NATO OTAN
Science and Technology Organization

2023 HIGHLIGHTS

SCIENCE AND TECHNOLOGY ORGANIZATION

EMPOWERING NATO'S TECHNOLOGICAL EDGE

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FOREWORD

FOREWORD

In 2023, NATO was confronted with an unpredictable security environment amidst ongoing geopolitical instability. As reaffirmed during the NATO Vilnius Summit, the Alliance, strengthened by the accession of Finland, stands united to address the most pressing challenges and reinforce its collective defence.

The NATO Science and Technology Organization (STO) remains key to the Alliance's efforts to maintain its technological advantage. The *Highlights 2023* publication showcases the STO's proactive efforts to anticipate future trends, its responsive action in addressing the changing security environment, and its work to build the resilience necessary to meet future challenges.

Over the past year, the STO continued to prioritise forward-thinking initiatives and anticipate future trends, especially in the impact and convergence of emerging and disruptive technologies (EDTs). In keeping with its **proactive** approach, the STO launched the *Science & Technology Trends: 2023–2043* report, providing a comprehensive insight into EDTs and their potential implications for the Alliance. Furthermore, the STO executed several activities investigating the impact of climate change on defence and security.

Taking swift and assertive action in response to changes in the security environment is critical to dealing with emerging challenges. The STO addresses the Alliance's needs by developing new ways of countering threats, identifying opportunities that arise from progress within the science and technology (S&T) domain, and delivering evidence-based advice to decision-makers. Throughout 2023, the STO remained **responsive** to advancements in S&T, and worked to ensure that advanced scientific knowledge, the latest technological developments, and innovation are readily available to NATO. The organization also participated in high-level initiatives on EDTs, including a von Kármán Horizon Scan (vKHS) on artificial intelligence (AI) and a Quantum Technology Workshop, bringing together experts from NATO and Allied countries.

As expressed in the Vilnius Summit Communiqué, NATO is now facing increasing strategic competition. Nurturing **resilient** structures, processes and working culture is of paramount importance for any organization to navigate the uncertainties of an evolving strategic environment. The STO remains committed to diversifying its network of world-class researchers, which will enable it to meet future challenges. Events organised in 2023, including the Women and Girls in Science Conference and the event for Women in Sensors and Electronics Technology, underscore the STO's commitment to closing the gender gap.

In 2023, the STO Collaborative Programme of Work (CPoW) comprised over 400 research activities, covering a wide range of areas: cyber, sensors, weapons, human-machine interfaces, EDTs, and their applications to the five operational domains (land, sea, air, cyber and space). This report demonstrates the high-quality work performed across the STO, and its unwavering commitment to delivering relevant, evidence-based advice while fostering a vast network of experts.

Dr Bryan WELLS
NATO Chief Scientist
STB Chairman

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Jens Stoltenberg, NATO Secretary General, Copenhagen Quantum Conference 2023

"Your research, your ideas, your dedication, are critical to strengthening NATO's capabilities."

Mircea Geoană, NATO Deputy Secretary General, STO Early Career Scientist Awards 2023

"Today, we have agreed significant measures to further enhance NATO's deterrence and defence posture in all domains (...). We are accelerating our own efforts to ensure that the Alliance maintains its technological edge (...)."

Vilnius Summit Communiqué

PROACTIVE

Anticipating future trends early and incorporating them into forward planning is decisive for maintaining the Alliance's technological advantage. The STO prioritises forward-thinking initiatives in emerging and disruptive technologies (EDTs), and their impact and convergence, in order to support a future-ready force.

PROACTIVE

ROBOTIC EXPERIMENTATION AND PROTOTYPING USING MARITIME UNCREWED SYSTEMS

The Recognised Environmental Picture augmented by Maritime Unmanned Systems (REPMUS) exercise series brings together academia, industry and military players to work on integrating and adopting Maritime Unmanned Systems (MUS) into operations. Organised by the Portuguese Navy, this exercise is at the core of fundamental technological and doctrinal issues around the evolution of maritime operations in NATO.

The STO Centre for Maritime Research and Experimentation (CMRE) participated in a REPMUS exercise for the tenth time in 2023, with its efforts focused on using collaborative autonomy to support command and control aspects of various vignettes, including autonomous missions carried out with multiple participants in a mine countermeasures (MCM) context. Such capabilities would be supported by the digital twin implementation of the CMRE's modelling and simulation federation. CMRE subject matter experts also helped to bridge industry and military operators in developing concepts of use for digital underwater communications.

During the REPMUS'23 exercise, the CMRE once again deployed its Command Control and Communications for Maritime Robotic Exploitation (C3MRE) infrastructure, allowing more than 100 different nodes from 30 institutions and 14 Nations to exchange status and tasking messages in support of MCM, anti-submarine warfare (ASW), rapid environmental assessment (REA), and amphibious operations serials. The CMRE's modelling and simulation tools were integrated into the CMRE infrastructure, enabling the integration of physical and simulated assets to augment the exercise. The Collaborative Autonomy Tasking Layer (CATL) was used to achieve collaborative autonomy, assigning autonomy tasking across a multinational force in MCM scenarios.

REPMUS exercises address fundamental problems of operational relevance and appeal to a broad range of Nations, which makes them an ideal venue for exercising interoperability aspects. Through participating in REPMUS'23, the CMRE contributed to further developing interoperability concepts for the Alliance, including the evolution of CATL and its introduction into STANAG 4817, and the development of concepts of use for STANAG 4748 (JANUS), NATO's standard on digital underwater communications.

Figure 1: Simulated view of CMRE's BiondO underwater autonomous vehicle performing a survey in an MCM scenario.

Figure 2: CMRE's autonomous underwater vehicle about to be deployed to perform a collaborative MCM serial in exercise REPMUS'23; also pictured: Portuguese Offshore Patrol Vessel NRP Sines.

CLIMATE CHANGE AND SECURITY

In 2023, the STO CMRE, sponsored by the Office of the Chief Scientist (OCS), developed a science and technology (S&T) line of research focused on several climate change and security (CC&S) challenges.

Recognising that the development of effective climate change adaptation strategies requires solid scientific evidence, the new CC&S department conducts research across a wide range of relevant topics. Its areas of focus include sea level rise and associated flooding of coastal bases; the evolution of "hot day" frequency at a global scale; underwater sound speed and the effect of acoustic propagation on sonar and acoustic communication performances; atmospheric evaporative duct affecting naval radar and electromagnetic communications performances; and wave climate and sea-state in the Mediterranean Sea and High North regions affecting naval operations. The department was also established to carry out field experimentation, including through the newly created NATO Arctic Climate Observatory. The CMRE is working to establish mechanisms to increase the Alliance's knowledge base, and is actively pursuing collaborations with civil society, academia and industry on CC&S-related issues.

COLLABORATIVE PROGRAMME OF WORK 2030

Since September 2022, the STO has been undertaking a review of the structures, processes, organization and presentation of the Collaborative Programme of Work (CPoW). The STB launched this initiative in response to the rapidly evolving and increasingly complex strategic environment, which demands cutting-edge capabilities across the Alliance. In seeking to evolve the CPoW, the STB recognised that S&T is the foundation upon which such capabilities are developed.

To deliver on this challenge, the CSO established a working group (WG), designated the CPoW2030 WG, with the task of recommending actions to ensure that the CPoW remains the "forum of choice for collaborative S&T" for decades to come. The WG's report, delivered in September 2023, set forth a new CPoW strategy with detailed actions to achieve the objectives it describes. The actions call for implementing ambitious changes to the structure, processes and presentation of the CPoW, with requisite support from Nations and the STO entities. The actions also aim to ensure that the CPoW is capable of supporting developments in new research areas, while reducing gaps and facilitating engagement. In addition, the actions call for new structures and processes to develop a diverse collaborative network to address future challenges, while specifying the necessary personnel and resources to support these changes.

The STB approved the strategy and the WG's recommended actions in November 2023, reaffirming its support for the STO to play a key role in maintaining the Alliance's technological edge in the future.

CRITICAL UNDERWATER INFRASTRUCTURE

In November 2023, NATO Secretary General Jens Stoltenberg met with European Union (EU) Defence Ministers to discuss the protection of critical underwater infrastructures (CUIs) and the importance of continued support for Ukraine. The Secretary General stressed that the sabotage of the Nord Stream pipelines last year, as well as the recent damage to the Balticconnector pipeline and cables, show that CUIs are vulnerable and that threats are real, highlighting the urgent need to improve CUI resilience.

Comprising gas pipelines and power and communication cables, CUIs connect countries across the world, and are critical for the global economy and stability. An attack targeting multiple CUIs could cause significant damage and greatly affect various aspects of daily life. In light of recent incidents, NATO has stepped up air and naval patrols, and has increased its presence in the Baltic and North Seas. At the Vilnius Summit in July, Allies agreed to establish a new centre on critical underwater infrastructure at NATO's Maritime Command (MARCOM) in the United Kingdom.

The Data Knowledge and Operational Effectiveness (DKOE) project, funded by NATO Supreme Allied Command Transformation (SACT), aims to provide enhanced capabilities based on artificial intelligence and information fusion (AI2F) to enable cognitive superiority and achieve seabed-to-space situational awareness (S3A).

Existing underwater surveillance solutions, such as autonomous underwater vehicles or remotely operated vehicles, are not adequate to ensure thorough monitoring. DKOE research activities focus on developing strategies to combine information from both underwater and above-water surveillance sensors enabling S3A, mainly thanks to AI and information fusion (AI2F) methodologies. These are designed to process immense volumes of information, fused from a variety of sources and generated from monitoring a very large number of assets. The learned knowledge can be used to anticipate future behaviours, identify threats and determine critical situations concerning CUIs.

To illustrate the capabilities and importance of S3A, the DKOE team considered three events that occurred in the second half of 2022: the aforementioned Nord Stream explosions, the cut-off of the underwater communication cable SHEFA-2 connecting the Shetland Islands and the UK mainland, and the suspicious activity of a large vessel in the Adriatic Sea. Specifically, the analysis of the available data from automatic identification system and satellite data, integrated with possible contextual information (e.g. bathymetry, patterns-of-life, weather conditions and human intelligence) is provided.

