads to effectiveness and efficiency in teamwork.

Dr. Frank Ehlers, DEU, Bundeswehr – WTD 71 – Ships and Naval Weapons

BACKGROUND

The challenge in co-ordination design is mapping between implementation details (and Measures of Performance) and specifications while reasoning about achieving operational goals (and Measures of Effectiveness). The difficulty is, the more autonomy implemented in a system, the harder the evaluation – and the harder the evaluation, the harder it is to co-ordinate components effectively and efficiently and thus, the more difficult it is to find the best co-ordination methodology.

OBJECTIVE(S)

The objective was to develop methods to establish the conditions, in a partially observable environment, under which specific sensor co-ordination schemes are beneficial.

> A person is smart; people are dumb. Is the opposite true for Distributed Mobile Sensors?

S&T ACHIEVEMENTS

Heuristic methodologies were collected and developed to maintain effectiveness while optimising co-ordination parameters and adapting to incoming sensor information (see Fig. 10). In addition, the SET-199 Task Group: collected state-of-the-art co-ordination and system design approaches; introduced reasoning about necessary functionalities to be co-ordinated across agents; established formal methods and architectural frameworks for "Verification and Validation"; introduced a formal methodology (see Fig. 11) to automatically include Efficient independent Validation and Verification (EiV&V); and recommended the combination of the NATO Architecture Framework (NAF), which fully describes a co-ordination design, with EiV&V. The result is that learned benchmark scenario results define the conditions under which specific sensor co-ordination schemes are beneficial.

SYNERGIES AND COMPLEMENTARITIES

The questions SET-199 considered are very topical in the international community (e.g., Institute of Electrical and Electronics Engineers (IEEE) Robotics and Automation Society (RAS) on Networked Robotics and Multi-Robot Systems) and are related to NATO's NAF developments.

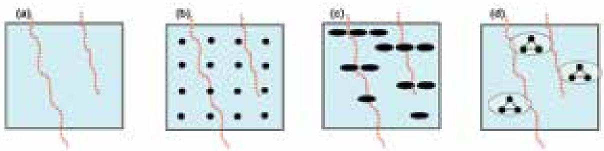

Figure 10: To track targets (red lines), there are various sensor arrangements: (a) None, (b) A grid of stationary simple sensors; (c) Mobile sensors able to adapt to incoming information from sensors; or (d) Small clusters of high-performance sensors positioned by optimal global control. [Source: F. Ehlers, "Cooperative Vehicle Target Tracking"; Springer Handbook of Ocean Engineering, Dhanak, M.R.; Xiros, N.I. (Eds) 2016.]

EXPLOITATION AND IMPACT

The EiV&V methodology enables persistent spatial distribution of autonomous sensor platforms under realistic resource limited conditions. Military pay-off results from effective use of existing sensor hardware (Military/Commercial-Off-The-Shelf or MOTS/COTS) and making informed procurement choices.

CONCLUSIONS

Sensor co-ordination is not just about what is or should be happening – it is about making efficient resource decisions which may, only later, prove to have been the right choices. The results of the SET-199 effort suggest ways to improve the odds of making the right resource decisions in the deployment of optimum sensor teaming arrangements.

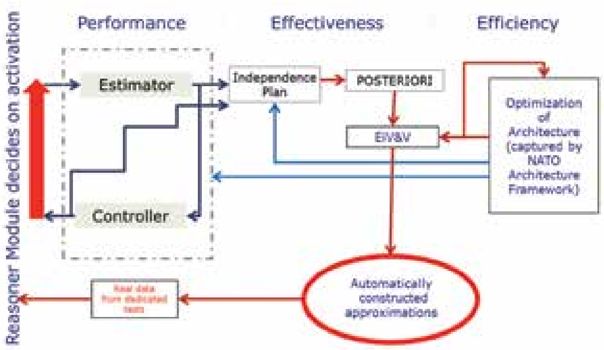

Figure 11: Sensor employment solutions are evaluated under a variety of situations including the ability of sensors to adapt to changes. Adding EiV&V to the standard learning scheme ensures solution effectiveness and allows for comparison of results leading to the best co-ordination method.

POTENTIAL OF AUTONOMOUS NETWORKS FOR SUBMARINE DETECTION (STO-CMRE)

CMRE has demonstrated the potential of autonomous networked Anti-Submarine Warfare (ASW) and data fusion to counter the next generation of submarines. By deploying off-board sensors in the 2015 Exercise Dynamic Mongoose (DMON15), NATO's largest ASW exercise off the coast of Norway, the benefits were showcased in operationally relevant northern waters for the first time.

Dr. Ryan A. Goldhahn, STO-CMRE

BACKGROUND

CMRE is pursuing distributed autonomous sensor networks as a scalable, cost-effective solution for autonomous submarine detection, relying on the fusion of information from several small, deployable platforms over the entire network. These sensors are able to make autonomous adjustments or re-deploy themselves based on observed data without human intervention.

Figure 12: DMON15 gave CMRE its first opportunity to demonstrate autonomous networked ASW in a northern NATO ASW exercise.

OBJECTIVE(S)

The objective was to focus on the reliability, endurance, and detection, classification, localisation and tracking performance of autonomous ASW sensor networks. CMRE will deliver a disruptive technology that will provide the materiel component of a new capability.

S&T ACHIEVEMENTS

In the operational envelope defined by vehicle performance, reliability and endurance, CMRE demonstrated the potential of the real-time classification processing which discriminates target detections from false alarms, autonomous vehicle behaviours which reposition the sensor networks to improve performance, and network-based navigation solutions. The performance of autonomous sensor networks was assessed against submarines in the clutter-rich environment near the Norwegian coast. As NATO's maritime S&T organisation, CMRE is uniquely positioned to demonstrate advanced autonomous ASW sensing concepts in NATO ASW exercises.

> The inclusion of CMRE in this exercise reflects NATO's recognition of the importance of these future capabilities, and the commitment to working with researchers to improve the way NATO's navies operate at sea.

SYNERGIES AND COMPLEMENTARITIES

As a hub of maritime research and development, CMRE exploited the similarities in the technology, processing, and vehicle architecture common to many autonomous vehicle missions for similar operations in communication-limited environments, working closely with MARCOM and NATO navies. CMRE was able to work synergistically with Norway to include elements of their national research programme into bottomed autonomous networked ASW sensors in the exercise plan.

EXPLOITATION AND IMPACT

While more work is needed to exploit CMRE's autonomous sensor network operationally, it was shown to have scientific potential in a challenging and operationally relevant ASW environment. The results show an unmistakable advantage in terms of performance and cost in using autonomous platforms for ASW. With heavy seas and the increased rate of false detections, the difficult environmental conditions stressed the scientific (processing) and engineering (vehicle endurance) challenges that must be met before their operational deployment. A post-exercise briefing in Norway highlighted the capability demonstrated.

CONCLUSIONS

DMON15 proved the potential impact of autonomous sensor networks in ASW, and their feasibility. Work is ongoing to set the requirements for these systems and to address the scientific and engineering challenges of operational benefit and savings.

TOWARDS NEW ACTIVE SONAR IN THE LITTORAL BATTLESPACE (STO-CMRE)

Continuous Active Sonar (CAS) will increase the number of submarine detection opportunities and improve tracking performance in highly dynamic, clutter-rich and noisy littoral environments.

Dr. Kevin LePage, STO-CMRE

BACKGROUND

CAS is an emerging technology that promises improved detection and tracking performance against submarines. While known in the open ocean, its efficiency in the littoral is still under investigation. A new multi-national project to characterise its performance in the littorals has been established, with a first sea trial conducted in 2015.

OBJECTIVE(S)

The objective was to evaluate the potential of CAS signals to deliver the technological component of a new capability in littoral environments, characterised by strong oceanographic variability, surface and bottom interaction, and high ambient noise.

S&T ACHIEVEMENTS

A high-quality data set was collected for post-processing and analysis. Real-time processing for detection, localisation, classification and tracking was demonstrated for the USA's Five Octave Research Array (FORA) and for arrays deployed by networked Autonomous Underwater Vehicles (AUVs). Experimental verification was also demonstrated by conventional means. These S&T achievements are synergistic to and leverage CMRE's ACT-funded PoW.

> Multi-static CAS signal processing concepts offer the potential for improved ASW coverage and performance for the Alliance and Partner Nations at reduced cost and manning requirements for a large range of mission areas.

SYNERGIES AND COMPLEMENTARITIES

Participants include NATO, Canada, Italy, Norway, the United Kingdom, and the United States, along with Australia and New Zealand. NRV *Alliance* deployed AUVs with towed arrays and a variable depth source, embarking FORA as a towed-array sensor, and the Canadian Maritime Acoustic Processor System as a real-time processing capability for the FORA and for a suite of passive and active sonobuoys. CRV *Leonardo*, funded by Canada and Italy, deployed CMRE's echo repeater to simulate a submarine target. This project exploits the target availability from Italy, CMRE's advanced ASW programme, its outstanding engineering department, and its unique capability to host multi-national experiments at sea on NRV *Alliance*.

EXPLOITATION AND IMPACT

The results will enable scientific advances in signal processing to offer improved detection in littoral environments. Multi-static CAS signal processing concepts have the potential for improved performance at reduced cost and manning for several mission areas. CMRE offers the right environment to accelerate advanced waveform R&D in the Nations who are able to guide the experimental design in order to exploit collection opportunities most effectively.

CONCLUSIONS

Low frequency Continuous Active Sonar (LCAS) is the first multi-national project to be conducted at CMRE since the introduction of the customer-funded business model. The partners provided significant resources, including financial support, scientific staff, and other in-kind contributions. These resources leveraged ongoing ACT work in autonomous security networks for ASW to enable the collection of a scientific quality data set for the evaluation of CAS performance for littoral environments.

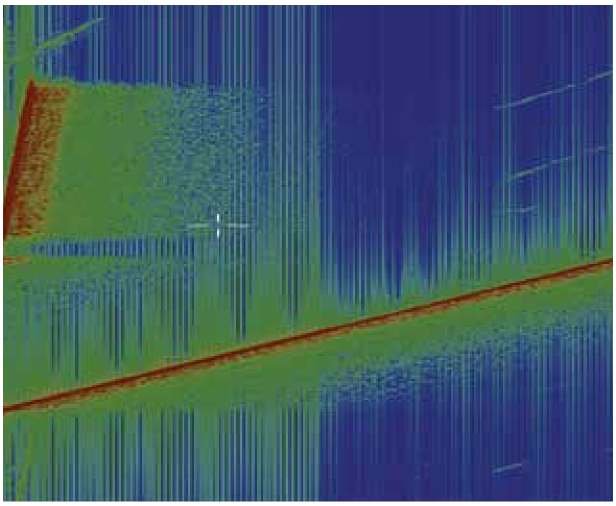

Figure 13: Spectrogram of data collected during the LCAS 2015 trial showing a CAS waveform (lower) and traditional pulse active sonar waveform (upper).

ADVANCING AUTONOMY FOR NAVAL MINE COUNTER-MEASURES (STO-CMRE)

In the area of Mine Counter-Measures (MCMs), CMRE has demonstrated a ground-breaking increase in advanced autonomy for unmanned maritime vehicles by developing specific algorithms for environmental perception and adaptation, and proposing a novel machine decision-making capability.

Dr. Samantha Dugelay, STO-CMRE

BACKGROUND

The goal was the provision of capabilities to counter all sea mines, ensuring the freedom of navigation, unimpeded access, and undisrupted sea lines of communication, interoperability between systems and tactics, and the adoption of agreed standards for maritime autonomy in the MCM domain.

OBJECTIVE(S)

The objective was to further robotic undersea perception through the use of multiple sensors. Advanced autonomous behaviours and accelerated machine decision capability enable unmanned systems to achieve their goals optimally within a doctrinally relevant framework.

S&T ACHIEVEMENTS

Adaptive processing and sensor behaviours have been developed and tested with the Mine hunting Unmanned Underwater Vehicle (UUV) for Shallow water Covert Littoral Expeditions (MUSCLE). State-of-the-art Synthetic Aperture Sonar (SAS) enables detection and classification at 150 m range. Through-the-sensor algorithms adapt the survey autonomously, based on the quality of data, the presence of sand ripples (detrimental to automatic target recognition), and on currents measured onboard the vehicle. The on-board processing for target classification senses the environment automatically and adapts to ensure optimal performance. These building blocks were brought together in a first machine decision-making experiment to demonstrate arbitration intelligence of a vehicle during Exercise Trident Juncture.

SYNERGIES AND COMPLEMENTARITIES

CMRE's seagoing capability, on-board demonstration of machine decision-making, interaction in a multi-national, collegial environment, and data collection infrastructure, are key leverage points for a Nations' own research, informing future multi-national procurement decisions, acquisitions and/or modernisation of NATO capabilities. CMRE's outputs, available to the many NATO and Partner Nations considering AUVs for MCM, will also ensure interoperability between systems and tactics and will push for the adoption of agreed standards for maritime autonomy in the MCM domain.

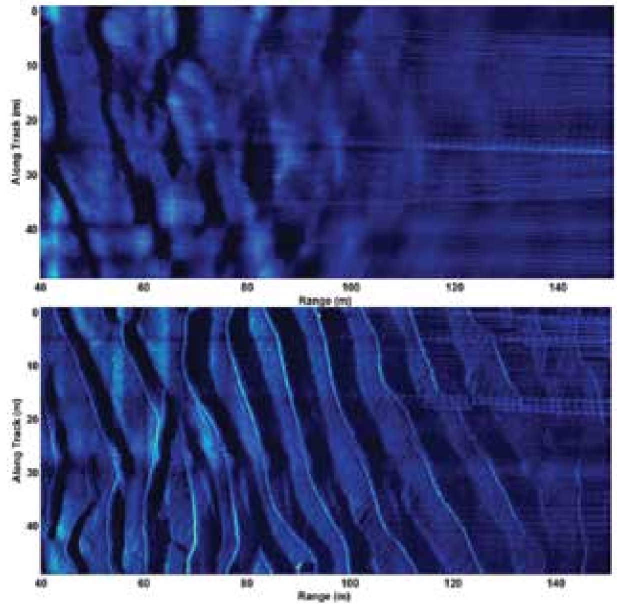

Figure 14: MUSCLE SAS collected during North Sea MCM Experiment 2015 (NSMEX'15). Top: A SAS tile when currents have an unfavourable effect on the SAS processing; Bottom: The area after the vehicle has detected the presence of adverse currents and has adapted its heading.

EXPLOITATION AND IMPACT

AUVs have shown exceptional promise for transforming the way NATO and Partner Nations perform MCM. CMRE's results, theoretically and at-sea, informs the Nations on the rate of progress and future solutions, thereby informing procurement decisions.

CONCLUSIONS

As a leader in research into autonomous maritime systems, CMRE has demonstrated leading-edge developments in machine decision capabilities for autonomous naval mine hunting. NRV *Alliance* hosts multiple AUV groups during scientific and national exercises, bringing scientists and operators together to address issues related to optimal employment of new technologies for stand-off MCM.

Many NATO Nations are considering the use of AUVs for MCM operations since they provide a stand-off capability, removing personnel from the mine field.

TOWARDS UNMANNED AUTONOMOUS PASSIVE ACOUSTIC ISR SOLUTIONS (STO-CMRE)

CMRE demonstrated the feasibility of acoustic array/sensor-equipped underwater gliders for characterising and monitoring the underwater battlespace in Anti-Access and Area Denial (A2/AD) regions.

Dr. Yong-Min Jiang, STO-CMRE

BACKGROUND

CMRE has been investigating novel sensing modalities/payloads for underwater gliders to support NATO ISR missions, especially in A2/AD regions. Five NATO Nations participated in demonstrating the capabilities of the acoustic payloads, newly developed for underwater gliders for battlespace characterisation during the GLISTEN15 (GLIder Sensors and payloads for Tactical characterization of the ENvironment) sea trial.

OBJECTIVE(S)

The objective was to demonstrate new sensors and solutions for underwater gliders for battlespace characterisation by passive acoustic sensing. Seabed characterisation using well-established methodologies was carried out to study the feasibility of transforming conventional approaches, such as using bottom-moored vertical line arrays and anthropogenic source/ambient noise, to autonomous platforms.

Figure 15: The glider fleet of three detected and reacted to the signal of interest at relevant distances from the source.

S&T ACHIEVEMENTS

To demonstrate the capability of an Underwater Autonomous Vehicle (UAV) network for a typical ISR task, the acoustic reactive behaviour was implemented in three omni-directional hydrophone-equipped gliders. For the first time, the glider fleet detected the signal of interest, triggered the predefined mission, and reported to the control centre. This capability will increase the probability of detection and allow better localisation of the source of interest in a large area. Moreover, a tri-axial cross-array (eight hydrophones) and an eight-element vertical line array equipped glider for bottom characterisation were tested at sea for the first time.

> CMRE expedites underwater glider sensor/network technology to enable the capabilities that may be required for future NATO multi-disciplinary and persistent ISR missions in the maritime environment.

SYNERGIES AND COMPLEMENTARITIES

Sponsored by ACT, this work will benefit all NATO Nations. The feasibility of transforming well-established bottom characterisation methods to autonomous platforms was tested so that the knowledge and technology gained from past research could be adopted. Nine external partners from five NATO Nations participated actively. All the participants provided their results and expertise to all the partners. Separately, CMRE is developing a capability for A2/AD based on the integration of smart sensing and long-endurance autonomous underwater platforms.

EXPLOITATION AND IMPACT

Underwater gliders are quasi-expendable with long endurance. The capabilities/payloads provide stealthy, persistent ISR in A2/AD areas. The goal is to extend coverage so that conventional NATO forces will not have to enter constrained areas to collect battlespace information. The results will advance the work of all the partners in converting S&T results to autonomous platforms.

CONCLUSIONS

The CMRE successfully demonstrated the payloads and capabilities for improving underwater glider technology for NATO ISR. The results will explore the potential of gliders for passive acoustic sensing and battlespace characterisation. The comprehensive data set will enable improvement in tactical modelling and facilitate research into the impact of environmental information on sonar performance prediction.

CORSAR – A RELOCATABLE OCEAN PREDICTION SYSTEM (STO-CMRE)

To enable characterisation of the battlespace for expeditionary operations, the relocatable ocean prediction system CORSAR (Corsica/Sardinia) provides operational forecasts of ocean environmental parameters for several days at a time.

Dr. Reiner Onken, STO-CMRE

BACKGROUND

NATO maritime forces often operate beyond the borders of Member Nations. Therefore, it is mandatory to have the most accurate, timely and relevant information – both current and forecast – describing the oceanographic environment which affects its strategic interests.