SCIENCE & TECHNOLOGY TRENDS 2023–2043

In March 2023, NATO Deputy Secretary General Mircea Geoană launched the STO's flagship report on *Science & Technology Trends 2023–2043*. The publication provides an assessment of the S&T trends that are likely to influence the Alliance and the world in the coming 20 years, and their potential impact on NATO military operations, defence capabilities, enterprise functions, and political decision space. The report is divided into two volumes, with the first providing an overview of key trends geared towards policymakers, and the second offering deeper analyses of each S&T area.

Science & Technology Trends 2023-2043 builds on the work of the STO collaborative network, which comprises more than 5,000 scientists across NATO Allies and partner nations. Indeed, the publication's analysis was supported by a large-scale survey of this network. These researchers provide the Alliance with in-depth research and analysis on S&T priority areas, which directly link to NATO's core tasks: deterrence and defence; crisis prevention and management; and cooperative security. The network's seven Scientific and Technical Committees (STCs) oversee more than 300 activities each year that are essential to the research, understanding, and analysis of future developments that will influence Euro-Atlantic security.

The report marks the first time that the STO has incorporated analysis from its AI-enabled research tool, the Science and Technology Ecosystem Analysis Model (STEAM). This tool draws upon millions of open source, English-language journal articles, pre-prints, and abstracts to gain valuable "weak signals" foresight into future EDT areas. STEAM also allows for a deeper analysis of trends over time in each EDT area, and to compare the volume of EDT-related research carried out across different countries.

The report concludes that, over the next 20 years, military technologies will develop to be increasingly intelligent, interconnected, decentralised, and digital. This, in turn, will enable military capabilities to become increasingly autonomous, networked, multi-domain, and precise. In remarks delivered at the launch, Mr Geoană emphasised that new technologies are transforming the way wars are fought and won, and that "the STO represents the elite of the elite" in NATO's research and innovation work.

STO WORKSHOPS: DISINFORMATION AND TRUST IN NUCLEAR VERIFICATION

DISINFORMATION

In April 2023, the STO and the NATO Public Diplomacy Division (PDD) jointly hosted a workshop on disinformation, bringing together experts from government, industry and academia for discussions with NATO officials. Topics covered included Russian disinformation against Ukraine, tackling foreign information manipulation, and international scientific collaboration to respond socially and technically to disinformation. Officials from the European External Action Service also presented their work on tackling foreign information manipulation and interference.

THE ROLE OF TRUST IN NUCLEAR VERIFICATION

As part of the STO's continuing work to support NATO's role in arms control, disarmament and non-proliferation, scientific experts have been examining the role of trust in the verification of nuclear disarmament. In September 2023, the STO hosted a workshop that brought together STO scientists with international arms control experts to address the work that the STO had undertaken in the field of nuclear disarmament verification. The outcome of this workshop will be reflected in an upcoming Chief Scientist Research Report on this topic.

CPOW CHALLENGES

In March 2022, the STB agreed on a new initiative, Challenges to the CPoW ("CPoW Challenges"), which promotes specific S&T topics in line with the medium-term funding priorities of Nations. Within 24 months, each Challenge aims to deliver an overarching problem statement and a set of suggested research projects for the STO Panels and Group to pursue. Taken together, these outputs will shape a forward-looking research agenda for each topic, driven by the most pressing needs of Nations and firmly embedded within the CPoW.

Emphasising the medium-term planning horizon and the Nations' leadership, the CPoW Challenges provide an innovative vehicle to:

- steer the CPoW towards novel topics;
- provide the clear orientation and lead time required for Nations to allocate their resources; and
- establish cross-domain communities of interest that attract additional experts to the CPoW.

In 2023, three of four pilot cases accomplished their mission:

- For the CPoW Challenge on cognitive warfare, the Lead Nation (Norway) held a scoping workshop in November 2022, where 75 participants developed 9 concrete projects to address cognitive warfare across four dimensions: situational awareness, cognitive effects, modus operandi and technological enablers.
- For the CPoW Challenge on hypersonics, the Lead Nation (Germany) hosted a workshop on "Technology Needs for Hypersonic Operational Threats – TecNHOT" in December 2022. Around 100 participants from a range of academic and operational backgrounds discussed new hypersonic threats; operators' perspectives; defence architecture and detection; decision-making and training; and testing and validation.
- For the CPoW Challenge on climate change and security, the Leads (Canada, Denmark, Norway, the Netherlands and the CMRE) conducted a series of virtual workshops to build a vibrant, cross-disciplinary community of more than 140 experts. In addition to the problem statement and 11 concrete projects, the team produced a compendium of over 130 parameters of climate change and security. These parameters will orient future research work within the STO and facilitate outreach to other NATO entities active in this area.
- For the CPoW Challenge on quantum technologies, the Lead Nations (the Netherlands, Denmark and Italy) conducted a scoping workshop with support from the CMRE. By the end of 2023, more than ten concrete projects were under consideration by the STCs (Panels/Group). A dedicated coordination group is envisaged to support the execution of these projects, and to foster coherence between them.

Furthermore, the STB agreed in 2023 to launch two new Challenges to the CPoW: the United Kingdom offered to lead a Challenge on weak signals in S&T, while Finland will lead a Challenge on resilience.

STO PARTNERSHIP EVENT

At the 2022 Madrid Summit, Allies agreed to strengthen engagement with partner countries by leveraging flexible groupings to provide a platform for cooperation on specific thematic areas, regardless of formal geographic partnership groups (e.g. Partnership for Peace, Mediterranean Dialogue, Istanbul Cooperation Initiative, etc.).

In November 2023, the STO organised an **STO Partnership Event** at NATO Headquarters for partners involved in "**EDTs and Innovation**." The event, attended by partner ambassadors and military representatives, provided partners with an update on STO and NATO S&T activities, and the value they create for both Allies and partners.

The event provided partners with an enhanced understanding of the opportunities the STO can offer, and how these fit into the wider NATO partnership picture. In remarks delivered at the event, the NATO Chief Scientist recalled the long and vital role that the STO has played in advancing NATO's S&T, noting that the new Strategic Concept and NATO 2030 place a high priority on maintaining NATO's technological edge. He also highlighted the critical contributions that partners make to these efforts, and the importance of upholding norms and standards in taking this agenda forward. Partnerships will continue to play a key role in expanding the STO's network and enriching it with new knowledge.

RESPONSIVE

Taking swift and assertive action in response to changes in the security environment is critical to dealing with emerging challenges. The STO addresses the Alliance's needs by developing new ways of countering threats, identifying opportunities that arise from progress within the S&T domain, and delivering evidence-based advice to decision-makers.

RESPONSIVE

EDTS/EDT++ (BIOTECH, BIOLOGY)

As noted in the STO's *Science & Technology Trends 2023–2043* report, society is currently going through an artificial intelligence revolution, following the information revolution, and the next revolutionary technology cycle will be based on synthetic biology. The Chief Scientist briefed the Military Committee on synthetic biology in January 2023, explaining its relevant military applications, as well as the opportunities and challenges it presents. In September, the OCS, together with the Policy and Planning Unit, conducted a workshop on the potential defence, ethical, legal, and moral implications of biotechnology and human enhancement. The workshop brought together stakeholders from across NATO to expand foresight around the long-term impact of emerging technologies.

QUANTUM TECHNOLOGIES

Recent years have witnessed substantial investment in quantum technologies, spanning communication, computing, sensing, materials, and optics applications. Quantum technologies are anticipated to mature in defence applications over the next two decades.

Based on the Chief Scientist's *2021 Quantum Technology Review* and extensive research on technology trends from 2023–2043, the STO has significantly contributed to the Alliance's understanding of the defence implications of quantum technologies. The STB's CPoW "Deep Dive" on quantum technologies, led by the Netherlands and complemented by a workshop organised by CMRE, has played a pivotal role in expanding our knowledge of cutting-edge research.

Under the NATO 2030 initiative, CMRE has developed a high-impact research programme focusing on quantum technologies. With support from OCS and Allied Command Transformation (ACT), CMRE formulated a forward-looking Quantum Strategy, shared with Allies to inform NATO's overarching Quantum Strategy. The Quantum Science and Technology Workshop in June 2023 identified quantum positioning, navigation, and timing (PNT) and quantum key distribution as mature topics. While quantum computing holds disruptive potential, its practical application remains uncertain.

CMRE's Quantum Lab, expanded in 2023, anticipates delivering results starting from early 2024. Active participation in the STB CPoW Challenge on quantum technology underscores CMRE's commitment to meeting the Alliance's security and defence needs.

In 2023, the STO Information Systems Technology (IST) and Sensors and Electronics Technology (SET) Panels organised a two-day research symposium on quantum technology. The event, attended by representatives from over 20 countries, explored quantum technology's implications in defence and security.

Topics included quantum PNT, sensing, imaging, communication, and information processing. The unclassified results are accessible to NATO Nations, NATO bodies, and STO Enhanced Opportunity Partners.

VON KÁRMÁN HORIZON SCAN ON ARTIFICIAL INTELLIGENCE

In 2023, the STO delivered a von Kármán Horizon Scan (vKHS) on AI that assessed the implications of AI on deterrence and defence over the next 10 years. Named after Dr Theodore von Kármán, the founding Chair of the NATO Advisory Group for Aeronautical Research and Development (AGARD), this type of technology forecasting brings together experts with military, research and business backgrounds to share their professional views and insights on the current state-of-play, and discuss plausible future development trajectories.

For the vKHS on AI, experts from nine Allies and partner nations, as well as NATO, considered five case studies on defence applications of AI: cyber; electronic warfare; intelligence, surveillance, and reconnaissance; missile defence; and swarms of autonomous vehicles.

Figure 3: Workshop of vKHS Experts, February 2023

Figure 4 : Artificial Intelligence [artist's impression].

Recognising NATO's forward-leaning efforts in promoting Principles of Responsible Use (PRU) for AI, as well as ongoing work strands on data exploitation and digital transformation, the experts considered the establishment of coherent management structures for data and AI applications during their development, procurement and use, in order to support and maintain human accountability. At the same time, the experts highlighted the risks inherent to AI (including traceability, explainability, brittleness and bias), as well as the vulnerabilities stemming from open source intelligence and free data sets, targeted cyber-attacks, lack of trust, or adversaries not constrained by NATO's PRU.

The experts also discussed the need to promote shared and safe AI development and advanced cybersecurity to protect AI applications. They emphasised the importance of fostering AI competence across the enterprise and remaining committed to operationalising its PRU.

The experts' follow-up engagements with various NATO fora (including the STB, the NATO Modelling and Simulation Group, the Joint Capability Group on Intelligence, Surveillance, and Reconnaissance, and the Data and AI Review Board) and with several Allied Nations illustrate the considerable interest in the topic, and the timeliness of this forecasting project.

FEDERATED MISSION NETWORKING

Federated Mission Networking (FMN) is a NATO initiative that aims to support command and control and decision-making in future operations through improved information sharing. It provides the agility, flexibility and scalability needed to manage the emerging requirements of any mission environment in future NATO operations. FMN is based on trust, willingness and commitment, as well as cost-effectiveness and the maximum re-use of existing standards and capabilities.

FMN is a key contribution to the Connected Forces Initiative (CFI), helping Allied and partner forces to better communicate, train and operate together. It enables the rapid instantiation of mission networks, thereby enhancing interoperability and information sharing. As a governed conceptual framework, FMN consists of people, processes and technology to plan, prepare, establish, use and terminate mission networks in support of federated operations.

The STO actively contributes to FMN through a range of scientific activities, including work carried out by the NATO Modelling and Simulation Group (NMSG) and the IST Panel.

TIDE SPRINT

The spring 2023 TIDE Sprint S&T Track provided a unique platform to integrate S&T themes into existing tracks, fostering collaboration between scientists and military operators. The event aimed to enhance upfront interoperability among NATO Nations by developing a common S&T culture. TIDE Sprints are crucial for advancing federate interoperability, bringing together operators, engineers, and scientists from various sectors to develop current and future solutions.

This TIDE Sprint S&T Track, organised by the STO, brought together operators and researchers to discuss a range of significant developments, from validating 5G deployment in military formations, to using viruses to combat bacterial infections in military personnel. The event raised greater awareness about the work of the NATO S&T community, while encouraging knowledge exchange, attracting valuable contributors, and enhancing collaboration beyond the workshops. The spring 2023 TIDE Sprint drew more than 500 attendees with briefings across 17 activities, and led to the creation of five follow-up events for future collaboration.

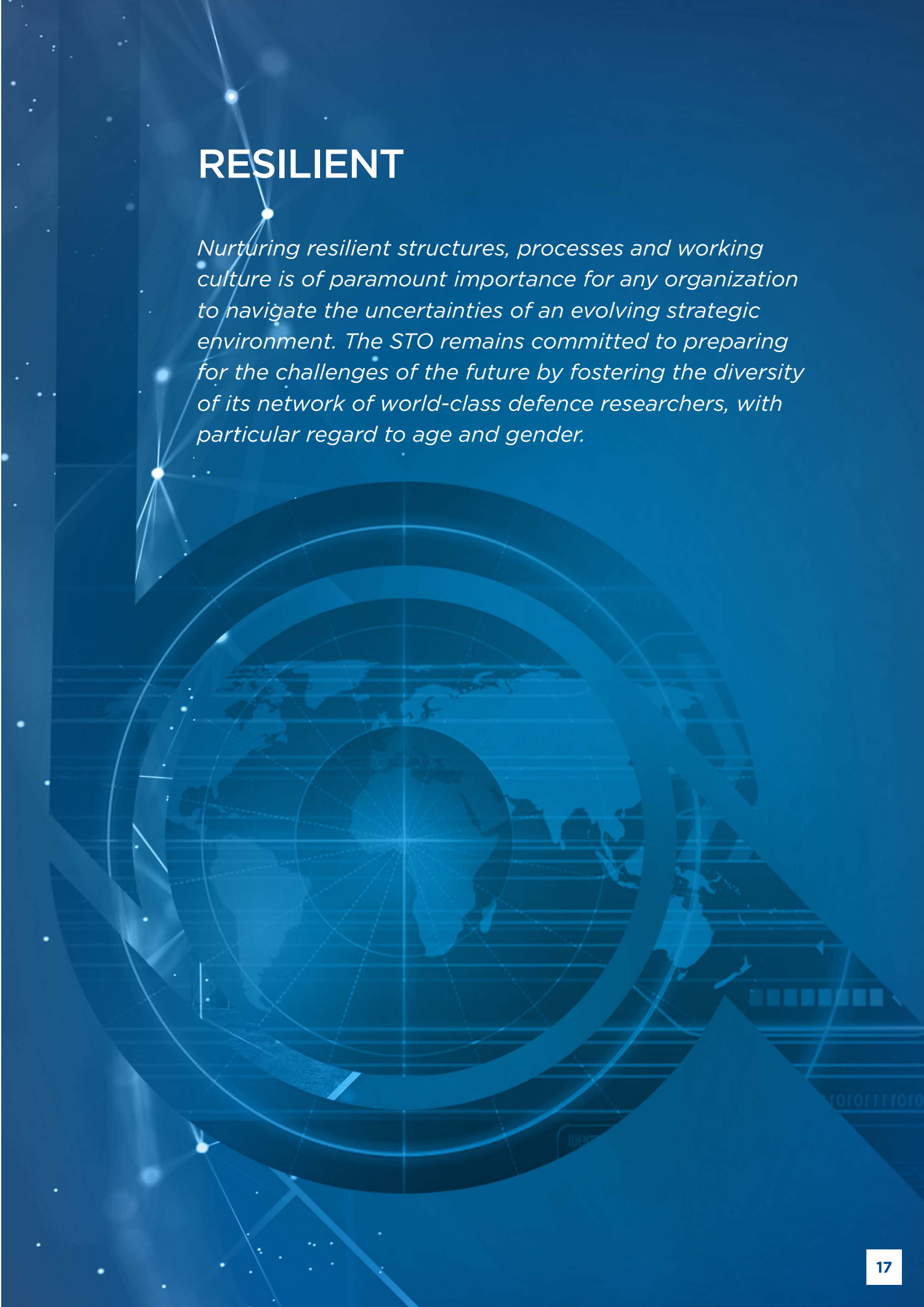
SUPPORTING NATO'S WORK ON RESILIENCE

Amid a rapidly evolving security landscape, NATO has increased its focus on enabling resilient societies, protecting citizens against hostile information campaigns and defending against hybrid threats. The STO supported these efforts in 2023 by undertaking a collaborative strategic activity on cognitive warfare, led by Norway. Next year, Finland will lead a related strategic challenge on resilience.

Figure 5: Collaboration Support Office presenting the CPoW Publications to the TIDE Sprint 42 Audience

RESILIENT

Nurturing resilient structures, processes and working culture is of paramount importance for any organization to navigate the uncertainties of an evolving strategic environment. The STO remains committed to preparing for the challenges of the future by fostering the diversity of its network of world-class defence researchers, with particular regard to age and gender.



RESILIENT

EARLY CAREER SCIENTISTS (EARLY CAREER SCIENTISTS EVENT, PANELS/ GROUP EARLY CAREER SCIENTIST AWARDS)

Figure 6: Twelve early-career scientists were selected to present their work at the NATO Science and Technology Board (STB) fall meeting in Helsinki, Finland.

Engaging with early-career scientists is a key priority for the STO, as they inject the CPoW with new perspectives and expertise, while also contributing to its long-term sustainability.

In September, the STO held a special event for early-career scientists at the NATO STB fall meeting in Helsinki, Finland, bringing together 12 researchers from 11 NATO Nations. Each scientist presented their work to the STB, and engaged in further discussions at a poster session afterwards.

Ms Barbora Hrnčířová (Czech Republic) won the award for best research presentation, for her discussion on "Unlocking the potential of inedible plant biomass using microbial engineering and synthetic biology." Mr Luke Galantree (United Kingdom) and Ms Kristin Waage (Norway) won the awards for best research posters. Mr Galantree presented his work on "Augmented Reality to Enhance Situation Awareness for Armoured Fighting Vehicle (AFV) Crews," and Ms Waage presented her work on "Economic Statecraft, Technology and Security." The scientists who presented at the STB meeting, as well as the topics of their presentations, are listed below.

"Your research, your ideas, your dedication, are critical to strengthening NATO's capabilities," NATO Deputy Secretary General Mircea Geoană said in a video address to the early-career scientists. "The work you do today will play a vital role in maintaining our competitive edge for years to come, bolstering our defences and ensuring the security of our Nations and our people."

The STO STCs also honoured the following early-career scientists at various events throughout the year:

SET Panel

- Sarah Welch, Space Situational Awareness (SSA)
- Theresa Scarnati, Machine Learning (ML) and Compressive Sensing (CS)
- Marco Boddi, Signal Processing
- Stefan Scholl, De-interleaving of radar emitters
- Michael Henrichsen, Threat evaluation and impact of laser eye dazzle
- Michele Maxson, Geophysical Sensors
- Jonas Schöttler, AI-based EO-sensor image classification
- Maciej Soszka, Detection of ISAR imaging capabilities of a passive radar
- Alexander Wentzel, Automated unmanned aerial robotic system to counter small UAVs

Systems Concepts and Integration (SCI) Panel

- Mathias Anneken, Artificial Intelligence, Machine Learning, and Anomaly Detection in the Maritime domain

Applied Vehicle Technology (AVT) Panel

- Luke Gallantree, Land Platform Systems and Augmented Reality Technologies
- Laura Mainini, Multi-fidelity Methods for Military Vehicle Design
- Marcel Baltzer, Augmented Reality and Human Autonomy Teaming

System Analysis and Studies (SAS) Panel

- Sean Havel, Operations Research/Simulation
- Berke Levent Capli, Defence Education

WOMEN AND GIRLS IN SCIENCE CONFERENCE 2023

On 8 February 2023, the STO held the Women and Girls in Science 2023 (WGS23) Conference at NATO Headquarters in Brussels, Belgium. The event, held ahead of the UN Day for Girls and Women in Science (11 February), provided an opportunity to discuss the importance of female participation in science, technology, engineering, and mathematics (STEM), and to celebrate the achievements of women and girls in S&T.