OBJECTIVE(S)

The objective of CORSAR is to address tactical planning space and timescales within expeditionary warfare contexts by exploring methodologies for local, high-resolution, fully relocatable, short-term prediction tools for any area of interest within useful timeframes. Such a tool will deliver accurate and detailed information of the ocean physical environment, feeding into decision-making systems.

S&T ACHIEVEMENTS

CORSAR runs fully automated on a daily schedule and provides now-casts and several days of forecasts of the three-dimensional fields of temperature, salinity, density, sound speed and horizontal velocity, and the two-dimensional distributions of sea surface height, mixed-layer depth and depth of the sound speed minimum.

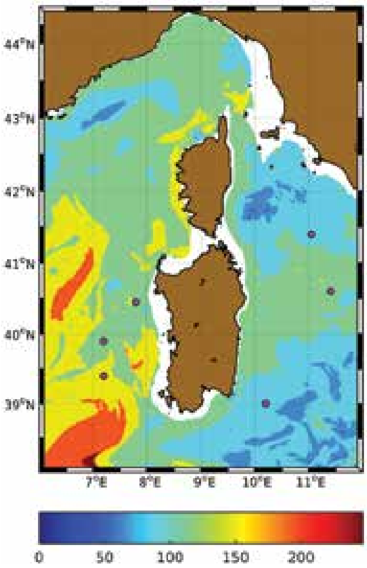

Figure 16: Predicted depth [m] of the sound speed minimum on 20 August 2015. Magenta dots indicate positions where data have been assimilated.

Due to its high horizontal resolution, CORSAR is eddy-resolving and enables the evolution of meso-scale and sub-meso-scale features. The core of CORSAR is ROMS, the Regional Ocean Modelling System, one-way nested in the coarser-resolution operational MERCATOR global ocean model for provision of the initial and lateral boundary conditions. At the sea surface, it is driven by RLM13 meteorological forecasts. Once a day, ROMS is slightly nudged towards MERCATOR in order to prevent the development of solutions which are not supported by the global model. At the same time, the assimilation of near-real-time data guarantees that the solution is in close agreement with reality.

SYNERGIES AND COMPLEMENTARITIES

The MERCATOR forecasts are downloaded daily from the website of the Copernicus Marine Environment Monitoring Service (CMEMS), actual high-resolution weather forecasts of the RLM13 atmospheric model are made available by the German Weather Service (DWD), and near-real-time observations for data assimilation are provided by CMEMS via automated download.

EXPLOITATION AND IMPACT

Images and digital data of the CORSAR forecast products are automatically uploaded to a CMRE server for further exploitation by decision-making systems. In the summer of 2015, CORSAR was used to support a sea trial in the Ligurian Sea, and in 2016 it will demonstrate its capabilities in the framework of Coalition Warrior Interoperability exploration, experimentation and examination eXercises (CWIX).

> NATO maritime forces often operate beyond the borders of the Member Nations, so it is important that they have the most accurate, timely and relevant information – both current and forecast – describing the meteorological and oceanographic aspects of these environments.

CONCLUSIONS

CORSAR, a high-resolution, fully relocatable, short-term ocean prediction system has been successfully implemented at CMRE. For the waters around Corsica and Sardinia in the Western Mediterranean Sea, CORSAR provides accurate and detailed information of the ocean's physical environment by means of now-casts and several days of forecasts. The NATO HQ website provides more information under Meteorology and Oceanography – http://www.nato.int/cps/en/natohq/topics_80282.htm.

PHENOMENOLOGY AND EXPLOITATION OF THERMAL HYPERSPECTRAL SENSING (SET-190)

PRONGHORN 2014 addressed the long-standing goal of creating a high-quality hyperspectral data set for hyperspectral imaging.

Dr. Alexandre Jouan, CAN, Defence Research and Development Canada

BACKGROUND

Hyperspectral imaging in the Long-Wave Infra-Red (LWIR) spectral range has potential in applications using a material's unique spectral fingerprint, as well as for day/night sensing capability. Over the past 10 years, several NATO Nations involved in the development of airborne thermal infra-red hyperspectral sensing technology have expressed a strong interest in working together on a high-quality hyperspectral data set.

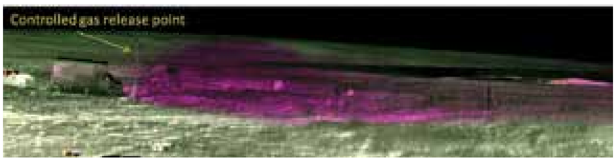

Figure 17: Three-band composite thermal image showing a gas release event in purple.

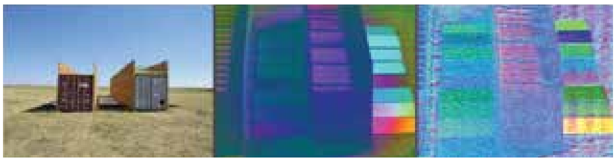

Figure 18: (Left) Indirect illumination site; (Middle) 3-band Mid-Wave Infra-Red (MWIR) image; (Right) Composite image using three principal components of the thermal hyperspectral image.

OBJECTIVE(S)

The objective was to understand the physics of airborne thermal infra-red hyperspectral sensing related to scenarios relevant to ISR and Chemical, Biological, Radiological, Nuclear and Explosive Improvised Explosive Device (CBRNE/IED) detection.

S&T ACHIEVEMENTS

Each participating Nation led an aspect of the PRONGHORN campaign's planning and execution according to their particular area of interest. Experiments addressed: the effect of angular variation of source illumination and target reflectance/emissivity on detection, indirect illumination and shadowing effects from nearby structures, change detection (CAN, NOR, USA); gas and spills detection (BEL, CAN); detection of buried IED surrogates (DEU, NLD); Unexploded Ordnance (UXO) detection (CAN); and infra-red signature-based rediscovery of moving vehicles (CAN, GBR). The dynamic experiments required meticulous co-ordination with airborne and ground-based collection teams. Exploiting thermal infra-red hyperspectral sensing required that complementary hyperspectral reflective sensors be flown with the thermal sensors. The sensor suite included all available COTS thermal systems, a well-characterised US-government thermal instrument (Spatially Enhanced Broadband Array Spectrograph System or SEBASS) and two COTS reflective sensors. These measurements were supported by an extensive array of state-of-the-art ground-based sensors.

SYNERGIES AND COMPLEMENTARITIES

The PRONGHORN campaign could not have been achieved without the exceptional contribution of the SET-190 Nations. They shared expertise, specialised instrumentation and deployed significant Technical Teams on the ground to support the effort. In particular, notable instrument contributions were provided by Belgium (Radiosonde and Geolocation Capability), Canada (Airborne Thermal Airborne Spectrograph Imager or TASI, Thermal Airborne Broadband Imager or TABI, Hypercam, HySpex), Germany (Thermal Camera and Spectral Radiometer), the Netherlands (SCORPIO, Short-Wave Cameras), Norway (Hypercams), and the United States (SEBASS and Longwave Advanced Compact Hyperspectral Imager or LACHI). The dedication of the participating Nations insured the success of the campaign.

EXPLOITATION AND IMPACT

Preliminary results for the detection and identification of a gas plume from a controlled release using the hyperspectral sensing technology are shown in Fig. 17. An example of indirect illumination effects is shown in Fig. 18. It is anticipated that a comprehensive exploitation of the data set will yield important results for the NATO community in providing recommendations on how hyperspectral sensing will serve to address the detection of CBRNE/IED threats.

CONCLUSIONS

The PRONGHORN data set generated by the SET-190/RTG-106 Nations is a major achievement that provides the baseline for extending our knowledge of long-wave hyperspectral phenomenology. The data set will ultimately serve to augment NATO's ISR hyperspectral detection capability.

ASSESSMENT OF MISSION IMPACT DUE TO CYBER-ATTACKS (IST-128)

To solve the problem of mission impact assessment after a cyber-attack, the cyber security community must develop and adopt a new model-driven paradigm.

Dr. Alexander Kott, USA, US Army Research Laboratory

BACKGROUND

Cyber security practitioners are usually unable to either predict or determine the impact of cyber-attacks on a mission supported by compromised computers and networks. Fundamental science and engineering – even basic concepts – are lacking.

OBJECTIVE(S)

The objectives were to: identify practical and research challenges, gaps and approaches, both current and future; assess post cyber-attack mission impact; and explore how attack detection, forensics and attribution, and related technologies and methods should support such an assessment.

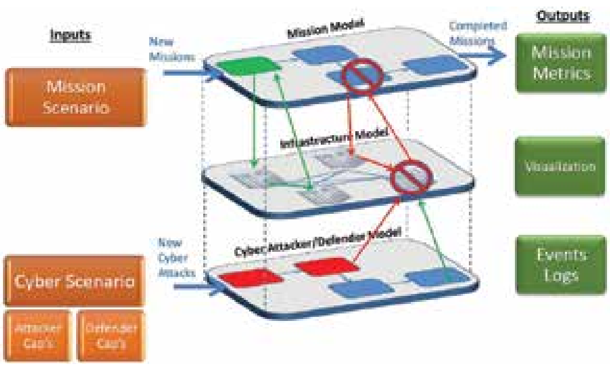

Figure 19: To identify impacts of a cyber-attack (Left) on mission metrics (Right), the overall model must include attacker, defender, infrastructure and mission sub-models. (Adapted by permission from: S. Noel et al., "Analyzing Mission Impacts of Cyber Actions", NATO IST-128 Workshop on Assessment of Mission Impact, Istanbul, Turkey, 15-17 June 2015.)

S&T ACHIEVEMENTS

In the initial assumptions, the key to addressing the challenges of mission impact assessment was thought to be the integration of intrusion detection, analysis, forensics, attribution, and related traditional disciplines of Cyber Defence (CD). The IST-128 participants rejected those assumptions, and produced a different, very strong and clear consensus – the key to solving the problem of mission impact assessment was in developing and adopting a model-driven approach. It required modelling the organisation whose mission is being assessed, the mission itself, and the cyber-vulnerable systems supporting the mission. The models would then be used to simulate the impacts of the cyber-attacks. This was a novel, unexpected perspective on the assessment issue.

SYNERGIES AND COMPLEMENTARITIES

The IST-128 Workshop welcomed 56 participants from nine countries, and made use of research results and insights produced in several national research programmes including: Penoptesec (EU); Analyzing Mission Impact of Cyber Attacks or AMICA (US Office of the Secretary of Defense or US OSD); and Cyber Security Collaborative Research Alliance (US Army).

EXPLOITATION AND IMPACT

The key ideas produced within the Workshop will be published as a public article in at least one high-quality technical magazine, as a publicly accessible website of the US Army Research Laboratory, as a publication of the US Defense Technical Information Center (DTIC), and will be available through the NATO STO. Furthermore, a new proposal for a follow-on activity was approved that will take a broader look at opportunities and recommendations for a model-driven approach to cyber security.

CONCLUSIONS

The conclusion of this broad group of international researchers is that post cyber-attack mission impact assessment cannot be based solely on detection, forensics and attribution. Instead, the key to solving the problem of mission impact assessment is in developing and adopting a new model-driven approach based on systems engineering principles.

A novel model-driven approach to allow assessment of mission impact due to cyber-attacks.

ENHANCING INTEROPERABILITY AND AFFORDABILITY

The Alliance and its Partner Nations collectively work together to achieve and maintain peace, security, safety and stability in our neighbourhood. 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. Furthermore, 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.

NATO S&T provides support by providing solutions to enhancing interoperability and affordability. The following outline of STO activities is presented to the reader in this context:

- Trusted Information Sharing for Partnerships (IST-114);
- Costing Support for Force Structure Studies (SAS-092);
- Economics for Evaluating Fleet Replacement (SAS-099);
- Cost-Benefit Analysis of Military Training (SAS-095);
- A Functional Architecture for Live Simulation Systems (MSG-098);
- Standards, Persistence and Hardware- and Software-in-the-Loop M&S for Maritime Unmanned Systems (STO-CMRE);
- Enhanced Computer-Assisted eXercise (CAX) Architecture, Design and Methodology – SPHINX (MSG-106);
- Building the Future NATO Underwater Communications Capability Standard (STO-CMRE);
- Connected Real-Time Acoustic Prediction for C2 Systems (STO-CMRE);
- From Science to Operationalization: STO-CMRE Participation in the Major NATO-led Interoperability Exercise, CWIX 2015 (STO-CMRE); and
- Modelling and Simulation of Effects of Ship Design on Helicopter Launch and Recovery (AVT-217). ■

TRUSTED INFORMATION SHARING FOR PARTNERSHIPS (IST-114)

Federated mission networking and NATO Network-Enabled Capability (NNEC) require the ability to exchange and share information between the Computer Information Systems (CIS) of NATO and Non-NATO Entities (NNEs). IST-114 identified NATO-relevant use-cases and analysed technical implementations of an Information Exchange Gateway (IEG) able to address this operational requirement.

Mr. Lorenzo Zamburru, ITA, Selex ES

BACKGROUND

The ability to exchange and share information securely between the NATO CIS and NNEs CIS is significant for the effective and efficient conduct of modern military operations. The NATO IEG concept does not currently cover cross-domain information exchange between NATO classified systems and NNEs. IST-114 examined how to exchange multi-level information across domains.

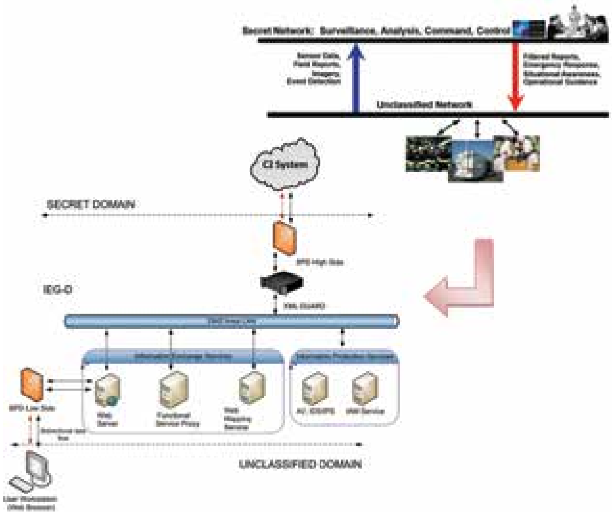

Figure 20: Secure Information sharing between SECRET and UNCLASSIFIED domains: a proposal study.

OBJECTIVE(S)

The objective was to identify relevant operational use-cases for information exchange between NATO and NNEs and present possible solutions to implement an IEG that supports a secure and automated information exchange from up to a SECRET domain down to an UNCLASSIFIED domain (Scenario D).

S&T ACHIEVEMENTS

IST-114 developed a solution to address multi-level access use-cases which directly impact the NATO IEG concept for Scenario D (Scenario D = SECRET to UNCLASSIFIED) in terms of general architecture and specifications for the Guard. The Guard is a multi-level security high-assurance component that limits the data flow between information security domains through enforcement of mandatory security policies. Additional work led to understanding the characteristics of Integrity and Availability in a cross-domain information security context that informs future work to add representations of Integrity and Availability to the existing Confidentiality metadata labels.

SYNERGIES AND COMPLEMENTARITIES

There was close collaboration between the NCIA and HQ SACT concerning related programmes for the development of IEG-Scenario D, the High-Assurance Guard and the content-based Protection and Release protocol. IST-114 also leveraged an Italian National Programme for a Military Research project (with prototyping) on IEG-Scenario D.

> Secure information sharing with NNEs is critical for the conduct of modern coalition and peace-keeping operations.

EXPLOITATION AND IMPACT

The proposed IEG-Scenario D approach meets the operational requirement for secure information exchange between NATO and NNEs for: tactical mine map information; tactical logistic transportation; Common Operational Picture (COP) information; and contamination after ballistic missile attacks.

Broad interest in IST-114's use-cases was expressed by NATO's Comprehensive Crisis and Operations Management Centre and Civil-Military Co-ordination (CIMIC) CoE, the United Nations (UN) Office for the Co-ordination of Humanitarian Affairs, and other stakeholders during the Workshops. Although IST-114 did not build and demonstrate IEG-Scenario D implementation, doing so is the next logical step; the proposed architecture is implementable and the use of the IEG prototypes supports experimentation in both field trials and/or NATO exercises.

CONCLUSIONS

IST-114 identified use-cases for information exchange between NATO and NNEs and proposed specific secure implementation solutions. IST-114 proposes to put the concept into practice through a prototype solution, which will be demonstrated and refined during NATO exercises.

COSTING SUPPORT FOR FORCE STRUCTURE STUDIES (SAS-092)

In fiscally constrained and operationally challenging times, national defence budget decisions are of critical importance. Cost analysis can help shape force structures to meet national aims. SAS-092 aims to share best practices and develop knowledge in a number of cost analysis areas.

Mr. Tony King, GBR, Defence Science and Technology Laboratory

BACKGROUND

In an environment of resource scarcity and high operational demand, long-term defence planning is essential for success. In order to define future defence structures, understanding their future costs using Defence-Specific Inflation (DSI), the average rate of increase in pay and prices of goods and services constituting the defence budget allowing for quality and quantity changes, is imperative. Cost analysis supporting force structure studies improves decision-making and optimises limited resource utilisation.

OBJECTIVE(S)

The objective was to make cost analysis best practices and knowledge available to the NATO Nations. Specifically, SAS-092 focussed on incorporating risk into force structure development, better communication and visualisation of cost analysis, DSI effects, and capability costing methods.

S&T ACHIEVEMENTS

The main achievement was developing a common understanding of the existing or partially existing methods from within Nations. Different approaches to the problem were collected and examined. While each method had unique merits, data requirements and level of maturity, together they contributed a powerful tool set for Nations looking to develop capability in this area of cost analysis.

> Future armed forces will be unsustainable if the conflict between presenting sufficient force structure and downward fiscal pressure is not addressed.

SYNERGIES AND COMPLEMENTARITIES

SAS-092 improved its understanding of DSI through data sharing amongst the participants. In aggregation, the data set produced was more robust and allowed for a deeper understanding and increased confidence in the Task Group's ability to advise on this important subject. Beyond this activity, the work will provide a reference for Nations conducting benchmarking or improving their cost analysis capabilities.

EXPLOITATION AND IMPACT

Canada, Norway and the United Kingdom all contributed applicable methods for benchmarking under different situations. A result of this work is a capability costing tool box for use by all NATO Nations. Tool box users will be able to make evidence-based and more robust future force structure decisions. As a result, senior leader confidence in costing of forces and modernisation decisions will increase.

CONCLUSIONS

All NATO Nations have force structure challenges and similar budget and operational pressures that could make future armed forces unsustainable. DSI will constrain what is affordable and is a real threat to the size and shape of future forces. However, the size and shape of the future force is not the most important part of force structure, rather it is the capability the force provides that makes capability costing a vital tool for national security planning and an essential capability for all Nations. The work of SAS-092 directly contributes to the ability of NATO Nations to better allocate their defence budgets for capability planning, the essence of Smart Defence.