Diversifying its network of researchers is a key priority for the STO. Attracting talent from different groups, including women, is crucial to ensuring the sustainability of the organization and enriching it with alternative perspectives, knowledge and expertise. The WGS23 was one of several STO initiatives aimed at boosting female participation in the collaborative network.

Dr Catherine Warner, Director of the CMRE, opened the conference by describing how she first became passionate about S&T as a child, and how that led to an illustrious career. The event featured three all-female panels on "Girls in Science," "Winning Stories to Inspire Future Generations," and "Looking into the Future." During the first panel, high school students from the region of La Spezia, Italy discussed their interests in S&T, and shared their plans and hopes for future careers. They also described their experience participating in the CMRE STEM outreach project *Progetto Giona*, which aims to further develop their scientific interests and introduce them to CMRE research.

Various other issues were discussed at the conference, including the obstacles that women in academia face today, success stories of female researchers, and efforts to integrate gender perspectives into the NATO workforce. The conference also featured a video message from Vanessa E. Wyche, the Director of NASA's Johnson Space Center, who provided practical advice and encouragement for aspiring STEM professionals.

WOMEN IN SET WORKSHOP

The STO held a Research Specialists' Meeting for "Women in Sensors and Electronics Technology (SET)" in June 2023, as part of an effort to build a more vibrant community of women experts within the STO collaborative network. Held on 13–14 June at the Hôtel de Talleyrand in Paris, France, the event brought together a diverse group of 33 experts from 11 NATO Nations and partner nations to discuss a wide range of topics, including sensor technology, radar, artificial intelligence/machine learning, quantum, and data fusion.

The initiative (SET-327) was launched as part of an effort to promote greater diversity in the SET Panel, as well as in the STO collaborative network and NATO more broadly. Keynote addresses were delivered by Mr John-Mikal Størdal, Director of the STO CSO, Col Laura Regan, Head of the Operations and Coordination Office at the CSO, and Ms Marie-Thérèse Velluet (FRA), who was an SET Panel Member from 2015–2022 and served as the Optical Focus Group Co-ordinator from 2018-2022.

"Diversifying our network of world-class scientists and engineers is a top priority for the STO, and key to the future of the Collaborative Programme of Work," said Col Regan. "Building new networks and support mechanisms for under-represented groups is an important step in this process, and that is exactly what the 'Women in SET' activity aims to achieve."

Figure 7: Participants at the "Women in Sensors and Electronics Technology" Research Specialists' Meeting in Paris, France on 13–14 June 2023.

ANNUAL AWARD WINNERS

2023 VON KÁRMÁN AWARD

The von Kármán Medal honours individuals for their lifetime dedication to international collaboration on science and technology in NATO, and for their contributions to STO activities over an extended period. At its spring meeting in March, the NATO STB awarded the 2023 von Kármán Medal to Prof Krzysztof Kulpa of Poland, in recognition of his exceptional contributions to the field of radar technology.

Figure 8: Prof Krzysztof Kulpa, Scientific Director of the Centre for Position Organisation in Scientific Research Defence and Security Technology at Warsaw University of Technology

Prof Kulpa is the Scientific Director of the Centre for Position Organization in Scientific Research Defence and Security Technology at Warsaw University of Technology. He has published more than 500 papers on radar technology – including more than 100 on passive radars – and has worked extensively with military experts to integrate passive radars within command and control networks, and apply them to the modern battlefield. Prof Kulpa has worked with the STO since 1999 and has led several Research Task Groups and Lecture Series, primarily in the SET Panel. He has won the SET Panel Excellence Award four times, and has demonstrated exemplary commitment, professionalism and expertise over the course of more than 20 years with the STO.

2023 STO EXCELLENCE AWARDS

The STO Excellence Awards recognise exceptional accomplishments in STO activities that were conducted and completed within the preceding four years, and can be granted to both teams and individuals. In 2023, the STB granted the STO Excellence Awards to Dr Paramsothy Jayakumar of the United States for his work on the modelling and simulation of mobility and vehicle dynamics, and to an international research group focused on high-energy laser weapons.

Figure 9: Dr Paramsothy Jayakumar, Senior Technical Expert at the US Army DEVCOM Ground Vehicle Systems Centre.

Dr Jayakumar is a recognised leader in the modelling and simulation of mobility and vehicle dynamics within the STO and the US Department of Defense. Over the course of his career, he has developed methods and tools that enable mobility performance assessments for current and future military ground systems. He currently works as a Senior Technical Expert at the US Army DEVCOM Ground Vehicle Systems Centre.

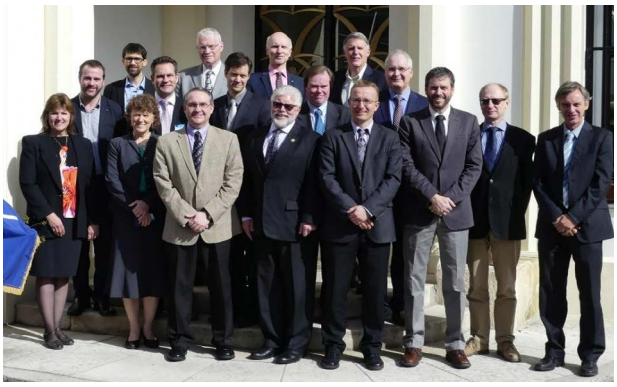


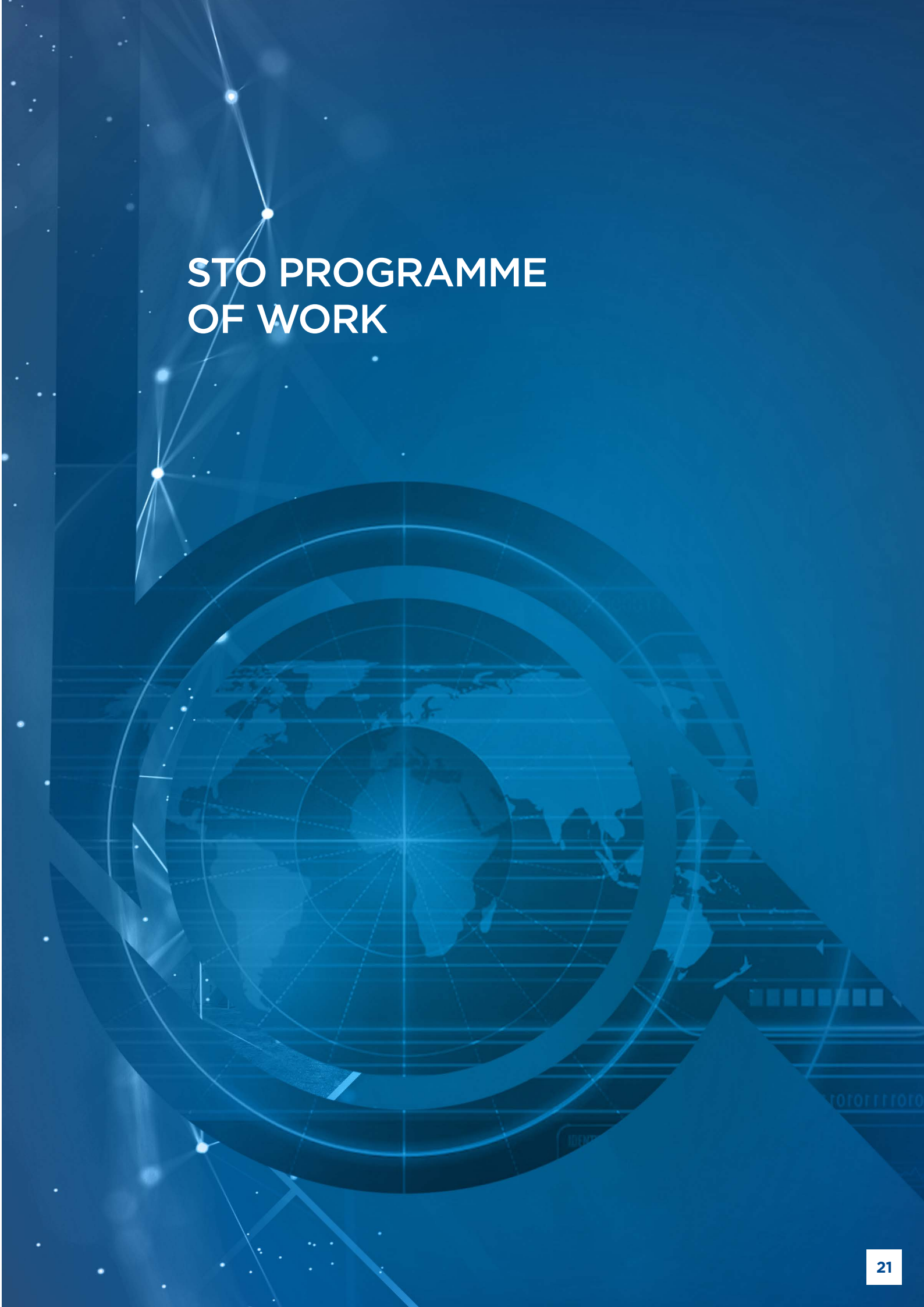
Figure 10: Members of the SCI-264 Research Task Group at the STO Collaboration Support Office in Neuilly-sur-Seine, France.

Between 2015 and 2022, Dr Jayakumar served as the co-chair of two Exploratory Teams formed under the AVT Panel, three AVT Research Task Groups, and two AVT Cooperative Demonstrations of Technology. He led teams that developed the Next-Generation NATO Reference Mobility Model (NGNRMM), which provides enhanced mobility prediction to support operational planning, vehicle design and acquisition. Two demonstrations of this model were held in 2018 and 2022, and it has been documented as a NATO Standardization Recommendation (STANREC 4813) as well as the corresponding NATO Standard AMSP-06

The STB also granted an STO Excellence Award to a Research Task Group (RTG) formed under the SCI Panel, in recognition of their work on the integration of high-energy laser (HEL) weapons in future coalition operations. The team (SCI-264) considered the impacts that the introduction of HEL weapons would have on the shared battlespace, and was the first STO research group to conduct joint testing of reflections from targets engaged by HEL weapons in realistic conditions.

From 2014 to 2018, the team carried out an assessment of the kill chain for HEL systems and developed an “HEL 101” briefing that NATO Nations can use to educate technical and operational staff. They also shared a large dataset that provided the basis for ongoing follow-on analysis. Together, these products have helped to improve Nations’ understanding of HEL safety hazards and impacts on interoperability. The Netherlands initiated a laser weapon programme following the release of the team’s report, and credited SCI-264 for helping to inform the decisions of leadership.

STO PROGRAMME OF WORK



STO Programme of Work

PROACTIVE

SENSING MODALITIES, ROBOTICS AND OPERATIONS RESEARCH FOR AUTONOMOUS ANTI-SUBMARINE WARFARE (AASW SAC000E01- E02)

The STO CMRE plays an active role in assessing EDTs and their impact on defence and military capabilities. The Centre's Autonomous Anti-Submarine Warfare (AASW) programme comprises the fields of advanced ASW sensing (including quantum), autonomous systems, underwater acoustics and operational analysis, supported by a dedicated sea-going capability, which enables cutting-edge maritime research in challenging conditions from the Arctic to the Mediterranean Sea.

Mr Robert Been, Dr Alessandra Tesei, Mr Chris Strode, Dr G. Ferri, Dr P. Stinco, Dr B. Akbulut, Mr Stefano Biagini, Mr Alberto Grati, STO CMRE

BACKGROUND

The CMRE began investigating unmanned systems technology in the early 2000s. In the field of ASW, this work focuses on complementing conventional capabilities to increase overall performance. Unmanned systems have also gained importance in the threat space, and both threats and capabilities are expected to evolve in the coming years. This is why Allied Command Transformation (ACT), the CMRE's major customer, invests in pioneering S&T for unmanned systems. Going forward, EDTs such as advanced sensing, autonomy (robotics) and AI, as well as operations research (OR) and operations analysis (OA), will become permanent features in future military operations.

MILITARY RELEVANCE

In a NATO operational context, it is paramount that future unmanned (autonomous) sensing systems remain under appropriate human control. The AASW team's work on autonomous sensing systems therefore runs in parallel with CMRE work in the field of command and control (C2), tasking and interoperability, which are integrated with the NATO standardization initiative STANAG 4817 and the STO SCI-343 Task Group on the Collaborative Autonomy Tasking Language (CATL). Given that the approach to unmanned technology will differ across Nations, deploying such systems in coalition operations will require NATO commanders to understand their field performance and effects on planning and C2. Creating standards, together with applying OR and OA, will help commanders to incorporate such systems effectively and efficiently in their planning and execution processes.

OBJECTIVE(S)

The main goals of the AASW activity were: the exploration of new sensing techniques documented in comprehensive technical reports and peer-reviewed publications; the production of a prototype OR framework for the optimal deployment of maritime unmanned systems (MUS) for ASW; and experimentation using MUS for ASW in operationally relevant environments.

S&T ACHIEVEMENTS

In 2023, the AASW programme's sea-going activities included a sea trial in northern Norway (June), and experiments in the Mediterranean near Elba (October). The Coherent Localisation Detection (COLD23) trial, conducted from 5 to 16 June in northern Norway, explored and exploited innovative low-frequency passive sea bottom sensing nodes for ASW in a planar, sparse configuration, and investigated space and time coherence among these sensors. Extending the nodes' capability towards the infrasound region offers the potential to detect energy emitted by targets of interest that propagates either through the water column or the water-sediment interface, possibly extending the detection range. In addition, having three sensing modes (acoustic vector sensors, compact volumetric arrays and geophones) available in an overlapping frequency band offers both redundancy and possibilities for coherent processing. These powerful capabilities highlight the potential of heterogeneous sea bottom sensing nodes for ASW scenarios that include autonomous remote monitoring of water spaces of interest.

The MED-ASWAN23 campaign, conducted near Elba from 13 to 29 October, incorporated mobile robots on the assets list, addressing heterogeneous robot collaboration using behaviour trees for the first time. Such collaboration is revolutionary in the underwater domain, as it enables the dynamic, in-situ reallocation of assets to ASW missions. Multiple full reports and peer-reviewed articles have been produced from this work.

The project Sensing Modalities, Robotics and Operations Research for Autonomous Anti-Submarine Warfare (AASW SAC000E01- E02) is funded by Allied Command Transformation (ACT).

An optimization framework was developed to allow for the future planning of heterogeneous unmanned ASW missions, whether for barriers or area search. This allows for the investigation of solutions employing a wide variety of platform types (including manned), in addition to those that the CMRE tested. Analysis of optimal solutions for candidate platform configurations provides valuable insights into future deployment strategies and tactics. The framework can account for platform performance, endurance and recharge requirements, system of system approaches, and logistic requirements.

SYNERGIES AND COMPLEMENTARITIES

Several Nations and two NATO bodies participated in the work of the AASW team. This diverse group contributed to the activity's success and to the high quality of its results. Synergies with STO activities were optimized, primarily with the SCI and IST activities.

EXPLOITATION AND IMPACT

The outcomes of AASW will contribute to NATO's defence planning priorities by leveraging advanced and cutting-edge technologies in order to maintain the Alliance's military advantage.

CONCLUSION(S)

In addition to advancing their research and producing publications in their field, the AASW team collected very rich and unique data sets in the Arctic and Mediterranean areas in 2023, which will inform multinational research in an area of strategic importance to the Alliance. The OR work further develops a planning framework to ensure that future unmanned deployments are conducted for optimal military effect. The exploitation and analysis of solutions will allow for future platform requirements to be determined.

The project Sensing Modalities, Robotics and Operations Research for Autonomous Anti-Submarine Warfare (AASW SAC000E01- E02) is funded by Allied Command Transformation (ACT).

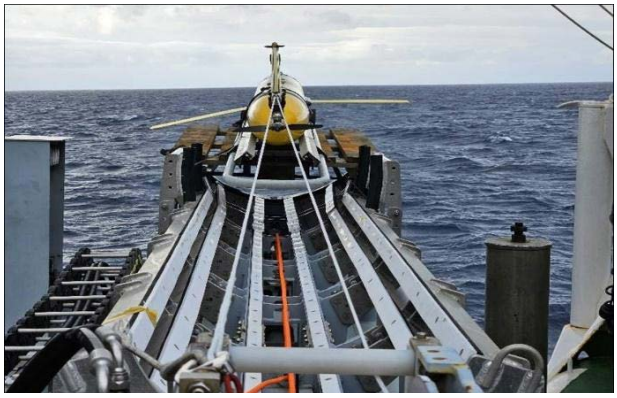


Figure 11: Underwater buoyancy glider equipped with an acoustic sensing, processing and communication capability prior to its launch from *NRV Alliance*.

IMPACT OF UNDERWATER DUMPED MUNITIONS AND MARITIME SAFETY, SECURITY AND SUSTAINABLE REMEDIATION (AVT-330)

This activity assessed the impact of munitions abandoned underwater, including effects on different environments. The approaches of NATO Nations were discussed and a NATO approach – including regular reassessments and coordination – was recommended to minimise various hazards.

Hon Prof Adam Cumming, School of Chemistry, University of Edinburgh
Mr Claus Boettcher, German Programme on Underwater Munitions

BACKGROUND

The handling and management of munitions and explosives of concern (MEC) underwater is an area in need of further study. NATO needs to be able to assess the impacts originating from MEC at sea, in estuaries, in rivers and in lakes. The methods for mitigating these impacts also need evaluation, with gaps identified. Multinational groups are developing new technologies that can be used to address NATO requirements. This offers an opportunity to work with groups outside of NATO, in order to gain the expertise and capabilities necessary for NATO to manage the impacts.

MILITARY RELEVANCE

Allied navies need to be able to efficiently mitigate the hazards produced by MEC. This requires greater understanding and harmonisation of practices inside NATO, which may lead to a STANAG.

OBJECTIVE(S)

The team's technical report assessed the current and prospective ability to handle MEC, as well as the risks associated with both dumped and recovered MEC. The updated capabilities included improvements to the common operational picture of the maritime area, including REA and Rapid Environmental Picture (REP) activities. This approach requires close links with other NATO bodies such as the CMRE and NATO Centres of Excellence (COE). These achievements have been reported and should lead to the development of a best practice handbook.

S&T ACHIEVEMENTS

Overall, the results form a solid foundation for tackling the problems associated with underwater MEC. The physical and chemical methods described in the report are being transferred into practice, though there are still unanswered questions regarding the introduction of environmentally friendly salvage.

SYNERGIES AND COMPLEMENTARITIES

Over the past decade, interdisciplinary scientific projects (both nationally and internationally funded) have described biological effects and have improved marine sensors and software in conjunction with MEC in marine and freshwater environments. A dedicated exchange on the most recent results is crucial for both sides to promote transfer of technology, develop a common operational picture, and find explanations for effects.