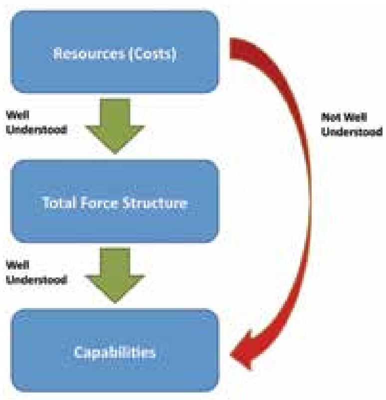

Figure 21: The capability costing problem.

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, 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.

> 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.

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.

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.

Photo Credit: Sgt Gaétan Racine, Canadian Forces Combat Camera

Figure 22: Maintenance of Canada's CC-177 Globemaster. Real option methods help balance the trade-offs between the benefits of replacement and gathering more information.

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.

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.

COST-BENEFIT ANALYSIS OF MILITARY TRAINING (SAS-095)

SAS-095 developed an economic evaluation framework for military training. This will assist military organisations in comparing and prioritising different training projects, as well as assisting in allocating scarce training resources among competing demands.

Dr. Zhigang Wang, CAN, Defence Research and Development Canada

BACKGROUND

Effective military training is the cornerstone of operational readiness and mission success; however, military training imposes a large and continuing demand on military spending. Many NATO Nations have already begun to scale back their defence spending. It is therefore vital that military organisations maximise training benefits and minimise training costs, while maintaining acceptable mission risk levels in this new fiscal environment.

OBJECTIVE(S)

The objectives were to: identify and compare current practices of Cost-Benefit Analysis (CBA) of military training among NATO Nations; advance the state of common knowledge among NATO Nations in the CBA of military training; and identify areas where further research could have a significant impact on improving the CBA of military training.

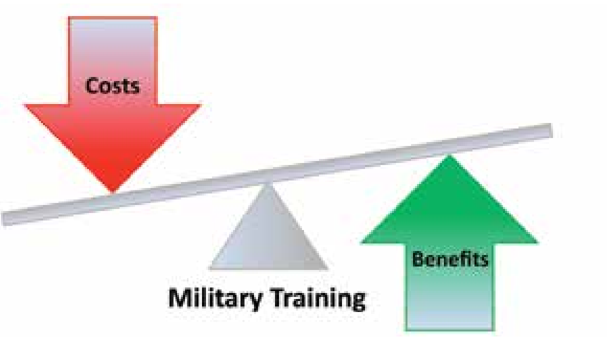

Figure 23: Producing effective military forces at maximum benefit and minimum cost.

S&T ACHIEVEMENTS

In consideration of current practices as well as empirical research and theories on and methods for CBA in literature, SAS-095 further developed an economic evaluation framework for all types of military training at the individual, collective and/or multi-national levels. In addition, SAS-095 initiated areas where further research could have a significant impact on improving the economic evaluation of military training.

SYNERGIES AND COMPLEMENTARITIES

The proposed economic evaluation framework was built upon the analytical methods and models on CBA among NATO Nations. For example, the Netherlands, Sweden and the United Kingdom provided data for case studies; the Netherlands provided methods on estimating training costs and measuring effectiveness, and Canada provided models on estimating training benefits.

> CBA leads to effective use of scarce resources while delivering maximum training benefit.

EXPLOITATION AND IMPACT

SAS-095 delivered a cost-benefit assessment framework for military training. The results will assist defence analysts and planners in estimating training costs, monetising training benefits, comparing and prioritising competing alternative training solutions, and optimising the cost-benefit ratio in producing trained effective military forces. Defence analysts have already adopted the proposed framework in their economic analysis of training simulation (e.g., Netherlands), developed a research requirement to examine the applicability of the proposed framework to current military training issues (e.g., United Kingdom), and further developed CBA techniques that can be applied to the other areas of defence R&D (e.g., Canada). In addition, the activity has great potential for exploitation through the NATO CFI in enhancing and sustaining NATO's military preparedness and operational edge.

CONCLUSIONS

SAS-095 advanced the state of common knowledge among NATO Nations in economic evaluation of military training. The work of SAS-095 is already assisting the military organisations of Canada, the Netherlands, the United Kingdom and others in analysing training costs, and has demonstrated its potential for reducing military training budgets in the future.

A FUNCTIONAL ARCHITECTURE FOR LIVE SIMULATION SYSTEMS (MSG-098)

Multi-national, instrumented live training becomes more important for mission preparation and rehearsal as coalition operations become more prevalent. To conduct training exercises with a “train as you fight” philosophy, an instrumentation system with appropriate fidelity and interoperability is vital. NATO’s Urban Combat Advanced Training Technology (UCATT) Task Groups (TGs) have developed a functional architecture to address this issue.

Mr. Armin Thinnes, DEU, Federal Office of Bundeswehr Equipment

BACKGROUND

The 1999 “Land Operations in the Year 2020” and the 2003 “Urban Operations in the Year 2020” Technical Reports concluded that NATO forces would have to conduct future operations in urban areas. These findings led to the initiation of the UCATT series of RTGs. Based on generic military interoperability use-cases, the UCATT Groups developed a functional system architecture. From this architecture, interfaces were derived as candidates for standardisation, and as a result, in 2011, MSG-098, entitled “Urban Combat Advanced Training Technology (UCATT) – Architecture”, was chartered to tackle further architecture and standardised interface development.

OBJECTIVE(S)

The objective was to maintain and improve the UCATT-developed Functional Architecture for Live Urban training systems and identify and prioritise external architecture interfaces to develop/enable interoperability.

S&T ACHIEVEMENTS

UCATT developed a generic functional architecture for live simulation training systems which forms a design blueprint for an interoperable live combat training centre. This architecture serves as the foundation for UCATT interface-standardisation activities. Based on the architecture and the generic use-cases considered, all relevant data sets were identified, a prioritisation of interfaces for standardisation was completed, and the information transitioned to UCATT interoperability-standards development. During MSG-098, the first Simulation Interoperability Standards Organisation (SISO) UCATT live simulation standard (Laser Engagement) was agreed upon as a joint result of both the MSG-098 and MSG-099 activities.

Figure 24: UCATT logo.

SYNERGIES AND COMPLEMENTARITIES

MSG-098 involved 10 Nations, including two partners who worked in close co-operation with MSG-099 on UCATT Standards. MSG-098 builds on the work of other NMSG Task Groups through the participation of SMEs who contributed to the UCATT meetings.

> NATO forces will need to understand, train for, and operate in complex urban environments.

EXPLOITATION AND IMPACT

The UCATT Architecture will enable joint and coalition military training through interconnected live simulation training systems. The resulting set of standardised live simulation interfaces better positions military users and acquisition organisations to: define requirements; target industrial internal R&D investments; open new tendering opportunities; and bring interoperable training to new levels of efficacy. The first evidence of these benefits is the adoption of the UCATT Laser Engagement interface standard.

CONCLUSIONS

Interoperability across instrumented live training systems benefits national procurement, provides training flexibility for the Nations, and renders international training events easier and less expensive to conduct. NATO’s MSG-098 was important in developing and promoting a UCATT architecture and its resulting interface interoperability standards for live simulation. With UCATT follow-on activities and SISO-approved interface standards in progress, the UCATT series remains a valuable M&S line of effort.

STANDARDS, PERSISTENCE AND HARDWARE- AND SOFTWARE-IN-THE-LOOP M&S FOR MARITIME UNMANNED SYSTEMS (STO-CMRE)

As an enabler and force multiplier for preparing the future of maritime unmanned systems, Persistent Autonomous Reconfigurable Capability (PARC) will be a key disruptive technology for future ASW and MCM capabilities. Excellent results have been obtained in all three focus areas: persistence; M&S; and interoperability. The latter is a key component of capability delivery.

Mr. Robert Been, STO-CMRE

BACKGROUND

Learning from the experiences of the unmanned air domain, PARC has considered standards, persistence and interoperability from its inception in 2014.

OBJECTIVE(S)

The objectives were to: create a standard for multi-domain control stations; develop a maritime autonomy virtual test-bed at the mission and physics levels; and construct an interoperable wireless supply of energy and high-speed data transfer between underwater robots.

S&T ACHIEVEMENTS

M&S: PARC developed a federation-based architecture for Hardware- and Software-In-The-Loop (HWITL/SWITL) simulation, and has generated a framework for standards in maritime robotics M&S and Command and Control (C2). An M&S system showcased the integration of an ROS (Robotic Operating System) and HLA (High-Level Architecture), using an AUV included in the PARC HLA Federation, thereby extending the test-bed capability.

> If you bring us an UGV, USV, or UUV that's not JAUS-compliant, we're not interested.

Standards: With interoperable systems key for NATO, PARC served on the NATO Industrial Advisory Group (NIAG) Quick Reaction Team for the development of a conceptual data model for a Multi-Domain Control Station (MDCS).

Energy Availability: This is a prime limitation for maritime autonomy, so a hardware interoperable and scalable Wireless Power Transfer (WPT) system was developed. A prototype was refined to fit in a man-portable AUV and the CMRE docking station. It is a first as a proof-of-concept, hardware-interoperable, scalable power charger, applicable to various types of vehicles.

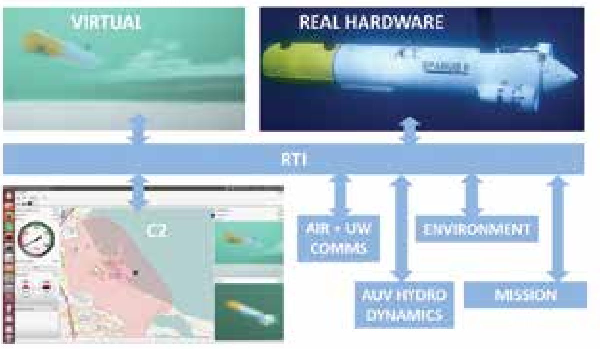

Figure 25: HWITL federation-based M&S capability that was developed within the framework of PARC in 2015.

SYNERGIES AND COMPLEMENTARITIES

This work was common to other areas of the ACT PoW. Aligned with the MDCS effort, PARC is developing a payload prototype that follows the STANAG initiative.

EXPLOITATION AND IMPACT

As an enabling technology, this work is central to the delivery of future unmanned systems in a NATO context. The M&S work can be exploited with CSO Panel activities (IST, NMSG and SCI), other ACT initiatives, and the Concept Development and Experimentation (CD&E) programme. The PARC work can be exploited by industry and CMRE, within the context of a NATO maritime test-bed for unmanned systems.

CONCLUSIONS

PARC has achieved a standards-based HWITL M&S capability, a WPT module for an AUV, and contributed to the creation of a STANAG for the MDCS through the NIAG, all of which are essential for interoperability of autonomous systems.

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

MSG-106 provides a complete response to the complicated undertaking of conducting distributed exercises through development of a conceptual model called SPHINX which 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, 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.

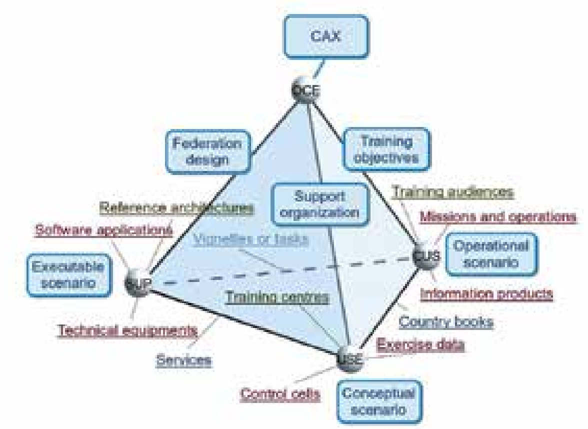

Figure 26: Conceptual model SPHINX describing a CAX.

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 reference document; and provide products and recommendations for standardisation, quality assurance, co-ordination, and risk management.

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).

> SPHINX provides CAX leaders/organisers with a clearer mutual understanding of the increased potential for success.

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 produced three Allied M&S publications, thereby delivering results not only on technical matters (NETN architecture and FOM design), but also on organisational and operational issues (Handbook for CAX). The SPHINX conceptual model developed and tested by MSG-106 provides a mutual understanding among planners, modellers and operators for improved training effectiveness.

BUILDING THE FUTURE NATO UNDERWATER COMMUNICATIONS CAPABILITY STANDARD (STO-CMRE)

Underwater communication is an important area of interest for NATO. CMRE has developed a protocol to enable the innovative employment of underwater assets through standardised, interoperable exchange of data.

Dr. João Alves, STO-CMRE

BACKGROUND

Underwater assets with different capabilities are being employed more-and-more to tackle challenging tasks co-operatively. Unfortunately, the connectivity of heterogeneous platforms cannot be taken for granted. In the air we connect to any Wi-Fi (Wireless Fidelity) hotspot without worrying about compatibility, but there is nothing remotely similar underwater.

OBJECTIVE(S)

The objective is to provide the first underwater digital communications standard – a common format to announce a presence, exchange low volumes of data, and create an ad-hoc network. This is now very close to being realised with the ratification of STANAG 4748.

S&T ACHIEVEMENTS

CMRE has finalised the technical description of the JANUS (Roman god of portals) protocol, collaborating directly with operational forces and engaging manufacturers through the NIAG. The STANAG is a long-overdue breakthrough, but underwater communications is not limited to standardising the conversion of bits of sound. Complex problems include implementation of scalable and secure networks. CMRE is exploring smart adaptation to the difficult underwater channel through an adaptable architecture following the paradigm of cognitive radio. Initial testing and data acquisition involved the Portuguese Navy (PRT(N)), the Universities of Porto and the Azores, and CMRE.

SYNERGIES AND COMPLEMENTARITIES

From the onset, CMRE has acknowledged industry and navies as key stakeholders in the JANUS process as it moves towards exploring advanced, comprehensive networking solutions. Physical layer developments will emerge from academia, while interoperability will be addressed at industrial and multi-national levels, with end-users (mainly navies) driving the requirements.

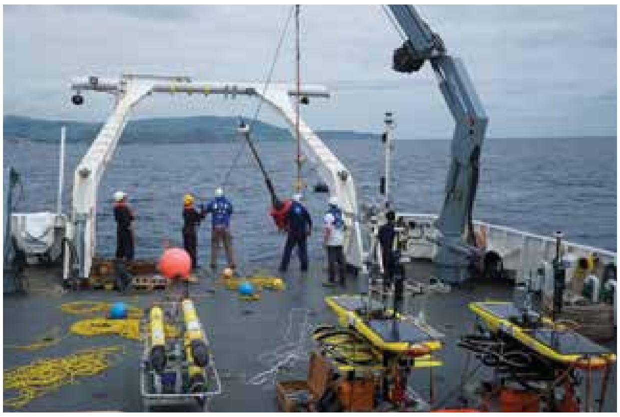

Figure 27: Equipment being deployed in a trial involving the PRT(N), Universities of Porto and the Azores, and CMRE.

EXPLOITATION AND IMPACT

The establishment of a standard can de-risk procurement and obsolescence management in the Nations. There will be no need to rely solely on one manufacturer for the life-cycle of communications equipment. This is an opportunity to look at the future of this and other relevant standards. With the help of the Nations' industry and academia, CMRE is shaping revisions of the STANAG, conducting tests, reviewing different scenarios, and exploring a broader approach, with collaborators plugging their "piece of the puzzle" into different architectural entry points.

> This STANAG will be a long-overdue breakthrough.

CONCLUSIONS

The challenges provided by the underwater communications channel provide fertile ground for R&D efforts across academia and industry. CMRE has taken those challenges onboard and set an ambitious objective. The future of underwater communications must be flexible, adaptable, cognitive and standardised, with several institutions being able to contribute without having to compromise their intellectual property.

CONNECTED REAL-TIME ACOUSTIC PREDICTION FOR C2 SYSTEMS (STO-CMRE)

The annual CWIX explores the interoperability of operational Command, Control, Communications, Computers and Intelligence (C4I) systems. At the 2015 event, CMRE's Multi-Static Tactical Planning Aid (MSTPA) tested the real-time generation and dissemination of ship sonar performance maps. Climatology and platform positions were ingested, allowing automated acoustic predictions to be published on national C2 displays and on the NATO Common Operational Picture (NCOP).

Mr. Christopher Strode, STO-CMRE

BACKGROUND

The Anti-Submarine Warfare Commander (ASWC) relies on sonar performance predictions from each platform, often employing different acoustic models. Each platform provides its assessment of the underwater conditions, such as sound speed profile and bottom type, resulting in the potential for prediction discrepancies, an inaccurate picture of ASW capability, and gaps in coverage. A common, linked environmental and acoustic prediction tool would be valuable.

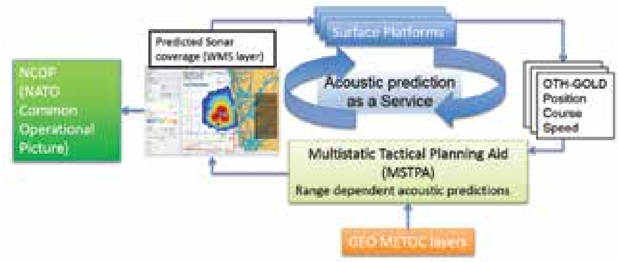

Figure 28: Graphic showing the acoustic prediction service demonstrated at CWIX 2015.

OBJECTIVE(S)

The objective was to demonstrate interoperability whereby MSTPA ingests platform positions and standard climatology in real time. The CWIX framework allowed for testing of data formats and transfer protocols compatible with fielded C2 systems.

> Representatives of the user community believe strongly that MSTPA can fulfil the shortfall in acoustic propagation and deliver an early capability.

S&T ACHIEVEMENTS

MSTPA provided regular sonar performance assessments for multiple platforms, taking into account the current position of each platform and up-to-date climatology. The process was completely automated with sonar performance maps appearing on multiple C2 systems without user interaction. The framework employed real-time ingestion of the recognised maritime picture, with environmental input from other Geographic, Meteorological and Oceanographic (GEOMETOC) providers. This allowed the tool to employ fully range-dependent acoustic predictions, and publish the results on national C2 systems and on the NCOP.

SYNERGIES AND COMPLEMENTARITIES

This research demonstrated compatibility with standard NATO systems and protocols and with environmental data produced by CMRE. In effect, MSTPA acted as a hub for environmental and acoustic predictions with multiple inputs and outputs operating within the CWIX C2 network. Nations that connect to this service will leverage CMRE's considerable investment in acoustic expertise. Furthermore, when operating within a deployed multi-national task group, all performance predictions will account for the most up-to-date environmental information, likely provided by the Host Nation. Nations with suitable METOC services are encouraged to participate in the future testing of this approach.

EXPLOITATION AND IMPACT

CWIX testing has demonstrated that surface platforms may receive acoustic predictions as a service, freeing sonar operators from the complex task of updating acoustic predictions and allowing the ASWC to observe consistent predictions within their task group. In addition to the real-time use demonstrated at CWIX 2015, MSTPA may also be used for ASW planning and post-exercise analysis.

CONCLUSIONS

CWIX has allowed a common acoustic prediction tool to provide output for multiple assets in real time. The data formats and links enable a fully automated process, providing valuable situational awareness in ASW operations directly on C2 systems.

FROM SCIENCE TO OPERATIONALIZATION: STO-CMRE PARTICIPATION IN THE MAJOR NATO-LED INTEROPERABILITY EXERCISE, CWIX 2015 (STO-CMRE)

At the annual CWIX held in 2015, CMRE provided six scientific products in support of the event's ongoing efforts to explore the interoperability of operational C4I systems.

Dr. Raul Vicen-Bueno, Dr. Alex Bourque, Mr. Christopher Strode, Mr. Manlio Oddone and Mr. Leonardo Millefiori, STO-CMRE

BACKGROUND

CWIX focusses on testing the interoperability of NATO and Nations' C4I systems. CMRE contributed with oceanographic forecasts, environmental (risk) assessment, asset planning, the MSTPA, Traffic Route Extraction and Anomaly Detection (TREAD), and Fusion as a Service.

Fig. 29 shows the allocation of CMRE capabilities and interactions at CWIX 2015.

OBJECTIVE(S)

The objective of CMRE's participation in CWIX 2015 was to demonstrate its ability to: transfer cutting-edge scientific products to the operational community, interoperating in a joint NATO exercise and/or operation; disseminate useful information to NATO and Nations' C2 systems using highly interoperable standards; act as a provider of oceanographic data, novel techniques for environmental risk assessment, positional and planning information from multi-objective optimisation algorithms, sonar performance surfaces from METOC predictions, traffic routes and anomaly detection and fuse information from multi-sources using efficient algorithms; federate MSTPA within the M&S environment; and participate and contribute to the Joint Vignette with novel scientific products, working in a coalition with air, land, maritime and special forces capabilities.

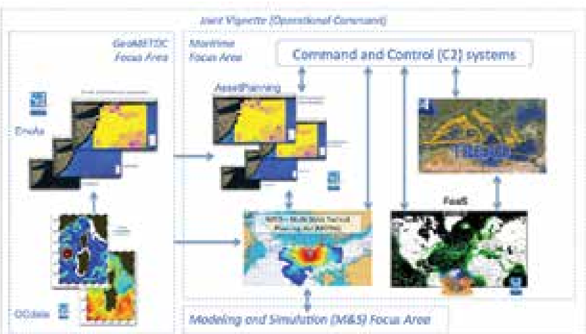

Figure 29: STO-CMRE capabilities at CWIX 2015.

CWIX 2015 provided an opportunity to present research and scientific products developed by STO-CMRE to the operational community.

S&T ACHIEVEMENTS

CMRE scientific capabilities provided useful information layers, such as METOC surfaces, risk maps, sonar coverage plots and maritime patterns of life, to several systems (GEOMETOC, C2, C4I). CMRE capabilities achieved interoperability with these systems via the latest version of Open Geospatial Consortium (OGC) protocols. Sending and receiving positions and planned intended movements of maritime assets, fused vessel tracks and predicted destination based on contextual information was also achieved. Federation of MSTPA with other models using HLA was successfully done.

SYNERGIES AND COMPLEMENTARITIES

CWIX 2015 offered access to a large community of NATO and Nations' systems for testing. Several Nations found scientific products provided by CMRE to be relevant while complementing their systems.

EXPLOITATION AND IMPACT

Deployment in CWIX 2015 provided an opportunity to showcase CMRE's research. Interactions with 40+ different capabilities from 10+ NATO and Partner Nations (interoperability success above 75%) gave clear visibility to CMRE products, opened a window into operational reality and provided a focus for future efforts. Nations' S&T organisations tested their products against CMRE and proved them interoperable.

CONCLUSIONS

By testing six scientific capabilities at CWIX 2015, CMRE exposed its research to the operational community, showcased its output, and took the first, significant step toward the interoperability of NATO and Nations' C4I systems.

MODELLING AND SIMULATION OF THE EFFECTS OF SHIP DESIGN ON HELICOPTER LAUNCH AND RECOVERY (AVT-217)

Conducting ship-based helicopter operations is a crucial capability supporting the naval doctrine of Allied fleets. Critical technical areas of the ship environment were identified to assess the maturity of computational and experimental methods and to recommend their use in the design of ships to better support safe and effective helicopter operations.

Mr. John Kinzer, USA, US Office of Naval Research and Ir. Jasper van der Vorst, NLD, Netherlands Aerospace Centre

BACKGROUND

With technology and "rules of thumb" that were available in 2002, ship-board helicopter operations were addressed in NATO STANAG 4154 on "Common Procedures for Seakeeping in Ship Design". RTG/AVT-217 built upon the work of two previous RTGs to execute a comprehensive assessment of the S&T exploitable to develop better ship design guidance for safer and more effective helicopter operations.

OBJECTIVE(S)

The objectives were to: identify critical areas of ship design guidance for rotorcraft operations; assess the S&T available for each of the areas; and recommend applications of S&T to improve ship design guidance.

S&T ACHIEVEMENTS

The RTG identified critical areas for ship design guidance and conducted an assessment of technologies which revealed advancements in S&T. The technology assessment showed that currently available data and computational methods can be used to effectively enhance ship design for the safe launch and recovery of helicopters. The data and methods can be included in integrated M&S of the helicopter's performance during a landing sequence. Recommendations for use of this S&T were passed to the NATO Ship Design Capabilities Group (SDCG) Specialists' Team on Seaway Mobility (ST-SM).

SYNERGIES AND COMPLEMENTARITIES

AVT-217 brought together experts in the field from seven NATO Nations with experience in critical ship design areas, along with the NATO SDCG ST-SM who shared the current ship design guidance for aircraft operations. As the assessments were nearing completion, members of the Task Group presented results to British and Canadian Defence Forces and to US Navy and

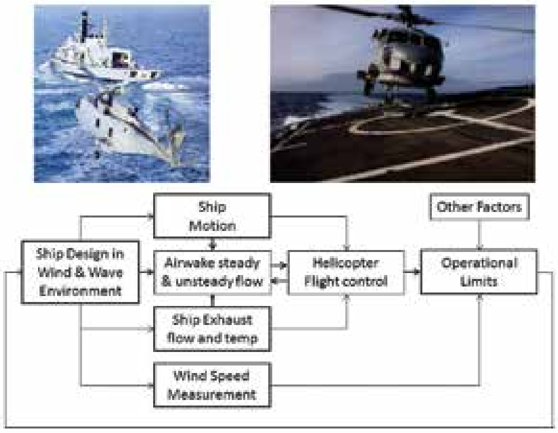

Figure 30: Ship-board launch and recovery of helicopters is a challenge. M&S can affect changes in ship design that make it safer.

Coast Guard programme managers for ship and aircraft design and integration in order to obtain their valuable comments.

EXPLOITATION AND IMPACT

NATO navies continue to use helicopters, manned or unmanned, to accomplish a variety of missions. With this as motivation, NATO SDCG ST-SM will use the results of AVT-217 in preparing an Allied Naval Engineering Publication on safe helicopter ship-board launch and recovery, thus enabling an M&S approach to evaluating the performance effectiveness of new ship/helicopter combinations at earlier stages of ship design and/or for ship modification supporting new mission areas.

CONCLUSIONS

The work of this Group delivered recommendations for the application of S&T results to improve ship design guidance; these recommendations will be directly exploited by the NATO SDCG to directly support NATO navies' requirements.

MITIGATING RISK AND THREAT

The world is changing at a rapid pace. Places that once looked safe don't seem so safe anymore, and people are threatened in their quality of life and well-being. The world is becoming more and more connected, economies across the world are relying heavily on each other, and the world population keeps growing.

NATO S&T can support finding solutions to mitigate risks and threats. The following outline of STO activities is presented in this context:

- Visual Analytics: Enabling Discovery and Decision-Making (IST-110);
- M&S to Support Decision-Makers in Cyber Defence (MSG-117);
- Unusual Activity? – Transitioning Maritime Traffic Anomaly Detection to the Operational Community (STO-CMRE);
- Periodic Port Analytics for NATO Maritime Command (STO-CMRE);
- Persistent Unmanned "Cutting-Edge" Acoustic Maritime Surveillance in Real-Time (STO-CMRE);
- Monitoring of Dumped Munitions (STO-CMRE);
- Range Contamination (AVT-244);
- Unmanned Search and Rescue – ICARUS (STO-CMRE);
- Advanced Materials, Systems and Evaluation Methods for Adaptive Camouflage (SCI-230);
- Military Suicide Prevention (HFM-218);
- Mental Health Training (HFM-203); and
- Optimizing Hearing Loss Prevention and Treatment, Rehabilitation and Reintegration of Soldiers with Hearing Impairment (HFM-229).

VISUAL ANALYTICS: ENABLING DISCOVERY AND DECISION-MAKING (IST-110)

Data collection and storage are ever increasing, and as the volume and complexity of data expands, effective use becomes increasingly challenging and traditional approaches are being rendered inadequate. Visual analytics provides an effective means to perceive, understand and reason about complex data, and thus supports informed decision-making and strategy development.

Dr. Margaret Varga, GBR, Oxford University

BACKGROUND

Visual analytics is the science of analytical reasoning facilitated by an interactive visual interface and represents the future for analysts and decision-makers who are overloaded with vast, often dynamic, complex, disparate and conflicting data sets. Through visual analytics, actionable information may be distilled to allow timely responses to threats.

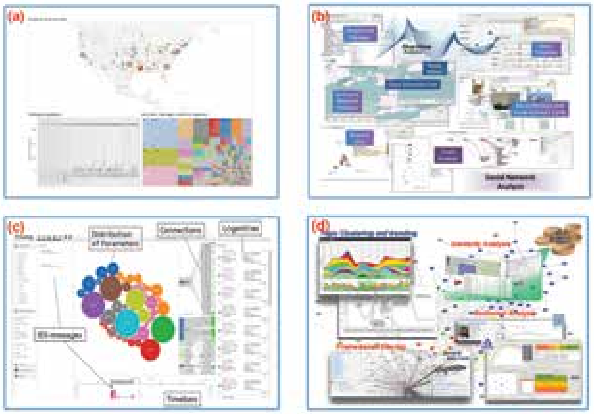

Figure 31: (a) Aviation safety – Bird strikes; (b) Maritime domain awareness and counter-insurgency; (c) CD; (d) Human terrain exploitation.

OBJECTIVE(S)

The objectives were to: develop and apply visual analytics to synthesise information and derive insight from massive, dynamic data; detect the expected and discover the unexpected; provide timely, defensible assessments; and communicate effectively for action.

S&T ACHIEVEMENTS

IST-110 successfully applied their innovative approach across radically different applications; transforming complex, non-visual data into visual forms which enabled dynamic analysis, exploration and understanding. The work has been presented at many prestigious international conferences, workshops and seminars.

The Task Group developed specific and generic visual analytics tools applicable across many domains. In particular, they examined the challenges of developing/transferring visual analytics approaches across aviation safety, CD, situation awareness, maritime domain awareness, and counter-insurgency, as well as tactical human terrain understanding (social networks, cultural inference, etc.), thus achieving significant cost savings. Furthermore, the Group facilitated the uptake and exploitation of visual analytics technologies within NATO and beyond.

> Detect the expected and discover the unexpected.

SYNERGIES AND COMPLEMENTARITIES

IST-110 collaborated with Defence Research and Development Canada (DRDC) on multi-intelligence sense-making in the maritime domain; this was highly praised by 16 maritime security specialists from the five Canadian federal departments involved in Maritime Security Operation Centres, and this technology has been transferred into their counter-insurgency applications. IST-110 collaborated in similar ways through Germany's Fraunhofer Institute for Communication, Information Processing and Ergonomics (cyber situation awareness), and through the US Army Research Laboratory (human terrain understanding).

EXPLOITATION AND IMPACT

The R&D success of IST-110 shows that visual analytics can and should be exploited across a wide range of domains relevant to all NATO Member and Partner Nations. Aviation safety (bird-strike) work received highly positive feedback. This GBR-led collaboration was with the Royal Netherlands Air Force and the Netherlands Military Aviation Authority; the latter organisations are custodians of the NATO bird/wildlife management policy, and provided data and invaluable operational insight/assessment. US Federal Aviation Administration (FAA) data were also used. This technology has been transferred to maritime and cyber domains.

CONCLUSIONS

Application of real data, in collaboration with military users, showed that the use of visual analytic tools can decrease the decision time, and can allow users to define additional patterns and information that had not previously been easily detected.

M&S TO SUPPORT DECISION-MAKERS IN CYBER DEFENCE (MSG-117)

Simulating cyber to put cyber into simulations. MSG-117 developed a high-level generic guidance to focus application of CD M&S application from the engineering level through mission rehearsal and joint collective training simulations.

Mrs. Stella Croom-Johnson, GBR, Defence Science and Technology Laboratory

BACKGROUND

Cyber is the “fifth domain”, and the fast-moving cyber threat environment necessitates renewed focus on the development of CD policy and capabilities. CD M&S is relatively new; the full benefits are still to be realised at all levels. New education and training solutions for CD are needed and M&S can play an important role in their development. M&S can provide supporting tools to create more realistic training scenarios and environments, and allow for the safe testing of new CD capabilities.

Figure 32: M&S support is vital to effective CD.

OBJECTIVE(S)

The objective was to investigate and recommend which aspects of CD could be supported with M&S.

S&T ACHIEVEMENTS

MSG-117 broke new ground in an area where no previous work existed and traction was notoriously difficult to obtain. The cyber and training simulation communities had not previously worked together; the collaboration generated an increased understanding of the problem space and identified areas of mutual benefit.

High-level generic guidance was formulated on where the focussed application of M&S would provide the most benefit to CD.

SYNERGIES AND COMPLEMENTARITIES

To ensure coherence and avoid duplication, MSG-117 worked with other Panels on several activities including a Symposium on Analysis Support to Decision-Making in CD and Security, a Workshop on M&S Support for CD, and participated with other Task Groups on Data Farming and CIS Security, providing leverage not otherwise obtainable.

EXPLOITATION AND IMPACT

The work of the Task Group informs NATO of national CD capability developments, including the NATO Computer Incident Response Capability Next Generation. Engineering-level tools and environments decrease residual risks in cyber and cyber-physical systems acquisition, ensure network protection/data integrity, and test new CD technologies. Using M&S for CD in campaign- and mission-level simulations will emphasise the impact of a cyber-attack, and train cyber and non-cyber personnel in cyber-related issues and procedures.

CONCLUSIONS

M&S plays a vital role in CD from the engineering level through to the campaign level. MSG-117 recommends the following next steps: a structured programme of cyber education and awareness for all personnel working in the military environment; representation of the impact of cyber-attacks in all force-level mission rehearsal and training exercises; development of the NETN FOM; and a catalogue of existing M&S tools highlighting current capabilities and informing standardisation work.

> 100 years ago we stood together on the frontline of a Great War; today we stand on the frontline of a virtual war – and though the warheads launched are invisible, cyber is far from being a theoretical threat.

UNUSUAL ACTIVITY? – TRANSITIONING MARITIME TRAFFIC ANOMALY DETECTION TO THE OPERATIONAL COMMUNITY (STO-CMRE)

Machine-learning methodologies have proven capable of inferring maritime traffic schemes from historical data, providing the capability to classify vessel activities and detect anomalous behaviours.

Mr. Leonardo Millefiori, Ms. Karna Bryan and Mr. Manlio Oddone, STO-CMRE

BACKGROUND

Progress in modern software engineering approaches such as common data standards and cross-platform architectures have created opportunities for collaboration throughout the Alliance in the area of Joint Intelligence, Surveillance and Reconnaissance (JISR). Advancements in concepts for networked information processing also create the need to overcome interoperability challenges regarding standardised terminology and definitions for all users.

Figure 33: Real-time AIS traffic on top of the recognised traffic schemes in the area of operations at CWIX 2015. The TREAD methodology generated the patterns of life, which are colour-coded depending on the average velocity of vessels on the route.

OBJECTIVE(S)

The objective was to demonstrate new capabilities and uncover challenges with the potential operational use of research products and experimental concepts via testing at CWIX 2015 with both NATO tools and with Nations' C2 systems.

S&T ACHIEVEMENTS

TREAD has demonstrated how algorithms can leverage historical information regarding patterns of ships and, when combined with live traffic, provides a baseline for a behaviour-based anomaly detector. TREAD's technology has been published extensively; the next steps are to demonstrate interoperability between these scientific results and C2 systems.

SYNERGIES AND COMPLEMENTARITIES

Interoperability tests related to TREAD were carried out with 15 other capabilities from five Nations and three NATO bodies. Enhanced collaboration between NATO and its Member Nations resulted in exploring new concepts for higher-level information interoperability, including in the use of anomalous vessels.

EXPLOITATION AND IMPACT

Machine-learning methodologies for extracting patterns of life and other information products have been evaluated by the NATO Shipping Centre (NSC) of the Allied MARCOM, enabling continuous improvement of the products and providing validated concepts for next-generation C2 systems.

CONCLUSIONS

The success of incorporating emergent capabilities for effective decision support depends on the ability of the interoperability of these next-generation products with existing and future operational systems.

At CWIX 2015, CMRE demonstrated how machine-learned knowledge can be used effectively for intelligence purposes by highlighting anomalous behaviours of ships at sea.

PERIODIC PORT ANALYTICS FOR NATO MARITIME COMMAND (STO-CMRE)

In response to a demonstrated MARCOM need, CMRE established a service where any authorised user may access the monthly statistics for ports of the world, which may for example be used to: “assure that any given (or particular) flag nation is acting in accordance with international sanctions through the cessation of transits to ports under scrutiny.”

Mr. Jonathan Locke and Dr. Luca Cazzanti, STO-CMRE

BACKGROUND

Since 2012, CMRE scientists have been working closely with the NSC to understand how basic AIS data may be best exploited by military end-users to enhance Maritime Situational Awareness (MSA). CMRE’s worldwide vessel database of AIS detections reaching back to 2007 provides an extensive data set with latent potential to meet the needs of the NSC users. Specifically, the analytics provide timely data related to ships or ports that may be under scrutiny in an easy-to-use format that is accessible to authorised users.