> *"Working to understand of the problems of sea dumped munitions and linking activities to help find solutions."* ***Prof Adam Cummings, 2023***

EXPLOITATION AND IMPACT

This work has increased NATO's expertise on handling MEC underwater in a range of aquatic environments. The achievements will affect NATO's overall ability to strategically approach the munition issue and to respond to *ad hoc* imminent threats originating from MEC.

CONCLUSION(S)

This activity made important advancements in understanding of the problems associated with underwater MEC and linking activities to help find solutions with clear recommendations for NATO.

Figure 12: A diver examining munitions underwater.

SUPPORT PROJECTS ON TURBULENCE AND THE AERODYNAMIC OPTIMIZATION OF NONPLANAR LIFTING SYSTEMS (AVT-SP-002) AND EVALUATION OF HYBRID ELECTRIC PROPULSION TECHNOLOGIES FOR UNMANNED AERIAL VEHICLES IN MILITARY APPLICATIONS (AVT-SP-009)

These projects explored the potential for hybrid-electric propulsion systems (HEPS) to make unmanned aerial vehicles (UAVs) cleaner and more energy efficient. They were carried out under the STO Support Programme, which contributes to NATO's capability development.

Prof Dr Melike Nikbay, Faculty of Aeronoautics and Astronautics, Istanbul Technical University (SP-002)
Prof Konstantinos Kontis, Aerospace Sciences Division, University of Glasgow (SP-002),
Prof Afzal Suleman, Department of Mechanical Engineering, University of Victoria (SP-009)
Ms Anna Mazur, Lukasiewicz Research Network – Institute of Aviation (SP-009)

BACKGROUND

In light of rising environmental concerns, there is a need to make UAVs cleaner and more energy efficient. This can be achieved by hybrid-electric propulsion, which was explored in the SP-009 and SP-002 projects.

MILITARY RELEVANCE

Hybrid-electric propulsion increases the manoeuvrability of military vehicles, which is advantageous for war fighters.

OBJECTIVE(S)

The support projects studied the potential of hybrid-electric propulsion systems to maximise fuel efficiency, reduce emissions, and reduce operational noise. Further advantages of HEPS include distributed propulsion and vertical take-off and landing (VTOL). For sensitive measurement equipment carriage, it is important to minimise on-board vibration, lower acoustic signatures, and reduce exhaust thermal signatures. To this end, a simulation environment will be developed to quantify HEPS at component and system levels, mission scenarios will be developed to optimize the performance of the system, and experimental methods will be implemented to quantify performance and devise new modes of operation.

S&T ACHIEVEMENTS

The teams developed methods to test parallel hybrid systems, as well as a custom data generator for validation. This was used to build and test a fixed wing UAV with hybrid-electric propulsion that can operate in four different modes: electrical mode, combustion mode, hybrid mode prioritising the electric motor, and hybrid mode prioritising the combustion engine. A new multirotor for hybrid-electric propulsion testing was also built. With this platform, HEPS tests were carried out with a new hydrogen fuel cell. Six master theses, two journal papers, and four conference papers were written based on this project, and approximately 20 students were trained, including a member of the Portuguese Air Force. The technology will be demonstrated at the AVT Panel Business Meeting in spring 2024.

SYNERGIES AND COMPLEMENTARITIES

Project participants learned from each other's experiences in flight testing and expertise, particularly during team visits.

> *"Team visits, which are made possible by the STO Support Programme, will enable the team to fully engage in the partner's activities."*
> ***Prof Dr Melike Nikbay, 2023***

EXPLOITATION AND IMPACT

These projects made significant contributions to future military materiel. Stealthier, more energy efficient materials create less noise and are capable of carrying more sensitive measurement equipment, due to lower on-board vibration, lower acoustic signatures and smaller thermal exhaust signatures.

CONCLUSION(S)

This work delivered notable achievements that are relevant to military operators, especially with regard to military materiel. Experts from universities and research institutes worked together, exchanged information, and provided facilities to test and validate the results.

EXPLOITATION AND IMPACT

The anticipated audience for this project is generally broad, including NATO officials, NATO Member civilian and military leadership, academics, private sector decision makers, and security analysts. Results of this work will ultimately be delivered to decision makers and policy specialists in NATO Members and partners. An interim preliminary findings report was published prior to the 2022 NATO Summit, focusing on the strategic implications of energy security within the context of hybrid warfare.

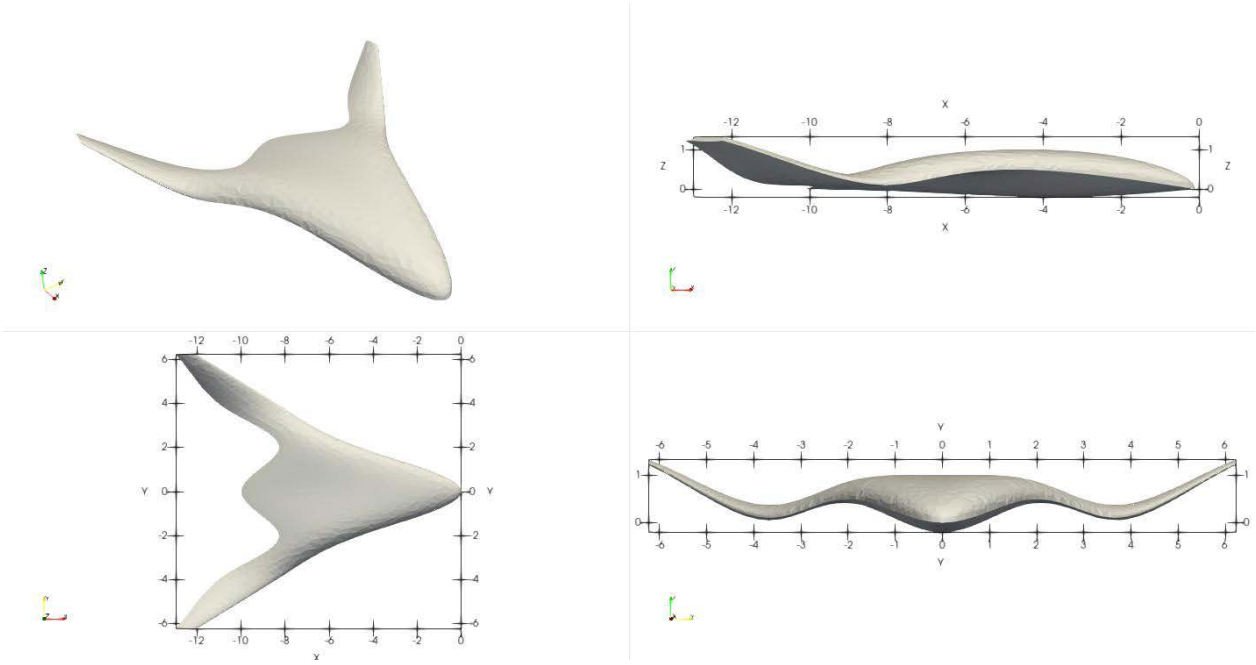


Figure 13: The fixed wing UAV model used for aerodynamic optimization testing. Istanbul Technical University.

CLIMATE CHANGE AND SECURITY (CC&S) (OCS000E58)

The new Climate Change and Security (CC&S) S&T programme aims to provide NATO with the scientific support it needs to become the leading international organisation on understanding and adapting to the impact of climate change on security. In addition to launching several projects in the CC&S field, the programme made significant achievements, including the establishment of the NATO Arctic Climate undersea Observatory (NACO), the creation of a solid community of interest through the CC&S Workshop, and the deployment of a framework for the exploitation of large climate datasets in an accredited cloud environment.

Mr Aniello Russo, Dr Sandro Carniel, NATO STO CMRE

BACKGROUND

NATO's 2022 Strategic Concept calls for NATO to become the leading international organisation on understanding and adapting to the impact of climate change on security. In 2023, the OCS commissioned the CMRE to conduct research in the CC&S field.

MILITARY RELEVANCE

Climate change is a threat multiplier that affects NATO's security, operations and missions. It makes it harder for militaries to carry out their tasks, as it affects the current and future operating environment. Awareness of, and adaptation to, future climate change impacts are key to preserving NATO's deterrence and defence posture.

OBJECTIVE(S)

In 2023, the CC&S programme aimed to establish the NACO, deploy a cloud-based framework for climate data exploitation, and analyse climate change impacts in the maritime domain.

S&T ACHIEVEMENTS

The CMRE initiated research on the impacts of climate change on naval infrastructure and capabilities. The CMRE focused on the Arctic climate hot spot, conducting sea trials to monitor the long-term evolution of oceanographic properties and acoustic ambient noise in the Fram Strait and the northern Norwegian Sea. To overcome the challenges of accessing, retrieving, analysing and visualizing large climate datasets and projections, the CMRE developed an innovative framework deployed for CC&S data exchange in the NATO Software Factory Cloud. This will make it easier to carry out tailored analyses and share results.

> *"NATO is determined to set the gold standard on addressing the security implications of climate change."* ***NATO Secretary General Jens Stoltenberg***

SYNERGIES AND COMPLEMENTARITIES

Institutions and scientists from several Nations collaborate on CC&S research activities. The CC&S Programme led and contributed to a series of workshops aimed at defining the scientific programme of the new CC&S Centre of Excellence (CCASCOE). Synergies have also been established with STO CPoW activities and with other NATO Enterprise CC&S stakeholders.

EXPLOITATION AND IMPACT

CC&S research activities in 2023 resulted in scientific publications and major outreach events such as the CC&S Workshop[1] held in Lerici, Italy from 3 to 5 October. An increasing amount of valuable information will be produced and assembled, and will contribute to key NATO reports and major CC&S initiatives across the NATO Enterprise. For example, the manifold impacts of climate change on ASW, and on sonar performance in particular, are being assessed. Early results indicate that by the middle of the century, underwater sound speed might lead to a drastic decrease of submarine detection ranges in certain areas of NATO interest, with other areas showing minor changes.