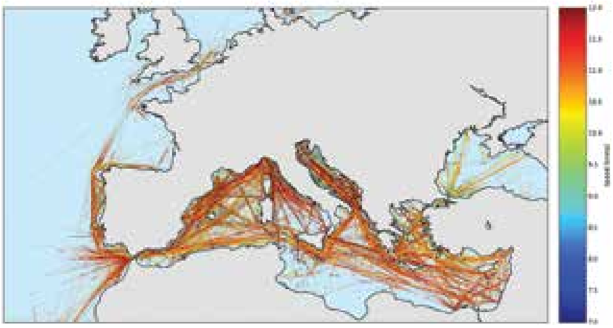

Figure 34: Monthly analytics for Italian ports.

OBJECTIVE(S)

The objective was to provide a chart-based information product of port statistics, categorised by vessel characteristics, which is easy to update on a monthly basis.

S&T ACHIEVEMENTS

Adopting a multi-domain approach, computational MSA takes advantage of the latest research in machine learning, signal processing and big data analytics. The port analytics product uses a prototype framework which more generally demonstrates how current industry standards can be applied to automate the synthesis of very large volumes of information.

SYNERGIES AND COMPLEMENTARITIES

Nations are facing a surge in information volume and variety, and must set requirements for C2 future systems. A remit of this work has been to help promote a Joint Research Project in distributed databases to de-risk the implementation of big data technologies. This activity is also an input to collaborative activities such as the System-of-Systems for MSA (SCI-280) and the future RTG on Visual Analytics.

EXPLOITATION AND IMPACT

The product is being evaluated by NATO operational staff and has direct national utility. Prototypes for the delivery of periodic information products inform requirements capture for future C2 systems and next-generation interoperability standards.

The analytics provide timely data related to ships or ports that may be under scrutiny in an easy-to-use format that is accessible to authorised users.

CONCLUSIONS

A set of information products has been provided to the user community while CMRE continues to refine the port analytics product to inform decision-makers and staff regarding maritime security related issues. Additionally, CMRE will continue to improve this prototype service by developing additional information layers, such as anomalous maritime indicators, and investigating standards for derived information products.

PERSISTENT UNMANNED "CUTTING-EDGE" ACOUSTIC MARITIME SURVEILLANCE IN REAL TIME (STO-CMRE)

Persistent maritime surveillance and vessel classification, which is critical for ISR yet difficult with conventional technology, was demonstrated at sea. A passive acoustic surveillance capability was fully integrated on a Wave Glider® and an underwater glider, as part of the EC project PERSEUS (Protection of European boRders and Seas through the intElligent Use of Surveillance).

Dr. Alessandra Tesei and Mr. Robert Been, STO-CMRE

BACKGROUND

The scientific challenge was to accurately track small, fast boats with small radar signatures and without automatic identification systems, in highly noisy littoral environments.

OBJECTIVE(S)

The objective was to demonstrate innovative concepts for unmanned passive, detection, classification and tracking of small, fast boats, difficult to detect with conventional surveillance technology.

> Full integration of a passive sonar was achieved on a Liquid-Robotics Wave Glider®. Acoustic surveillance with highly persistent mobile robots was proven as a technology demonstrator.

S&T ACHIEVEMENTS

In an innovative combination of existing technologies, passive sonar was integrated into the vehicles with embedded real-time processing. Two multi-national events demonstrated system integration and portability, sonar power consumption below 10 W, integration into an existing C2 environment, and post-analysis through agreed key performance indicators. High scientific quality was recognised by multiple invitations to conferences and dissemination events.

SYNERGIES AND COMPLEMENTARITIES

This effort has synergy with SCI Panel work on Affordable Robots. It leveraged CMRE's background in platform technology, acoustic sensing and digital data acquisition technology, including national work on vessel noise measurement from a compact acoustic antenna installed on a hybrid AUV. It is linked to the EC project Argomarine (2008 – 2011), a distributed network of underwater moored and cabled acoustic sensor stations for traffic monitoring (in post-processing).

EXPLOITATION AND IMPACT

Being recognised for its vast amount of expertise and experience in unmanned systems and their sensor capabilities, the CMRE continues to be actively involved in multi-national co-operative efforts. Deployed organically without air superiority or sea control, autonomous vehicles with smart sensors improve ISR significantly and counter A2/AD strategies. This can be exploited for maritime security by fusing the proposed underwater sensing capability with above-water sensors, such as optical and/or thermal cameras, or radar intercept devices. By tuning the antenna geometry and customising part of the processing, the system may be exploited for the passive detection and localisation of submarines.

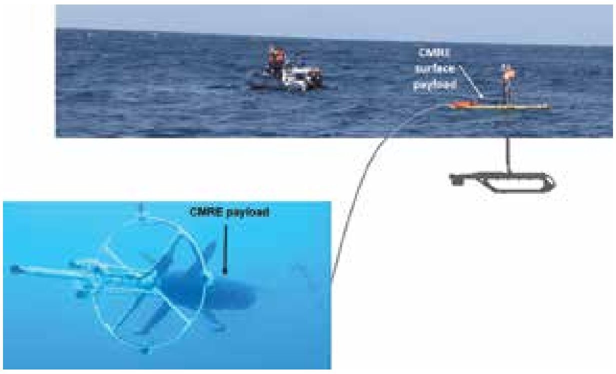

Figure 35: Liquid-Robotics Wave Glider® with CMRE's real-time underwater acoustic surveillance payload.

CONCLUSIONS

Underwater acoustic surveillance with highly persistent mobile robots was proven as a technology demonstrator. Real-time detections were made and the detection, tracking and classification results were forwarded to the PERSEUS National Control Centre (NCC). PERSEUS is considered the model of R&D in the maritime security sector for the period 2012 – 2015.

MONITORING OF DUMPED MUNITIONS (STO-CMRE)

This NATO SPS project investigates the use of networked Autonomous and Remotely Operated Underwater Vehicles (AUVs and ROVs) for the monitoring of chemical warfare dumpsites in the Baltic Sea.

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

BACKGROUND

Chemical warfare material dumped in the Baltic Sea constitutes a hazard to public safety and health. The NATO SPS programme is sponsoring CMRE and others to investigate the use of networked AUVs and ROVs for detection and monitoring. On NRV *Alliance* in 2014, the MODUM team trained for the 2015 Baltic mission preparation, programming and analysis. Specific targets of interest for dumped munitions monitoring (objects similar to dumped munitions and targets) that would allow quality assessment of the MODUM AUV's Klein side-scan images, were deployed; targets with known mass of iron were also laid to get representative conditions for the magnetometer. The results allowed for the calibration of the AUV on-board magnetometer, and tools were provided to estimate the AUV's navigation accuracy. The 2015 Baltic experiment explored real dumped munition sites in the Baltic Sea by employing an ROV and an AUV carrying a towed magnetometer and a side-scan sonar.

OBJECTIVE(S)

The objective was to provide the capability for the MODUM team to characterise the sub-bottom in order to interpret the AUV sensor output properly.

Figure 36: RV *Oceania* performing sub-bottom profiling during the trial in the Gdansk Deep.

S&T ACHIEVEMENTS

CMRE gained knowledge in conducting tests on dumped munition sites with the collection of multi-disciplinary information. Merging information from

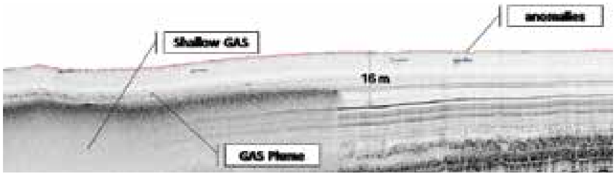

Figure 37: Sub-bottom data of the ammunition dumping area showing the presence of a thick soft mud layer, shallow gas, and possible anomalies (targets).

acoustic imaging devices with chemical analysis is an important capability. Attaching these sensors to autonomous vehicles enabled highly efficient, persistent monitoring of historic munition dumping sites. Sub-bottom profiling and sediment data analysis were crucial for the mission planning and chemical analysis of the seafloor. As the data showed, the seafloor was characterised by a thick soft mud layer which makes burial highly probable.

SYNERGIES AND COMPLEMENTARITIES

The model of multi-national, multi-team, multi-sponsor sea trials can be applied to share experience and cost optimally with NATO S&T programmes. The information obtained from various sensors provides a good baseline for future investigations.

EXPLOITATION AND IMPACT

The MODUM team took the opportunity to train and learn from CMRE's experience, resulting in very high-quality data sets to be used for the removal of UXO in the North and Baltic Seas in the future.

CONCLUSIONS

Having been operating these systems since the last century, CMRE excels at multi-national team training in the emerging area of maritime unmanned systems. Further, the data will be of particular interest for further investigations related to the detection of UXO in the Baltic.

We're not talking about peanuts here, but a cocktail of chemicals in our waters.

RANGE CONTAMINATION (AVT-244)

Military readiness is critical to NATO and its Allies. Combat units require live-fire training with munitions that contain environmentally hazardous constituents. To control risks and sustain training ranges, AVT-244 assembled a platform of experts to present state-of-the-art topics related to range contamination.

Mr. Michael Walsh, USA, US Army Cold Regions Laboratory

BACKGROUND

As stability falters along Eastern European borders and in the Middle East, it is vital that our militaries remain able to operate as a unified force. This is the thrust of NATO's CFI, the implementation of which requires an increased tempo and scale of live-fire training. Training ranges are essential to maintain combat readiness. However, the political reality is that we risk losing these ranges, and combat readiness, if we do not sustain their environmental health.

OBJECTIVE(S)

The objective was to promulgate the results of prior AVT work on range-sustainment through a dialogue between researchers and range operators. The purpose of this dialogue is two-fold: to ensure an exchange of knowledge on issues related to military training range sustainability; and to build capacity in Nations burdened with legacy range contamination.

S&T ACHIEVEMENTS

The dialogue between scientific experts and military users from NATO Member and Partner Nations led to a better understanding of the current problems and a path forward for national action to ensure range sustainability. AVT-244 built upon the range management guidance in the Technical Reference Document developed by AVT-197 and its widely accepted set of baseline issues. AVT-244 established the technical foundation for a CDT on range characterisation, which will demonstrate the state-of-the-art in range contamination prediction and management in NATO and its Partners.

SYNERGIES AND COMPLEMENTARITIES

Contributions by authors from nine Nations and participation by 17 Nations indicated a high degree of synergy. Nations having no previous involvement in STO's munitions arena gained valuable understanding of the problem, and are interested in future collaboration, thus further leveraging technical transfer under the STO umbrella.

EXPLOITATION AND IMPACT

AVT-244 contributes to the CFI through the application of the Technical Reference Document on Range Management. Environmentally compliant range management ensures range availability for military training, thus sustaining the critical infrastructure necessary for combat readiness. Several Nations new to range sustainment and burdened by legacy issues are eager to implement the technology described and improve their national military readiness. The planned CDT will demonstrate the resulting guidance in the field in the United Kingdom in 2016, with follow-on demonstrations occurring in Germany and other NATO Nations.

CONCLUSIONS

The AVT-244 successfully fostered knowledge sharing on critical topics for range sustainability, leading several participating Nations to investigate initiation of range sustainability programmes. Understanding and mitigating the environmental impacts of live-fire training on the range environment is crucial for maintaining availability of critical training range infrastructure and for sustaining combat readiness for NATO forces.

Figure 38: Live fire artillery training is a major source of range contamination.

UNMANNED SEARCH AND RESCUE – ICARUS (STO-CMRE)

ICARUS is an EC project for the development of unmanned technologies for Search And Rescue (SAR). It has particular humanitarian applicability in the context of uncontrolled mass migration. CMRE has developed, realised and tested a set of tools at sea to perform the mission in the maritime environment.

Dr. Stefano Fioravanti, STO-CMRE

BACKGROUND

The experience gained during recent disasters (Haiti, Italy, Japan) confirmed a significant discrepancy between robotic technology developed in laboratory and its use for SAR operations and crisis management. In this framework, the unmanned maritime scenario is complex, involving multiple actors operating simultaneously and interacting with others; the introduction of unmanned devices can offer a valuable lifesaving tool.

OBJECTIVE(S)

The objective is to apply innovations, a toolbox of integrated components for unmanned SAR, for improving the management of a crisis. Accomplishing this is crucial if the robotic assets involved are to achieve higher levels of autonomy and interoperability.

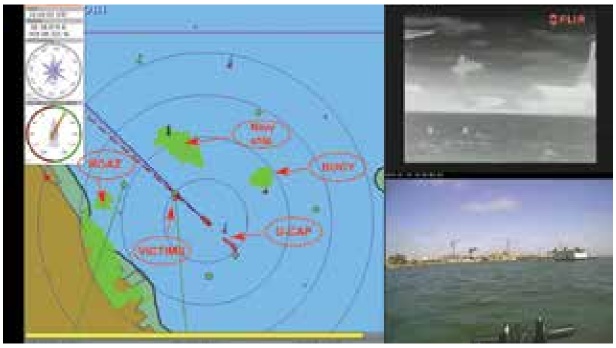

Figure 39: Sensor data fusion allows for the detection of small objects (Clockwise, from the left: obstacle map with radar/lidar data, thermal camera, gyro-stabilised visual camera).

S&T ACHIEVEMENTS

CMRE has designed, realised and tested at sea a generic autonomy toolkit for Unmanned Surface Vehicles (USVs) including a set of behaviours combined with real-time sensor data fusion, able to achieve high performance in terms of speed, safety and reliability, and be interoperable with other robotic assets. This toolkit combines a set of ad-hoc hardware solutions (radar, gyro-stabilised laser scanner, thermal sensors) and behaviours (waypoint navigation, obstacle avoidance) to achieve augmented levels of autonomy. The adoption of the Joint Architecture for Unmanned Systems (JAUS) protocol has granted system interoperability and a common C2 station.

> Rescue Robots are making the transition from being an interesting idea to an integral part of emergency response.

SYNERGIES AND COMPLEMENTARITIES

The ICARUS consortium comprises 24 partners, from academia to private industries, including end-users to validate the requirements and results. There are synergies with the ACT project, PARC, with NIAG, and as an initiative on the MDCS.

EXPLOITATION AND IMPACT

Traditionally a hub for multi-national co-operation, CMRE has many years of experience in the operation of unmanned systems and the sensor capabilities. Tools for improving the effectiveness of SAR/extraction operations, which ultimately save lives and reduce costs, have been developed. Robotic assets in such operations will allow the execution of missions in hazardous areas. The results will provide a test case for other NATO standardisation efforts.

CONCLUSIONS

Behaviours tested in the maritime scenario have proved the robustness of autonomous USVs and the high level of interoperability between them. The choice of the new hardware devices combined with new behaviours proved to be effective for maritime SAR missions.

ADVANCED MATERIALS, SYSTEMS AND EVALUATION METHODS FOR ADAPTIVE CAMOUFLAGE (SCI-230)

SCI-230 combined expertise from several countries and fields to assess the possibility of developing adaptable multi-spectral camouflage. Potential benefits of multi-spectral camouflage include reduced adversary detection ranges leading to improved soldier and vehicle survivability. Ultimately, the Task Group concluded that adaptive camouflage is feasible and militarily relevant; however, some aspects still require research before being fielded.

Dr. Hans Kariis, SWE, Swedish Defence Research Agency

BACKGROUND

Camouflage, Concealment and Deception (CC&D) measures are used to enhance survivability in most NATO operations. Today's equipment uses static materials designed to give an appropriate signature in a predetermined environment. Background, surroundings, weather, objectives and the technical capability of opponents vary, and each of these impacts the effectiveness of static materials.

OBJECTIVE(S)

The objective was to counter the threat imposed by the development and proliferation of new and more effective sensors. The team postulated that adaptive, flexible and multi-spectral CC&D will likely be an effective way to counter advanced sensors. SCI-230 set out to study adaptable camouflage as protection against visible, near-infra-red and thermal infra-red sensors. The main focus of the Group was on land systems, but results are also applicable in both the naval and air domains.

S&T ACHIEVEMENTS

Three different test panels were designed with the ability to change appearance in both the visible and infra-red regimes. Each panel employed a combination of Light-Emitting Diodes (LED) to adapt in the visible spectrum and a flow of air or water to adapt in the thermal infra-red spectrum. Human observers were used in a field trial to evaluate the effectiveness of each design. Because quantitative analysis had never been applied to adaptive camouflage in a military setting, the team also developed new scientific measurement techniques for adaptive materials.

SYNERGIES AND COMPLEMENTARITIES

By sharing scientific competence and experience from Estonia, Germany, Netherlands, Romania, Sweden and Switzerland, a broader investigation of different adaptation technologies was possible. The team shared access to facilities, equipment and data that were otherwise not available to all Nations. This enabled them to effect more S&T discovery with the same financial budget, which ultimately led to a new STO research activity that will study the impact of camouflage on survivability in tactical scenarios.

EXPLOITATION AND IMPACT

Current camouflage techniques are static and must be removed or replaced depending on the environment of the deployed asset. Adaptive camouflage is a promising technology that may be used in the future to enable assets to actively blend with their surroundings, thus increasing survivability, flexibility and mission effectiveness.

CONCLUSIONS

SCI-230 revealed that adaptive camouflage is a feasible technology that should be further developed in an effort to increase the survivability and flexibility of land forces, reduce their logistics costs and reduce deployment time.

> Adaptive camouflage has the potential to provide protection against a broad spectrum of adversary sensor systems.

Figure 40: Adaptive camouflage panels in field-trial conditions.

MILITARY SUICIDE PREVENTION (HFM-218)

This is the first international Working Group striving to understand, scope and address the problem of military suicide across all NATO Member and Partner Nations.

Dr. Marjan Ghahramanlou-Holloway, USA, Uniformed Services University of the Health Sciences

BACKGROUND

Globally, suicide is the second leading cause of death among individuals between the ages of 15 – 29 years (World Health Organisation (WHO), 2014). Suicide remains a significant public health problem for the armed forces. NATO's evolving crisis management operations across various regions of the world require that increasing attention be paid to psychological fitness and effective strategies that provide timely and evidence-based practices to service members with suicidal intentions.

OBJECTIVE(S)

The objective was to foster international collaboration across NATO Member and Partner Nations for the exchange of ideas and strategies for the prevention of military suicide.

Figure 41: Military suicides are preventable.

S&T ACHIEVEMENTS

RTG/HFM-218 designed a survey to collect epidemiological data on military suicides, as well as information on suicide prevention, intervention practices, and potential gaps. This systemic data collection, along with literature reviews, and consensus-building meetings among experts, led to recommendations for the development of standardised procedures, definitions, and systematic surveillance for documenting military suicides internationally. Moreover, a series of nine white papers on the following topics have been prepared for NATO leadership: Military Suicide Prevention; Role of Leadership in Suicide Prevention; Myths and Facts on Military Suicide; Technology Based Suicide Prevention; Stigma and Barriers to Care; Tactical Level Leadership; Risk-Taking Behaviours and Suicide; Military Life Stages; and Policy Recommendations on Military Suicide.