1 www.climatechangesecurity.org

CONCLUSION(S)

In its first year of activity, the CC&S programme initiated a wide range of S&T research, and played a key role in creating a dedicated COE. By collaborating with world-class institutions and leveraging the expertise of different NATO stakeholders, the CC&S programme helps to strengthen NATO's ability to understand, anticipate and respond to climate-related security risks.

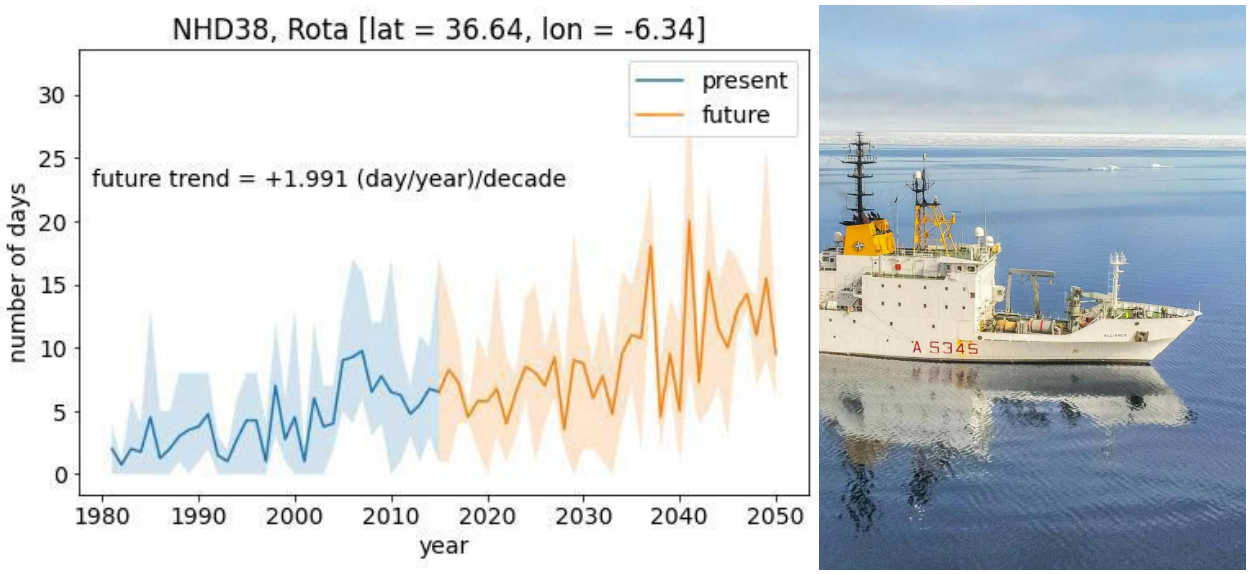


Figure 14: Evolution of the number of hot days (defined in this example as air temperature higher of 38 °C) in the area of Rota (Spain) naval helicopter base, according to an ensemble of four high-resolution climate models under climate scenario SSP585; with air temperature above 38 °C, the lifting capacity and consequently the payload of medium/heavy naval helicopters is progressively reduced (above 40 °C take-off might even not be possible at all).

NRV Alliance conducting research near the sea ice edge in the central Fram Strait during NREP23/ACO23 sea trials (June–July 2023).

SEXUAL VIOLENCE IN MILITARY (HFM-295)

Sexual harassment and violence affect unit cohesion, morale and operational effectiveness. They are destructive to the victims and damaging for organisations that do not address this insidious behaviour. This activity developed culturally sensitive ways of defining and identifying sexual harassment and violence, and made suggestions for more targeted training.

Dr Sanela Dursun, Director General Military Personnel Research and Analysis, Department of National Defence

Prof. Matt Fossey, Director, Veterans and Families Institute for Military Social Research, Co-Director, Center for Military Women's Research, Anglia Ruskin University

BACKGROUND

Sexualised behaviours are a pervasive problem in many NATO militaries, despite numerous initiatives to end them.

MILITARY RELEVANCE

Sexual violence and harassment have a negative impact on unit morale, cohesion and operational readiness. They also negatively affect individual physical and mental health, leading in some cases to post-traumatic stress disorder (PTSD) and even suicide. These behaviours may also have a negative impact on retention and recruitment at a time when many militaries are struggling in these areas.

OBJECTIVE(S)

This activity aimed to investigate the approaches taken by different NATO militaries, and gain a common understanding of the mechanisms and challenges involved in eradicating sexual harassment and violence within the military. It also sought to provide the command structure with the tools to address and minimise the problem, thereby improving effectiveness and operational readiness.

S&T ACHIEVEMENTS

The team reviewed and contrasted various approaches to address sexual harassment and violence among contributing Nations, including the legal and punitive approaches taken by different militaries and civilian justice systems. The team produced up-to-date definitions of sexual harassment and violence for the NATO community, and developed and validated a culturally sensitive survey instrument to assist NATO militaries in assessing and tracking the prevalence and impact of such behaviours. This instrument has been translated into seven NATO languages. The team also suggested approaches to training, including the use of scenarios to stimulate discussion and action.

SYNERGIES AND COMPLEMENTARITIES

Academics, psychologists, policy makers and service personnel from seven Nations contributed to the work of this activity. The team drew on the expertise, backgrounds, and cultural insights from the members and their respective countries.

EXPLOITATION AND IMPACT

In addition to the NATO technical report, the team is producing a number of academic papers exploring the range of issues that have emerged from its research. The team has written to NATO leaders to integrate its definitions of sexual harassment and violence into NATO policies and frameworks alongside the validated survey instrument.

In December 2023, the team reported on its findings at an international conference on military sexual violence, held in Cambridge, United Kingdom. Its workplace sexual violence and harassment survey is also being adapted and piloted for use in university settings, where many of the issues are similar to those experienced within the military.

> *"Sexual exploitation and abuse runs counter to NATO's principles and core values, and undermines the effectiveness and credibility of the Alliance and risk mission success."* ***NATO Policy on Preventing and Responding to Sexual Exploitation and Abuse, 20 November 2019***

CONCLUSION(S)

Sexual violence and harassment have no place in NATO militaries. This team's work will contribute significantly to the understanding and eradication of these serious and damaging behaviours. The insights, tools and recommendations produced by this work will be critical in helping the NATO community to achieve this goal.

5G TECHNOLOGIES APPLICATIONS TO NATO OPERATIONS (IST-187)

The operationalization of civilian 5G standards has the potential to revolutionize wireless communications through a quantum leap in performance. This RTG aims to investigate and determine the applicability of 5G technologies for military operations, particularly in a federated environment. The RTG also aims to identify existing gaps of 5G and deliver recommendations on additional security protocols that need to be considered.

The operationalization of civilian 5G standards has the potential to revolutionize wireless communications. As 5G is primarily designed for civilian uses, this activity is focused on the application of 5G technologies for NATO operations. The group has worked to study, experiment and validate its findings, and has engaged with a number of stakeholders (including FMN and ACT) to inform the Alliance on the potential of the technologies and to move towards implementation.

Mr Warren Low, ACT; Mr Souradip Saha Fraunhofer FKIE

BACKGROUND

5G holds the promise for anytime, anywhere and interoperable connectivity for both static and deployed forces. The large increase in bandwidth and capacity to conduct processing at the "edge" will enable forward-deployed forces to exchange and exploit multimedia video streams, use virtual and augmented reality capabilities, and leverage AI applications. With the rise of military internet-of-things, 5G will also be able to connect a massive number of sensors and to control machines such as drones through low-latency communications.

OBJECTIVE(S)

In order to better advise NATO on the aforementioned technologies, the activity aims to develop military scenarios that are likely to benefit from this 5G capability; perform technology analysis on the radio access network, extreme coverage, continuous computing and security aspects, and provide recommendations on how NATO can apply those technologies within military scenarios; and track and follow 5G standardization and introduce any requirements, if appropriate.

S&T ACHIEVEMENTS

The RTG provided a greater understanding of the military utility of 5G technologies through analysis, demonstrations, experimentation, and development of the human capital within NATO and Nations. The work contributed to several publications in scientific journals, including: "Jamming and Jamming Mitigation for Selected 5G Military Scenarios" (2022); "Sustainment of Military Operations by 5G and Cloud/Edge Technologies" AINA CCPI 2023; and "DOTMFLPI Analysis of 5G for Several Military Use Cases" (2023). The RTG was also represented in two ACT 5G technology events in 2022 and 2023.

SYNERGIES AND COMPLEMENTARITIES

Thirteen nations and three NATO bodies participated in this RTG. The team also engaged with FMN Tactical Edge Syndicate, ACT Capability Developers and NATO Maritime Services, as well as Combined Joint Operations from the Sea COE to disseminate the research and receive feedback. It developed synergies with other NATO groups including IST-ET-126 (6G Telecommunications), IST-220 (NATO Wireless Communications Standards Project) and IST-161 (Efficient group and information centric communications in mobile military heterogeneous networks).

EXPLOITATION AND IMPACT

Initial results were briefed at the NATO C3 Board and the NATO TIDE Sprint in 2023, and initial requirements have been incorporated into ACT capability delivery activities. The RTG also provided input to the NATO C3 Board's NATO Vision and Strategy for 5G.

CONCLUSIONS

The work of this RTG will improve understanding of 5G technology for military scenarios and deliver insights in underlying specifications for 5G solutions and required improvements in 5G standardization. A number of other initiatives have been made possible by the team's scientific conclusions, professional contacts and results from demonstrations. The members have also formed other teams to support investigation of the technologies within the framework of the European Defence Fund. A knowledgeable group of practitioners in this area will serve NATO and Nations for many years to come.

EXPLORATORY VISUAL ANALYTICS (IST-141)

The ever-growing volumes of big, complex, and ubiquitously available data cannot be exploited using conventional approaches. This activity leveraged visualization and visual analytics, together with human factor methods, to make it possible to explore, analyse, understand and exploit such data for acute situation awareness, thereby supporting informed decision-making.

Dr Margaret Varga, University of Oxford/Seetru Ltd.