> NATO, NATO Member and Partner Nations must take the next step in addressing military suicide.

SYNERGIES AND COMPLEMENTARITIES

Overall, a total of 14 NATO Nations and three Partner Nations participated in this international effort to systematically collect information on military suicide.

EXPLOITATION AND IMPACT

Military suicide prevention strategies such as minimising stigma and barriers to care, and maximising leadership involvement in promoting timely help-seeking behaviours, will enhance mission readiness, unit morale/cohesion, psychological fitness, hopefulness, and personnel performance.

CONCLUSIONS

According to the WHO, "suicides are preventable". RTG/HFM-218 acknowledges the significant contributions of NATO leadership, service members themselves, and the military community in preventing suicides. The sharing of knowledge, best practices, and lessons learned across NATO Member, Partner, and contributing Nations is essential in taking the important next step in addressing the public health problem of military suicide.

MENTAL HEALTH TRAINING (HFM-203)

Mental health training has the potential to strengthen the ability of service members to respond to the psychological demands of military life. Ideally, this kind of mental health and resilience training should begin during basic training and be continued throughout the individual's military career. RTG/HFM-203 has compiled a database of standardised mental health and resilience training programmes in an effort to begin developing a training module template for mental health training during basic or recruit training.

Dr. (COL ret.) Carl Castro, USA, Centre for Innovation and Research on Veterans and Military Families

BACKGROUND

Military service and combat place a tremendous burden on service members – yet there is much that national militaries can do to prepare their service members for the military tasks they are asked to perform, and building mental health resilience through training is one. By building resilience, service members will be able to self-monitor more effectively when they are under high performance demands, and be able to more effectively observe and help mitigate the stress demands of their "buddies".

OBJECTIVE(S)

The objective was to develop a resilience-building training module suitable for delivery during the basic military training of all NATO Nations.

S&T ACHIEVEMENTS

HFM-203 conducted a survey of recent basic training graduates who were representative of the Group membership. The survey and resulting analysis identified the aspects of basic training that were the most stressful or demanding, and how basic trainees coped with these stressors. In all, four key resilience skills emerged: acceptance and control; goal setting; self-talk; and tactical breathing. These skills were presented within a mental health continuum framework; a framework that focussed on service members' self-evaluation to enable them to maintain healthy thoughts, emotions and physical reactions/behaviours. Practical exercises to reinforce these skills were provided. A trainer's guide and an implementation guide were also provided for implementation.

Figure 42: Military service and combat place a tremendous burden on service members.

Resilience training should begin as soon as possible during military service.

SYNERGIES AND COMPLEMENTARITIES

Eleven Nations provided data. In Belgium, the standardised mental health training was designed for student pilots and air traffic controllers. The British mental health training for recruits has consistent objectives across Services. Other programmes reviewed were the Canadian Road to Mental Readiness programme, US BATTLEMIND training system and Australia's BattleSMART model.

EXPLOITATION AND IMPACT

The findings of this review of mental health training delivered during basic training in several NATO Nations provided a starting point for the development of a NATO mental health resilience training module for initial basic training. It provided valuable information for the development of Resilience Training Guidelines, Implementation Principles, and a standardised "Train the Trainer" programme for mental health training.

CONCLUSIONS

Resilience training should begin as soon as possible during military service. Resilient service members will be better able to self-monitor and better able to observe and help mitigate the stress demands of their "buddies", leading to a more resilient force.

OPTIMIZING HEARING LOSS PREVENTION AND TREATMENT, REHABILITATION AND REINTEGRATION OF SOLDIERS WITH HEARING IMPAIRMENT (HFM-229)

A product of scientific collaboration focussed on data standardisation, auditory fitness for duty criteria, and methods for programme comparison to identify best practices and improve outcomes.

COL Dr. Roland Jacob, DEU, Central Military Hospital and COL Mark Packer, USA, Defense Hearing Center of Excellence

BACKGROUND

Hearing loss and tinnitus are the most prevalent disabilities in veterans. The implication is that a hearing health surveillance system is necessary; it should have hearing readiness criteria, ensure criteria are met, identify soldiers at risk, and provide a means to evaluate the quality and timeliness of hearing rehabilitation and prevention programmes.

OBJECTIVE(S)

The objectives were to: review the current state of hearing health in NATO Nation militaries; review best practices for hearing screening, surveillance, and diagnostics; recommend a comprehensive international hearing database; and review areas for future collaborative research.

S&T ACHIEVEMENTS

A thorough review of current hearing health programmes was undertaken, and the concept for the development of a comprehensive international hearing database was developed to expand the common knowledge base, improve prevention and rehabilitative efforts, and help define hearing readiness criteria. The architecture is military relevant and internationally comparable. The database concept is modular for integration with existing databases, or implementation with other health care systems.

SYNERGIES AND COMPLEMENTARITIES

A review of NATO Nations' monitoring practices revealed substantial differences in data collection. HFM-229 recommends normalising military hearing assessment and tracking across the Alliance. Having common data elements and methods allows international comparison and facilitates collaborative research and best practice identification; the resulting knowledge-sharing speeds solutions and avoids duplication.

EXPLOITATION AND IMPACT

HFM-229 optimised limited resources by exploiting currently available automatic screening systems to facilitate workload management, and reduce cost and time.

Tests support NATO languages to facilitate comparisons, allowing efforts to improve auditory fitness and reduce loss, all of which can be shared throughout NATO.

Figure 43: People with damaged hearing can be rehabilitated and reintegrated in many cases.

Monitoring hearing identifies exposure, provides early identification and intervention, and helps establish readiness criteria. Ensuring hearing capability by monitoring audibility exploits a natural human capability which impacts communication, unity of effort, performance, and survivability and quantifies this aspect of a soldier's effectiveness.

> Hearing loss and tinnitus are the most prevalent disabilities in veterans of conflict and peace-time military service.

The modularity of the resulting architecture exploits integration capability and is scalable to expand screening innovations, while international comparability enables ongoing communication risk analysis in multi-national operations.

CONCLUSIONS

Accurate information exchange requires hearing acuity. Hearing impacts soldier performance, communication, and safety. Military organisations should minimise risk and maximise hearing readiness through prevention and programme monitoring to preserve hearing capabilities. To this end, HFM-229 improved epidemiological understanding, evaluated hearing readiness, prevention and rehabilitation programmes, built foundational outcomes knowledge and promoted a database concept for further research, especially for the special challenges faced by multilingual organisations.

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 autumn, the STB grants NATO S&T awards – the von Kármán Medal and the Scientific Achievement Award (SAA). These landmarks of excellence will be granted when the STB considers that appropriate candidates were nominated. The NATO CS, in their capacity as Chair of the STB, ceremonially presents the achievements to the successful candidates during the STB meeting in the autumn.

Figure 44: Mr. James MacLeod receives the 2015 von Kármán medal from the NATO Chief Scientist, MGen Albert Husniaux (BEL AF).

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, NATO's 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 scientific and technological activities. The emphasis is on recently completed work that has significant impact for NATO, the Nations and the technical community. An SAA can be granted to individuals or to teams. The SAA consists of a certificate and an accompanying citation, signed by the STB Chair.

In 2015, during the autumn meeting in Tirana, Albania, the STB awarded one von Kármán Medal and five SAAs.

THE 2015 VON KÁRMÁN MEDAL

Mr. James MacLeod is an internationally recognised authority on advanced technologies in the areas of innovative sensor systems for gas turbine engine performance, engine test facilities, and icing for both commercial and military aircraft engines. He has been a major contributor for over 30 years to NATO activities within the Advisory Group for Aerospace Research and Development (AGARD), the RTO and several STO Committees, Task Groups, and Technical Teams. In particular, he played key roles in the NATO's AVT Panel, as Chair and Vice-Chair of Technical Committee for Propulsion and Power Systems, as well as the Chair of the Awards Committee, and a member of the AVT Strategic Committee.

Throughout his career, Mr. MacLeod has shown outstanding dedication to gas turbine performance research and technology development in both the NATO community, and industry and military circles. He has had a direct impact on establishing improved engine test facility operational procedures and practices for NATO Nations that have resulted in significant cost reductions and quality improvements. He has also had a direct and long-lasting impact on the flight safety and airworthiness of commercial and military aircraft operating in hazardous environmental conditions, particularly icing. Mr. MacLeod's achievements include several AGARD Support Projects for both the Hellenic and Turkish Air Forces to transfer knowledge and improve their engine testing capabilities, the development of innovative sensor systems for gas turbine engine performance measurements related to aviation safety in adverse environmental conditions such as volcanic ash or severe icing, and the establishment of world-leading engine test facilities.

During his long service to NATO, Mr. MacLeod has demonstrated an outstanding commitment to partnership and team work across the NATO community. In the true spirit of the vision of Dr. Theodore von Kármán, he has made outstanding and enduring contributions promoting international scientific collaboration.

For his steadfast dedication and leadership within NATO S&T and his remarkable contributions to research in the field of gas turbine testing and aviation safety, we hereby recognise Mr. MacLeod for his exemplary work by presenting him with the 2015 S&T von Kármán Medal.

DESIGN FOR DISPOSAL OF PRESENT AND FUTURE MUNITIONS AND APPLICATION OF GREENER MUNITION TECHNOLOGY (AVT-179)

Managing the impact of the military on the environment is increasing in importance, both to safeguard NATO troops and minimise the damage done by operations and training, which requires understanding and tools – AVT-179 addressed both.

Prof. Adam Stewart Cumming (Task Group Chair – on behalf of the RTG), GBR, University of Edinburgh

BACKGROUND

All military activities affect the environment in some way; the manufacture, use and disposal of munitions is no exception. Additionally, risks cannot be managed without understanding the critical issues and assessing the available analytic tools.

OBJECTIVE(S)

The objective was to identify critical issues for the effective design of munition disposal, including explosives, pyrotechnics, initiators, missile, gun propellants and non-energetic components. In addition, the Task Group was to examine ways of producing and employing greener munitions, and finally to make recommendations on future policy, including the assessment of developing technology for applicability.

Figure 45: Munitions contamination on a training range.

S&T ACHIEVEMENTS

AVT-179 examined requirements and existing legislation and matched them to available technologies. The in-depth examination used eco-toxicology and hydrogeology techniques to understand the fate and behaviour of expended explosives. Sample treatment and analytical chemistry methods were developed to better understand dispersion and biotechnology, and bioremediation methods were designed to deal with contamination once it occurs.

SYNERGIES AND COMPLEMENTARITIES

AVT-179 worked with NATO's Support and Procurement Agency (NSPA) and Munitions Safety Information Analysis Center, The Technical Cooperation Program (TTCP) Weapons Group and the EDA, as well as the USA's Strategic Environmental Research and Development Program in approaching the problem, and all participants contributed their national programmes.

EXPLOITATION AND IMPACT

All reports and information were provided to the CASG, as well as the NSPA and national bodies, to help validate and support policy decisions. The work will support revision of NATO's Design for Disposal STANAG and has already been used to support work in Bulgaria and Romania to develop national policies, studies and training courses. New AVT activities covering toxicology and managing the impact of legislation through focussed research have been proposed and a NATO Lecture Series is being developed to accelerate the education process. The end result is the creation of a database and methodologies that will lead to significant reductions of dangerous and aging munitions and dramatic annual cost savings for the monitoring and maintenance of these munitions systems.

CONCLUSIONS

Military training ranges are critical to maintaining combat readiness, but the environmental issues associated with managing munitions are real and they must be considered as part of the training range life-cycle. To this end, AVT-179 undertook R&D projects to: understand explosive material contamination of soils; develop the sampling techniques needed to obtain representative samples for characterisation studies; and develop the required analysis tools for those studies. The results are annual cost savings with no loss of range capabilities.

RADAR AUTOMATIC TARGET RECOGNITION (ATR) AND NON-CO-OPERATIVE TARGET RECOGNITION (NCTR) (SET-172)

Radar offers day/night, all-weather, and beyond-visual-range sensing capability which maximises target detection range. The addition of an ATR or NCTR capability means that potential targets are presented to the operator with identity, allowing timely decisions and maximising self-protection.

Prof. David Blacknell (Lecture Series Director – on behalf of the RTG), GBR, Defence Science and Technology Laboratory

BACKGROUND

With the rapidly increasing availability of radar sensors to support NATO military and peace-keeping activities, there is a crucial requirement for automated systems to facilitate time-critical targeting in tactical applications. This requirement has led to the development of automated techniques for use against ground targets, typically referred to as ATR systems, and against air targets, typically referred to as NCTR systems.

OBJECTIVE(S)

The objective was to provide an overview of the state-of-the-art and continuing challenges of radar ATR and NCTR, covering both the fundamentals of classification techniques applied to data and selected advanced techniques that capture themes currently at the forefront of active research.

S&T ACHIEVEMENTS

The most relevant S&T results were achieved in aggregating and presenting the advanced topics which provided insight into the current state-of-the-art and challenges that remain for the various techniques used in target recognition. The use of change detection techniques and multiple aspect angles has improved performance, while the use of compressive sensing demonstrated robustness in challenging Radio Frequency (RF) environments. Methods for achieving high-quality imagery, including autofocus techniques (Fig. 46), were described and shown to result in high probabilities of correct classification.

SYNERGIES AND COMPLEMENTARITIES

The Lecturers were drawn from five NATO Nations, which brought together a number of different but complementary perspectives and expertise in the topic area. The team displayed enormous commitment to NATO by delivering a total of three iterations of the Lecture Series, giving the two-day-long set of lectures in a total of 11 NATO Nations in both Europe and North America.

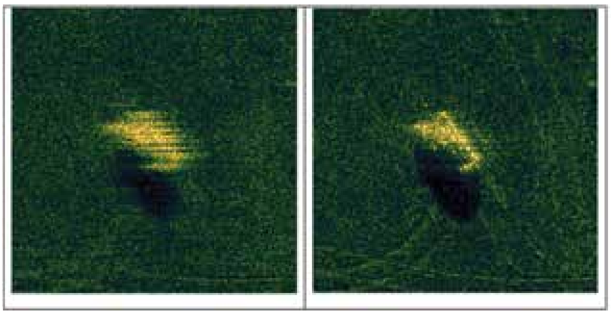

Figure 46: Synthetic Aperture Radar (SAR) image of a tank: Raw (Left) and after implementing autofocus algorithms (Right).

EXPLOITATION AND IMPACT

Radar ATR and NCTR contribute to the identification of otherwise unidentified objects, making a significant contribution to the understanding of the air, or surface picture, and enabling operators to readily identify the targets of greatest interest and, hence, prioritise further action. The other clear benefit for NATO is from the education achieved by attendees who gained an appreciation of the issues which need to be addressed for successful operational radar target recognition, providing them with a suitable knowledge base from which to plan for the future weapon system procurement and field within their Nations.

CONCLUSIONS

SET-172 successfully provided a solid common background on the state-of-the-art and continuing challenges of radar ATR and NCTR, with particular reference to those advanced topics which will have to be further investigated in the near future to support NATO military decision-makers.

SHARING THE BURDEN OF COMMUNICATION INFRASTRUCTURE THROUGH PCN (IST-103)

Protected Core Networking (PCN) provides the ability to deliver on the CFIs, and IST-103 helped bring PCN closer to reality by resolving some outstanding technical issues surrounding Quality of Service (QoS), scalability, federated management and risk assessment, as well as providing guidance on the transition to PCN.

Mr. Roland Schutz (Task Group Chair – on behalf of the RTG), FRA, Thales Communication and Security

BACKGROUND

Diminishing defence budgets are driving the Alliance to share the load in terms of "boots on the ground" and also in communication and information services. PCN is a federated approach to enable interoperable communications transport services.

OBJECTIVE(S)

The objective was to study the following in the context of PCN: QoS, scalability, federated management, and Real-Time Automated Risk Assessment (RTARA); and to provide guidance for the application of PCN, and illustrate operational benefits.

S&T ACHIEVEMENTS

IST-103 made significant advances in addressing issues with the federation of autonomous network segments. The concept of Protected Core (PCore) Communities (PCCs) was further developed, which allowed differentiated information exchange models, for federated management purposes, between members of PCCs and PCores. This helped to address scalability issues related to the PCN concept. Particular focus was placed on the exchanges relating to QoS and RTARA to support the federated capability provided by these fuctions.

SYNERGIES AND COMPLEMENTARITIES

Close collaboration was enjoyed with the TACOMS+ consortium (Tactical Interoperable Communications Standards+ consortium is a MoU-based project among 13 NATO Nations), which led to strong convergence between the works of the two groups. Based on PCN principles, TACOMS+ is addressing the networking and service layer required for NATO's FMN – Spiral-2. Furthermore, IST-103 synchronised with the draft PCN Interoperability Specification (ISpec) through collaboration with NCIA. Finally, IST-103 complements STANAG 4711 on Internet Protocol QoS, which is currently undergoing ratification.

EXPLOITATION AND IMPACT

The PCN approach is targeted at communication transport interoperability among NATO and its Partners at both fixed and higher echelons of deployed networks through the provision of a PCore. The NATO Communications Infrastructure (NCI) upgrade and FMN Spiral-2 will be based on PCN principles. As a result, future evolutions of NCI and FMN, along with national fixed and deployed projects, will be able to realise the full capability offered by PCN.

CONCLUSIONS

IST-103 completed the technical analysis of the PCN concept, which means it is now time to evolve the specification and to put the concept into practice. Ultimately, users from any Alliance Nation will be able to seamlessly connect to the PCore with confidence in the continued provision of transport services according to agreed service-level agreements. With PCN equally applicable to fixed and deployed networks, the PCore supports protected interoperable networking worldwide.

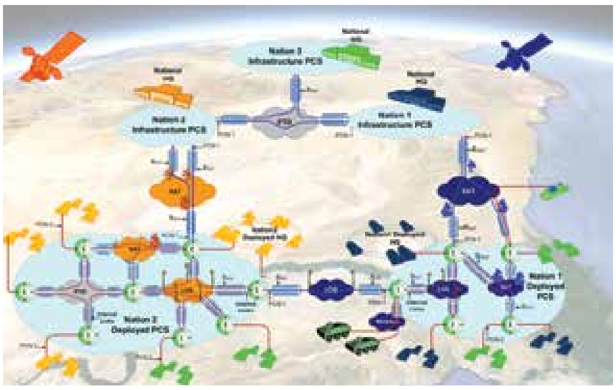

Figure 47: Sharing the burden of a flexible and secure networked battlefield.

SWITCHING TO A NEW PARADIGM: MODELLING AND SIMULATION AS A SERVICE (MSG-131)

The combination of service-based approaches with ideas taken from cloud computing – known as Modelling and Simulation as a Service or MSaaS – is a very promising approach for realising next-generation simulation environments.

Dr. Robert Siegfried (Task Group Co-Chair – on behalf of the RTG), DEU, Aditerna GmbH and Mr. Brian Miller (Task Group Co-Chair – on behalf of the RTG), USA, CERDEC Night Vision and Electronic Sensors Directorate

BACKGROUND

To a great extent, future military training, analysis, and decision-making will be provided by M&S. Two main barriers are cost and accessibility; hardware, software, and personnel necessary to implement and utilise models and simulations can be both time and cost intensive. Furthermore, limited credibility resulting from unknown validity and ad-hoc processes is still a serious problem.

OBJECTIVE(S)

The objective was to develop an M&S "ecosystem" where M&S products can be accessed simultaneously and spontaneously by a large number of users. An additional goal was to establish MSaaS to support stand-alone use as well as integration of simulated and real systems into a unified simulation environment whenever needed.

S&T ACHIEVEMENTS

ACT invited the MSG-131 participating Nations to conduct a survey on the topic of MSaaS which resulted in the identification of existing applications as well as simulation architectures and recommendations on the way ahead for an MSaaS Reference Architecture. In all, 16 MSaaS applications and case studies from 12 Nations and two NATO bodies were identified and evaluated, resulting in the first-ever exhaustive overview of service-based approaches used in the M&S domain.

SYNERGIES AND COMPLEMENTARITIES

The S&T work relied heavily on web conferences to meet cost and time requirements. Within one year, 45 members held 23 meetings and produced more than 19 versions of the final deliverable. This rapid development cycle enabled qualified stakeholder feedback at any opportunity and ensured that the S&T work finished on time.

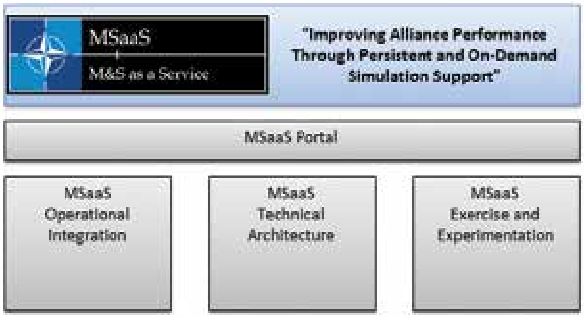

Figure 48: The vision: "To ensure M&S products, data and processes are accessible to a large number of users for their individual purposes."

EXPLOITATION AND IMPACT

ACT forwarded the results to the NC3B for consideration in future development. Key findings were presented at the NATO CAX Forum, SISO events, and at national conferences. MSG-131 successfully prepared a follow-on activity (MSG-136) to focus all MSaaS activities within NATO. This activity has attracted more than 70 members from 16 Nations and six NATO bodies, and builds on MSG-131 to define the technical and organisational cornerstones for implementing an Allied MSaaS Ecosystem.

CONCLUSIONS

MSG-131 successfully defined MSaaS in the NATO context, and provided the foundation for a follow-on activity that will define the technical and organisational cornerstones for an Allied MSaaS Ecosystem that benefits operational readiness through enhanced military training, analysis, and decision-making.

MISSION EFFECTIVENESS OF DENIAL AND DECEPTION (SCI-200)

SCI-200 explored how to evaluate the effectiveness of adversarial Denial and Deception (D&D) against NATO and develop a process where D&D operations can be predicted and countered. Historically, D&D has played a key role in all levels of warfare and NATO has witnessed its resurgence as a force multiplier over the past decade. D&D will continue to be employed and its importance will not diminish; to the contrary, it will continue to transform with and against NATO technology, doctrine and practices.

Ms. Rosemary Pearce (Task Group Chair – on behalf of the RTG), USA, National Air and Space Intelligence Center

BACKGROUND

NATO-led air campaigns in Libya and the former Yugoslavia required the Alliance to confront and counter D&D techniques used by our adversaries. While NATO maintains strong technological advantages, D&D TTPs can be effective in limiting adversary operational success and misallocating operational resources. SCI-200 sought to evaluate the effectiveness of adversarial D&D tactics against the Alliance and develop a process where D&D operations can be effectively predicted and countered.

Figure 49: Representative deception technique using inflatable systems.

OBJECTIVE(S)

The objective was to assess the effectiveness of D&D within military operations and expand NATO's view of D&D, thus improving operational doctrine.

S&T ACHIEVEMENTS

SCI-200 researched, studied and evaluated military operations where D&D TTPs were employed, determined how to evaluate their effectiveness, and recommended updated TTPs in order to improve operational survival. The results and conclusions made significant contributions to NATO and national defence capabilities by generating relevant and beneficial TTPs to improve D&D operations. The study provided a breakthrough analytical methodology that can be used by operational planners, intelligence analysts, and targeteers to increase the survivability of NATO assets and personnel during future conflicts.

SYNERGIES AND COMPLEMENTARITIES

SCI-200 was comprised of eight NATO Nations (CAN, CZE, DEU, GBR, NLD, NOR, ROU, USA) and four NATO organisations (ACT, Camouflage, Concealment, Deception and Obscurants – Working Group or CCDO-WG, Joint Capability Group Intelligence, Surveillance and Reconnaissance or JCGISR, NATO Air Force Armaments Group or NAFAG). SCI-200 gained access to previous lessons learned studies, NATO documentation, Nation-specific information, and varied military operators, all of which were critical to producing the results.

EXPLOITATION AND IMPACT

The results generated by SCI-200 were directly exploited within NATO and the Nations as they were specifically requested by NATO agencies and organisations to enhance existing doctrine. In addition, SCI-200 participated in Unified Vision 2012 and provided D&D material as well as technical personnel to support the trial to ensure the scientific community was meeting the needs of the Alliance's military leadership. This is a core premise of the STO model.

CONCLUSIONS

The analysis techniques developed and demonstrated during this effort directly influenced existing doctrine within NATO and the NATO Nations, and the exceptional findings of SCI-200 will enable further doctrine development and implementation of TTPs that will save lives and equipment.

Annexes

ANNEX A – NATO SCIENCE AND TECHNOLOGY ORGANIZATION

The NATO STO is a NATO subsidiary body to the NAC, to which the NAC granted a clearly defined organisational, administrative and financial independence by approval of the Charter of the STO on 1 July 2012. It was established with a view to meeting, to the best advantage, the collective needs of NATO, NATO Member and Partner Nations in the fields of S&T.

The STO conducts and promotes S&T activities that enable the Nations and NATO to cost-effectively augment and leverage their S&T investments in support of the core tasks of the Alliance.

The STO comprises organisational bodies and committees on three levels – governance, programmes and activities. The governance level is represented by the STB. The programmes level reports to the STB; it is composed of the STCs and the CMRE. Last, the activities level, on which experts do the actual S&T work, reports to the programmes level. In addition, there are several supporting and co-ordinating committees, and executive bodies within the STO, to ensure smooth and transparent operation.

THE SCIENCE AND TECHNOLOGY BOARD

The STB, in which all NATO S&T stakeholders are represented, is the highest authority in the STO. It exercises governance on behalf of the NAC and reports to the NAC through the MC and the CNAD. The STB's main responsibilities are governing the STO and implementing NATO S&T unified governance.

The membership of the STB is comprised of up to three leading senior defence S&T representatives from each NATO Nation, one of those being the principal board or voting member. Decisions of the STB are taken by unanimous consent. STB members are appointed by the Nations and may come from government, academia, institutes or industry. In addition, the STB has also ex-officio members representing the other stakeholders including the NATO structures and industry. The STB is chaired by the NATO CS.

The inter-related nature of the main responsibilities of the STB introduces the necessity for the STB to meet in different formats. To that end, the STB meets twice a year, in spring and autumn. In the spring session the STB has two different formats – Strategy and Policy, and Executive. In the autumn the STB meets in Executive format only, partly together with Partners.

The STB is supported by several sub-groups, all consisting of STB members.

CHAIRMAN'S ADVISORY SUB-GROUP (CASG)

The CASG is the think-tank and soundboard to the STB Chair; it provides recommendations pertaining to all issues requiring formal executive action by the STB.

FINANCE AND AUDIT SUB-GROUP (FASG)

The FASG provides recommendations to the STB pertaining to the financial governance of the STO and STO's executive bodies, including audits and risk aspects.

MARITIME S&T SUB-GROUP (MASG)

The MASG provides recommendations to the STB pertaining to NATO maritime S&T and the CMRE.

SCIENTIFIC AWARDS SUB-GROUP (SASG)

The SASG provides recommendations to the STB pertaining to the yearly selection of those to receive the von Kármán Medal and the SAAs.

SCIENTIFIC AND TECHNICAL COMMITTEES

The STCs are responsible for the planning and execution of STO's CPoW, which is mainly funded by the Nations. They are composed of national defence S&T managers and SMEs from all stakeholders, i.e., government, academia, institutes and industry. The STO provides the framework and delivers executive support through the CSO, which is an executive body of the STO and is located in Neuilly-sur-Seine, France.

There are seven STCs in the STO. They encompass a broad spectrum of scientific fields and are designed to be able to address almost every relevant military scientific and technological topic. Every committee is chaired, on a rotational basis, by a senior scientist or engineer from one of the participating NATO Nations.

APPLIED VEHICLE TECHNOLOGY (AVT) PANEL

The mission of the AVT Panel is to improve the performance, affordability and safety of vehicle, platform, propulsion and power systems operating in all environments for new and aging systems through advancement of appropriate technologies. The three main technology areas of AVT are: mechanical systems, structures and materials; performance, stability and control, fluid physics; and propulsion and power systems.

HUMAN FACTORS AND MEDICINE (HFM) PANEL

The mission of the HFM Panel is to provide the S&T base for cost-effective optimisation of health, protection, well-being and performance of the human in operational environments, with consideration of mission effectiveness and affordability.

This involves understanding and ensuring the physical, physiological, psychological and cognitive compatibility among military personnel, technological systems, missions and environments. The goal is accomplished by exchange of information, collaborative experiments and shared field trials. The scope of the Panel is multi-disciplinary and encompasses a wide range of theory, data, models, knowledge and practice pertaining to Health, Medicine and Protection (HMP), and Human Systems and Behaviour (HSB). These two domains are complementary and represent the two "Area" Committees of the HFM Panel.

INFORMATION SYSTEMS AND TECHNOLOGY (IST) PANEL

The mission of the IST Panel is to advance and exchange techniques and technologies in order to improve Command, Control, Communications and Intelligence (C3I) systems – with a special focus on interoperability and cyber security – and to provide timely, affordable, dependable, secure and relevant information to warfighters, planners and strategists. The scope of this Panel includes: information warfare and assurance; information and knowledge management; communications and networks and architectures; and enabling technologies.

NATO MODELLING AND SIMULATION GROUP (NMSG)

The mission of the NMSG is to promote co-operation within the Alliance, together with Partner Nations, to maximise the effective utilisation of M&S. The NMSG has been designated by the NAC to supervise the implementation of the NATO M&S Master Plan (NMSMP) and to propose updates. The scope of this Group includes M&S standardisation and associated S&T, including support to customers, users and suppliers in the five areas of simulation: support to operations; capability development; mission rehearsal; training and education; and procurement.

SYSTEM ANALYSIS AND STUDIES (SAS) PANEL

The mission of the SAS Panel is to conduct studies and analyses of an operational and technological nature, and to promote the exchange and development of methods and tools for Operational Analysis (OA) as applied to defence problems. The scope of this Panel includes studies, analysis and information exchange activities that explore how operational capability can be provided and enhanced through the exploitation of new technologies, new forms of organisation, or new concepts of operation, as well as activities to develop and promote improved analysis methods and techniques to support defence decision-making.

SYSTEMS CONCEPTS AND INTEGRATION (SCI) PANEL

The mission of the SCI Panel is to advance knowledge concerning advanced system concepts, integration, engineering techniques and technologies across a spectrum of platforms and operating environments to assure cost-effective mission area capabilities. Integrated defence systems, including air, land, sea and space systems (manned and unmanned), and associated weapon and counter-measure integration, are covered. Panel activities focus on NATO and national mid-to-long-term, system-level operational needs. The scope of this Panel includes a multi-disciplinary range of theoretical concepts, design, development and evaluation methods applied to integrated defence systems. Areas of interest are: integrated mission systems including weapons and counter-measures; system architecture/mechanisation; vehicle integration; mission management; and system engineering technologies and testing.

SENSORS AND ELECTRONICS TECHNOLOGY (SET) PANEL

The mission of the SET Panel is to foster co-operative research, the exchange of information, and the advancement of S&T in the field of sensors and electronics for Defence and Security. To fulfil this mission, the Panel has three focus groups: Radio-Frequency Technology (RFT); Optical Technology (OT); and Multi-Sensors and Electronics (MSE). The scope of this Panel includes topics pertaining to Reconnaissance, Surveillance and Target Acquisition (RSTA), EW, communications and navigation, and the enhancement of sensor capabilities through multi-sensor integration and fusion.

CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION

The Centre's portfolio includes ASW systems concepts and decision support, communications and networking, autonomy for mine search, advanced sensors, characterisation and understanding the underwater battlespace, decisions in uncertain environments, ocean science, M&S, acoustics, communication, and signal analysis. It also contributes new technologies for enabling access to unmanned systems that have the ability to sense, comprehend, predict, communicate, plan, make decisions and take appropriate actions to achieve mission goals.

The CMRE has an engineering department than can design, build and modify maritime advanced platforms and (underwater) sensors, including the required signal processing and communication. This important department of the Centre is also capable of providing S&T-based enhancements to unmanned (autonomous intelligent) systems and integrated defence systems.

NATO owns two research vessels, the NRV *Alliance* and the CRV *Leonardo*, flagged and crewed by Italy.

The NRV *Alliance*, designed especially for underwater acoustic research, is capable of operating in all the oceans of strategic importance to NATO and the NATO Nations. It is equipped with extensive and sophisticated navigation, communications and computer equipment, winches, cranes, loading frames, and other deck machinery for the deployment, towing and recovery of a variety of sensor arrays and oceanographic instrumentation in all sea conditions. A sophisticated Windows-based integrated navigation system, which uses Differential Global Position Systems (DGPS), includes the ARCS (Admiralty Raster Chart Service, an electronic chart system), and ensures that the ship's position is logged with great precision to provide precise time-tagged navigation strings to other fixed vessel sensors such as the Swathe Mapping System and the Acoustic Doppler Current Profiler.

NRV *Alliance* enables scientists from the Centre to conduct a wide range of experiments. The vessel has been designed for eight different noise states; the quietest one operates on batteries to minimise the noise generated by the ship in order to reduce interference with the environmental measurements and acoustic experiments.

The CRV *Leonardo* has been designed to provide a stable yet flexible sea-going scientific platform suitable for operations in shallow waters. Like NRV *Alliance*, CRV *Leonardo* has a state-of-the-art communication and navigation system as well as substantial deck-handling equipment. The vessel has significantly enhanced NATO's capabilities, especially in shallow seas. It has one very silent low-speed condition and enjoys the benefits of diesel electric propulsion driving twin azimuth thrusters and one azimuth pump jet bow thruster controlled by fully automated Dynamic Positioning (DP) and a power management system.

STO SUPPORTING AND CO-ORDINATING COMMITTEES

The smooth and transparent operation of the STO is supported by the following bodies and committees.

LEVEL TWO CO-ORDINATION COMMITTEE (L2CC)

The L2CC supports the STB and its Chair in co-ordinating the optimisation of the NATO STO CPoW by seeking synergies and complementarities while avoiding unnecessary duplication. The L2CC meeting is composed of the STC Chairs and STO staff and is chaired by the Director of the CSO.

NATIONAL CO-ORDINATORS COMMITTEE (NCC)

The NCC consists of government representatives who support their STB members and facilitate the participation and smooth running of the STCs by effective planning, co-ordination, administration and publication, as well as addressing public relations matters as they may arise. The NCC is chaired by the Deputy Director of the CSO.

MARITIME S&T COMMITTEE (MSTC)

The mission of the MSTC is to provide solicited and unsolicited scientific advice in the maritime domain, including seeking leverage between CMRE's and Nations' maritime S&T activities.

The scope of this Committee includes NATO and its Nations' maritime S&T, with a particular focus on the activities of the CMRE. The MSTC is composed of S&T experts and customers from the Centre and the Nations, and is chaired by a senior scientist from one of the NATO Nations on a rotational basis. The MSTC reports to the STB through MASG.

KNOWLEDGE/INFORMATION MANAGEMENT COMMITTEE (KIMC)

The mission of the KIMC is to provide expert advice to the STB, its Chair and the STO on knowledge, information management, technology and policy matters for supporting effective and secure exchange of knowledge and information within the STO. The KIMC also supports the development of mechanisms to facilitate the discovery and secure exchange of NATO and shared national information.

The scope of this Committee includes processes and mechanisms that touch the entire life-cycle of information and knowledge, including its creation and acquisition, security, processing, retrieval, storage, exchange, distribution and disposition. This includes facilitating information and knowledge exploitation and sharing between the Nations, regardless of the form of exchange.

NATO STO EXECUTIVE BODIES

NATO STO is composed of three executive bodies: the CMRE; the CSO; and the OCS.

CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION (CMRE)

The CMRE is located in La Spezia, Italy, and is an executive body of the STO. The Centre is STO's customer-funded S&T facility. It carries out projects and experiments to deliver military relevant state-of-the-art scientific S&T. For that purpose it has its own capabilities, infrastructure and personnel. The main customer is NATO, through the ACT.

COLLABORATION SUPPORT OFFICE (CSO)

The CSO is located in Neuilly-sur-Seine, France, and is an executive body of the STO. The CSO provides executive and administrative support to the formation, execution, and delivery of STO S&T activities conducted through the STO STCs, which comprise the CPoW. The CPoW is funded mainly by the Nations. The Office is comprised of Executive Officers and Assistants who work full time with the STO STCs and sub-groups to help shape and strengthen the CPoW. The CSO also provides Information Technology (IT) products and support for CPoW execution, which include internet-enabled virtual meeting rooms, allowing conferences of up to 25 simultaneous users, and a live collaborative internet-enabled work space allowing common information storage, retrieval, and editing from users home stations. Finally, in addition to maintaining an archive of completed CPoW deliverables, the IT section formats and publishes the findings of RTGs, the literature prepared for Lecture Series, and the contributions stemming from STO Symposia, Meetings and Workshops.

OFFICE OF THE CHIEF SCIENTIST (OCS)

The OCS is located at NATO HQ, in Brussels, Belgium. It is an executive body of the STO which provides executive and administrative support to the NATO CS in their role as the Chair of the STB and the senior scientific adviser at NATO HQ. The OCS is comprised of NATO International Civilians (NICs) and International Military Personnel (IMP) to carry-out, within its area of responsibility, the STB decisions and implement its policies and guidance. The functions of the OCS include assisting the STB Chairperson and the STB in developing and updating the long-term NATO S&T strategy and the medium-term NATO S&T priorities, supervising the implementation of STB guidance and direction, acting as the focal point for co-ordinating the STO PoW and the S&T activities of other NATO PoWs, and co-ordinating the STO's contribution to the NDPP. Furthermore, the OCS supports the senior scientific adviser in delivering analyses and assessments of S&T trends and developments and their potential impact on Alliance objectives, including the potential security impact of emerging technologies.

ANNEX B – FACTS AND FIGURES

NATO STO

The STO has three executive bodies, the CMRE, the CSO and the OCS, which enable the organisation to function smoothly and effectively.

RESOURCES

Resources for the STO encompass human and financial resources related to STO's executive bodies. In 2015 the NATO Security and Investment Programme (NSIP) was not used by the STO.

HUMAN RESOURCES (STAFF)

Centre for Maritime Research and Experimentation (CMRE) – In 2015 the customer-funded CMRE employed 158 people (effective 31 December 2015):

- 151 NIC; and
- 7 IMP – voluntarily contributed by Nations.

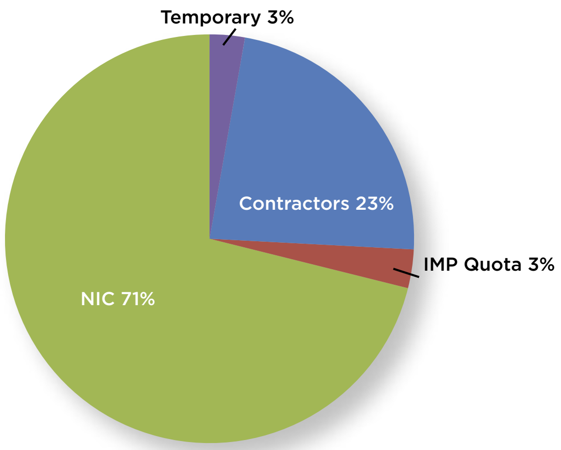

Figure 50: 2015 CMRE workforce.

Collaboration Support Office (CSO) – In 2015 the CSO employed 41 people (effective 31 December 2015) and had recourse to external services:

- 31 NIC; and
- 10 IMP – voluntarily contributed by Nations.

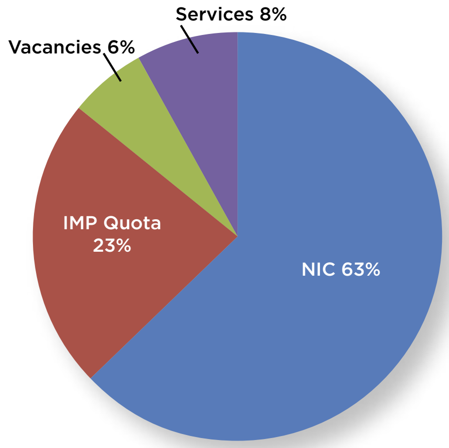

Figure 51: 2015 CSO workforce.

Office of the Chief Scientist (OCS) – In 2015 the OCS employed 11 people:

- 6 NIC; and
- 5 IMP – voluntarily contributed by Nations (two of which were temporary to reinforce the OCS).

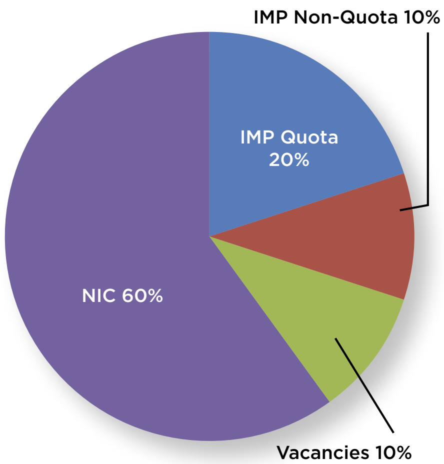

Figure 52: 2015 OCS workforce.

FINANCIAL RESOURCES

Centre for Maritime Research and Experimentation (CMRE) – The 2015 overall customer-funded financial volume was 28.1 MEuro.

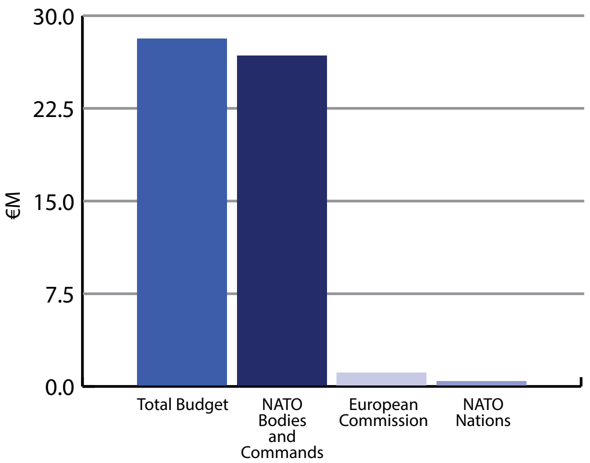

Figure 53: 2015 CMRE Budget.

Collaboration Support Office (CSO) – The 2015 overall common-funded budget was 5.45 MEuro.

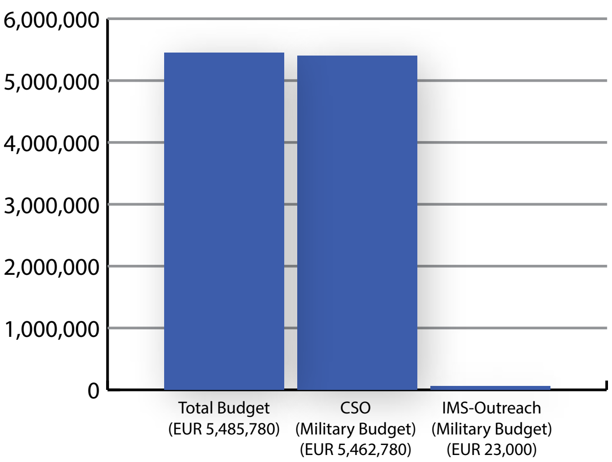

Figure 54: CSO budget.

Office of the Chief Scientist (OCS) – The 2015 common-funded budget was 0.838 MEuro.

ACTIVITIES PROGRAMME/DISTRIBUTION

STO SCIENTIFIC AND TECHNICAL COMMITTEES

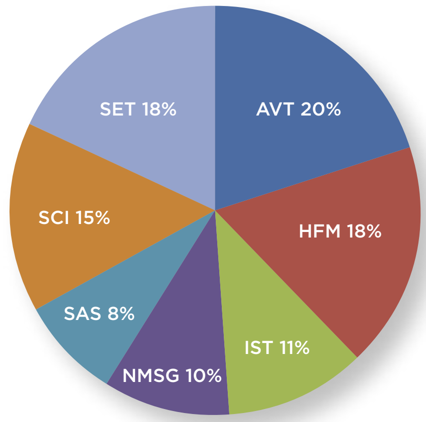

Figure 55: 2015 Distribution of activities per S&T Committee.

CMRE

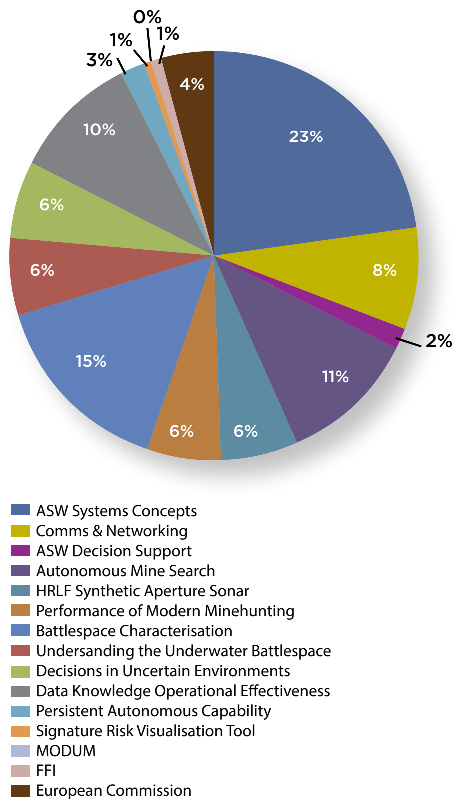

Figure 56: 2015 Distribution of activities over the CMRE programme.

ANNEX C – LIST OF ACRONYMS

24/7	Twenty-four hours a day / 7 days a week
A2/AD	Anti-Access and Area Denial
ACT	Allied Command Transformation
AF	Air Force
AFSC	Alliance Future Surveillance and Control
AGARD	Advisory Group for Aerospace Research and Development
AIAA	American Institute of Aeronautics and Astronautics
AIS	Automatic Identification System
AMICA	Analyzing Mission Impact of Cyber Attacks
AR	Army
ARCS	Admiralty Raster Chart Service
ASW	Anti-Submarine Warfare
ASWC	Anti-Submarine Warfare Commander
ATR	Automatic Target Recognition
AUV	Autonomous Underwater Vehicle
AVT	Applied Vehicle Technology
AWACS	Airborne Warning And Control System
BEL	Belgium (or Belgian)
C2	Command and Control
C3I	Command, Control, Communications and Intelligence
C4I	Command, Control, Communications, Computers and Intelligence
CAN	Canada
CAS	Continuous Active Sonar
CASG	Chairman's Advisory Sub-Group
CASG	CNAD Ammunition Safety Group
CaT	Capability Team
CAX	Computer-Assisted eXercise
CBA	Cost-Benefit Analysis
CBRNE	Chemical, Biological, Radiological, Nuclear and Explosive
CC&D	Camouflage, Concealment and Deception
CCDO-WG	Camouflage, Concealment, Deception and Obscurants – Working Group
CD	Cyber Defence
CD&E	Concept Development and Experimentation
CDT	Co-operative Demonstration of Technology
CERDEC	Communications-Electronics Research, Development and Engineering Center
CFAR	Constant False Alarm Rate
CFD	Computational Fluid Dynamics
CFI	Connected Forces Initiative
CIMIC	Civil-Military Co-ordination
CIS	Computer Information System
CMEMS	Copernicus Marine Environment Monitoring Service
CMRE	Centre for Maritime Research and Experimentation
CNAD	Conference of National Armaments Directors
CoE	Centre of Excellence
CoI	Community of Interest
COP	Common Operational Picture
CORSAR	Corsica/Sardinia
COTS	Commercial-Off-The-Shelf
CPoW	Collaborative Programme of Work
CRV	Coastal Research Vessel
CS	Chief Scientist
CSO	Collaboration Support Office
CWIX	Coalition Warrior Interoperability exploration, experimentation and examination eXercises
CZE	Czech Republic
D&D	Denial and Deception
DASG	Deputy Assistant Secretary General
DEU	Germany
DGPS	Differential Global Position System
DI	Defence Investment
DMON15	Dynamic Mongoose Exercise (2015)
DND	Department of National Defence (CAN)
DP	Dynamic Positioning
DPPC(R)	Defence Planning and Policy Committee (Reinforced)

DRDC	Defence Research and Development Canada (CAN)
DSI	Defence-Specific Inflation
DTIC	Defense Technical Information Center (USA)
DVE	Degraded Visual Environment
DWD	German Weather Service
EC	European Commission
EDA	European Defence Agency
EiV&V	Efficient independent Validation and Verification
EOP	Enhanced Opportunities Partner
ESC	Emerging Security Challenges
ESS	Energy Security Section
EST	Estonia (or Estonian)
EU	European Union
EW	Electronic Warfare
EXTAC	Experimental Tactic
FAA	Federal Aviation Administration
FASG	Finance and Audit Sub-Group
FMN	Federated Mission Network
FOM	Federation Object Model
FORA	Five Octave Research Array
FRA	France
FT-3	Flight Test Technical Team
GBR	Great Britain (or United Kingdom)
GEOMETOC	Geographic, Meteorological and Oceanographic
GFOE	Global Foundation for Ocean Exploration
GLISTEN	GLIder Sensors and payloads for Tactical characterization of the ENvironment
GNSS	Global Navigation Satellite System
HFM	Human Factors and Medicine
HGA	Higher Grazing Angle
HLA	High-Level Architecture
HMP	Health, Medicine and Protection
HP	Harbour Protection
HQ	Headquarters
HRLF	High Resolution Low Frequency
HSB	Human Systems and Behaviour
HWITL	Hardware-In-The-Loop
I/ITSEC	Interservice/Industry Training, Simulation and Education Conference
IED	Improvised Explosive Device
IEEE	Institute of Electrical and Electronics Engineers
IEG	Information Exchange Gateway
IMHM	Integrated Munitions' Health Management
IMP	International Military Personnel
IMS	International Military Staff
IS-DI	International Staff, Defence Investment
ISARN	Inverse Synthetic Aperture Radar Node
ISEG	Independent Scientific Evaluation Group
ISpec	Interoperability Specification
ISR	Intelligence, Surveillance and Reconnaissance
IST	Information Systems Technology
IT	Information Technology
ITA	Italy
JAUS	Joint Architecture for Unmanned Systems
JCGISR	Joint Capability Group Intelligence, Surveillance and Reconnaissance
JISR	Joint Intelligence, Surveillance and Reconnaissance
KIMC	Knowledge/Information Management Committee
L2CC	Level Two Co-ordination Committee
LACHI	Longwave Advanced Compact Hyperspectral Imager
LCAS	Low frequency Continuous Active Sonar
LED	Light-Emitting Diode
LoI	Letter of Intent
LWIR	Long-Wave Infra-Red
M&S	Modelling and Simulation
MARCOM	Maritime Command
MASG	Maritime S&T Sub-Group
MC	Military Committee
MCM	Mine Counter-Measure
MCR	Minimum Capability Requirement

MD	Mediterranean Dialogue
MDCS	Multi-Domain Control Station
METOC	Meteorological and Oceanographic
MGen	Major General
MODUM	Monitoring Of DUmped Munitions
MOTS	Military-Off-The-Shelf
MoU	Memorandum of Understanding
MRN	Marine Radar Node
MSA	Maritime Situational Awareness
MSaaS	Modelling and Simulation as a Service
MSE	Multi-Sensors and Electronics
MSTC	Maritime S&T Committee
MSTPA	Multi-Static Tactical Planning Aid
MUSCLE	Mine-hunting UUV for Shallow-water Covert Littoral Expeditions
MWIR	Mid-Wave Infra-Red
NAC	North Atlantic Council
NAF	NATO Architecture Framework
NAFAG	NATO Air Force Armaments Group
NATO	North Atlantic Treaty Organization
NC3B	NATO Consultation, Command and Control Board
NCC	National Control Centre (PERSEUS)
NCC	National Co-ordinators Committee
NCI	NATO Communications Infrastructure
NCIA	NATO Communications and Information Agency
NCOP	NATO Common Operational Picture
NCTR	Non-Co-operative Target Recognition
NDPP	NATO Defence Planning Process
NETN	NATO Education and Training Network
NIAG	NATO Industrial Advisory Group
NIC	NATO International Civilian
NLD	Netherlands
NMSG	NATO Modelling and Simulation Group
NMSMP	NATO Modelling and Simulation Master Plan
NNAG	NATO Naval Armaments Group
NNE	Non-NATO Entity
NNEC	NATO Network-Enabled Capability
NOAA	National Oceanographic and Atmospheric Administration
NOR	Norway
NRV	NATO Research Vessel
NSC	NATO Shipping Centre
NSIP	NATO Security and Investment Programme
NSMEX'15	North Sea MCM Experiment 2015
NSPA	NATO Support and Procurement Agency
NURC	NATO Undersea Research Centre
OA	Operational Analysis
OCS	Office of the Chief Scientist
OGC	Open Geospatial Consortium
ONR	Office of Naval Research
OR&A	Operational Research and Analysis
OT	Optical Technology
P&P	Plans and Policy
PA	Parliamentary Assembly
PARC	Persistent Autonomous Reconfigurable Capability
PCCs	Protected Core Communities
PCN	Protected Core Networking
PCore	Protected Core
PERSEUS	Protection of European boRders and Seas through the intElligent Use of Surveillance
PfP	Partnership for Peace
PoW	Programme of Work
PRT(N)	Portuguese Navy
QoS	Quality of Service
R&D	Research and Development
R&T	Research and Technology
RAdm	Rear Admiral
RAS	Robotics and Automation Society
ret.	Retired
RF	Radio Frequency
RFT	Radio Frequency Technology
ROMS	Regional Ocean Modelling System
ROS	Robotic Operating System
ROU	Romania

ROV	Remotely Operated Vehicle
RSN	Radar Sensor Network
RSTA	Reconnaissance, Surveillance and Target Acquisition
RTARA	Real-Time Automated Risk Assessment
RTG	Research Task Group
RTO	Research and Technology Organisation
RV	Research Vessel
S&C	Stability and Control
S&T	Science and Technology
SAA	Scientific Achievement Award
SACLANTCEN	SACLANT Undersea Research Centre
SACT	Supreme Allied Commander Transformation
SAR	Search And Rescue
SAR	Synthetic Aperture Radar
SAS	Synthetic Aperture Sonar
SAS	System Analysis and Studies
SASG	Scientific Awards Sub-Group
SB	Steering Board
SCI	Systems Concepts and Integration
SDCG	Ship Design Capabilities Group
SEBASS	Spatially Enhanced Broadband Array Spectrograph System
SET	Sensors and Electronics Technology
SISO	Simulation Interoperability Standards Organisation
SME	Subject-Matter Expert
SPS	Science for Peace and Security
ST-SM	Specialists' Team on Seaway Mobility
STANAG	Standard NATO Agreement
STB	Science and Technology Board
STC	Scientific and Technical Committee
STO	Science and Technology Organization
SWE	Sweden
SWITL	Software-In-The-Loop
TABI	Thermal Airborne Broadband Imager
TACOMS+	TActical interoperable COMmunications Standards +
TASI	Thermal Airborne Spectrograph Imager
TG	Task Group
TREAD	Traffic Route Extraction and Anomaly Detection
TTCP	The Technical Cooperation Program
TTPs	Tactics, Techniques and Procedures
UAS	Unmanned Aerial System
UAV	Underwater Autonomous Vehicle
UCATT	Urban Combat Advanced Training Technology
UCAV	Unmanned Combat Aerial Vehicle
UGV	Unmanned Ground Vehicle
UN	United Nations
US	United States
US OSD	US Office of the Secretary of Defense
USA	United States of America
USAF	United States Air Force
USCG RDC	US Coast Guard Research and Development Center
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
UXO	Unexploded Ordnance
VAdm	Vice Admiral
WHO	World Health Organisation
WI-FI	Wireless Fidelity
WPT	Wireless Power Transmission

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