BACKGROUND

Information superiority is key to military dominance, and NATO's cognitive superiority relies on the exploitation of all relevant information from multiple sources. The challenge, however, is to exploit effectively vast volumes of heterogeneous data.

MILITARY RELEVANCE

Visual analytics is the science of analytical reasoning facilitated by interactive visual interfaces[2]. It provides decision-makers with effective and efficient means of understanding and analysing massive volumes of invaluable data. Visualization and analytics research are therefore essential in addressing the objectives of the 2015 NATO S&T Priorities Targets of Emphasis in Information Analysis and Decision Support: IA&DS-1 on Decision Support, and IA&DS-2 on Big Data and Long Data Processing and Analysis.

OBJECTIVES

This activity aimed to explore how visualization conveys information effectively by leveraging human perception and enhancing human cognition (i.e. bringing together visual analytics technology and the user's mental model through user-centred design). The team researched, developed and applied exploratory visual analytics techniques to:

- exploit and make sense of large and complex data sets;
- help make tacit knowledge explicit;
- develop tools/systems that are both useful and usable (the Liggett's U^2 rule[3]);
- provide acute situation awareness; and
- support informed decision-making across a wide range of defence application domains including cyber, maritime, data from simulation procedures, improvised explosive device (IED) incidents, social media, and genomic domains.

> *"The simple act of visualizing data can change your perspective and decision-making process."* ***Edward Tufte***

The team also explored storytelling techniques as a means of reporting findings from the analysis.

S&T ACHIEVEMENTS

IST-141 undertook scientific and technological research addressing the above domains and demonstrated the effectiveness of the techniques. In addition, the team facilitated the interest in, as well as the uptake and exploitation of, visual analytics technologies within and beyond NATO through:

- organising the Cyber Symbiology Specialists' Meeting (IST-HFM-154), and the inter-Panel and inter-Group workshop (IST-178: Big Data Challenges: Situation Awareness and Decision Support);
- lecturing on two NATO Cyber Security Science and Engineering Lecture Series (IST-143 and IST-170) in eight different countries;
- participating in NATO CSO activities organised by others and participating in joint meetings with RTGs from HFM, IST and SAS; and
- presenting at many prestigious international conferences, workshops and seminars such as IEEE VIS. Overall, the team generated 32 publications.

SYNERGIES AND COMPLEMENTARITIES

Representatives of nine nations (CAN, DEU, EST, FRA, GBR, LTU, SWE, TUR USA) and the CMRE participated in IST-141. This collaboration generated new ideas, tools and data that were shared among the participants. Monthly video conferences helped to foster the collaboration, which was key to the team's success.

2 Thomas, J.J. and Cook, K.A. (Eds.) (2005). Illuminating the Path: The Research and Development Agenda for Visual Analytics. National Visualization and Analytics Centre.

3 Dr Kristen Leggitt, Air Force Research Laboratory, Airman Systems Directorate, USA, a member of the group.

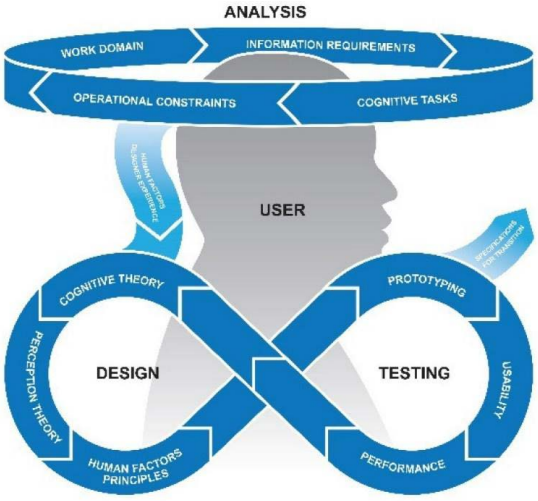


Figure 15: User-centred design

EXPLOITATION AND IMPACT

IST-141 demonstrated the benefits of exploratory visual analytics across a wide range of domains relevant to all NATO Nations and partner countries for use in situation awareness and informed decision-making. The Cyber Security Science and Engineering Lecture Series (IST-143 and IST-170) raised awareness of related challenges and technologies in the cyber domain.

CONCLUSIONS

IST-141 demonstrated the effectiveness of its interactive visual analytics and storytelling approaches for knowledge discovery and gaining insight (i.e. situation awareness) to support informed decision-making.

Figure 16: An interactive storytelling system providing information on IED incidents using visual analytics techniques. (http://nato-project.github.io)

FAMOS - FRAMEWORK FOR AVIONICS MISSION SYSTEMS (SCI-307)

Effective collaboration between NATO partners is critical to delivering battle-winning capabilities. Modularity and open systems architectures (OSA) have been identified as fundamental to partnering and rapid upgrades. This activity was established to develop a way forward in ensuring that the national approaches to OSA can be applied consistently to enable pan-NATO collaboration and bolster military capabilities.

Mr Mike Lane, Dstl, UK Ministry of Defence

BACKGROUND

Increased demand on avionics capability, together with the need for rapid upgrades and effective collaboration between NATO partners, are well understood. The approach to mission systems design has traditionally been bespoke to individual projects, and not optimized for partnering. The SCI-033 Exploratory Team was established to investigate the problem space, and found that as NATO partners worked on national solutions, there was a risk that their approaches would continue to diverge. SCI-307, the Framework for Avionics MissiOn Systems (FAMOS), was therefore established to consider how these approaches could be applied consistently to enable greater collaboration and interoperability.

MILITARY RELEVANCE

Figure 17: The FAMOS logo (produced by FAMOS team)

Mission systems are becoming increasingly complex, with almost all military capability delivered by software. In addition, military leaders face an operational environment that demands rapid reactions to a range of threats, from state actors to small, non-state terrorist networks. To enable greater flexibility, some NATO Nations are now pursuing programmes to enable an open systems software approach. While this may enable individual Nations to realise the benefits of an open system approach, the benefits will not be optimised if these approaches diverge.

OBJECTIVE(S)

FAMOS was initiated to investigate and deliver clear recommendations on how to consistently apply OSA for mission systems in order to achieve enhanced collaboration, rapid adaptability, a wider base of suppliers, and joint programmes and capability exchange.

> *"We don't get to decide anymore what good enough looks like. If our adversaries adapt faster, they're better at software delivery than we are, then our capability will fall behind and we will lose."* ***Air Chief Marshal Sir Rich Knighton, Modular Open Systems Approach (MOSA) Summit in Atlanta, GA, USA, September 2023***

S&T ACHIEVEMENTS

The scope of the problem space, and indeed the national initiatives, is vast. Through a process of technical review and analysis, the FAMOS team identified clear recommendations including the creation of Allied publications to ease adoption, and to initiate a STANREC to articulate guidance on how to apply the standards.

SYNERGIES AND COMPLEMENTARITIES

Eight Nations supported FAMOS, and engaged with the Avionic Systems Working Group (AVSWG), SCI-260, AVT-245, and AVT-ET-178. Outputs from major national initiatives were directly fed into the work.

EXPLOITATION AND IMPACT

The recommendations are being implemented and will directly enable effective collaboration between partners, paving the way to international programmes and rapid capability insertion, where and when required, to maintain operational effectiveness against NATO's adversaries.

CONCLUSION(S)

The problem space was well understood prior to this work, but the solution was not. The team drew on significant S&T initiatives from NATO partners and technical experts, as well as the experience of acquisition programmes and military and business drivers, to develop clear recommendations that are already being implemented. From this perspective, the work has been a major breakthrough against one of NATO's highest profile technical problems.

INTEROPERABILITY AND NETWORKING OF DISPARATE SENSORS AND PLATFORMS FOR TACTICAL ISR APPLICATIONS (SET-256)

This activity set out to achieve coalition interoperability of widely disparate tactical intelligence, surveillance and reconnaissance (ISR) sensors from different Nations. It also aimed to develop interoperability standards and demonstrate middleware for ease of integration and interoperability of the ISR assets to increase military effectiveness and support burden sharing.

Ms Susan Toth, United States Army Research Laboratory

BACKGROUND

NATO forces today cannot effectively leverage available disparate mobile and fixed ISR assets from coalition partners during coalition ground operations. Coalition partners must provide all the ISR assets they need respectively, which creates significantly increased costs in logistics, sustainment and required personnel.

MILITARY RELEVANCE

Using critical infrastructure protection as the scene for the experimentation, SET-256 conducted a capstone experiment in September 2021 in Portsmouth, United Kingdom to address the interoperability problem. Four Nations participated in the trial.

OBJECTIVE(S)

The experiment aimed to:

- flow relevant information from any sensor integrated into the processing, exploitation and dissemination (PED) system to decision-makers through a single PED/C2 node regardless of the Nation owning the sensors or the PED systems;
- have a single PED/C2 node control sensor within the system regardless of the Nation owning the sensors or the PED systems;
- filter and fuse information so that decision-makers only receive relevant information; and
- report in NATO standard formats regardless of native format.

S&T ACHIEVEMENTS

The team proved each hypothesis during the experiment, and successfully integrated sensors using three separate middle wares running simultaneously on sensors: communication to Canada via Open Standards for Unattended Sensors (OSUS), the UK via its SAPIENT protocol, and NATO via the draft STANAG 4789. SET-256 also successfully tested the draft STANAG 4789 and was able to publish MASINT Reps (STANAG 4716).

SYNERGIES AND COMPLEMENTARITIES

Three workshops were conducted leading up to the live experimentation. These included "Sensor and Component Integration using OSUS," conducted in April 2018 at the French-German Research Institute of Saint-Louis (ISL); "SAPIENT Architecture and Integration," conducted In January 2020 at the Defence Science and Technology Laboratory (Dstl) in Salisbury, United Kingdom; and "Wisdom Introduction and Hands-on Training," conducted virtually in April and May 2021, and hosted by Defence Research and Development Canada (DRDC). The UK provided the network architecture, facilities, personnel and trials management.

EXPLOITATION AND IMPACT

The team's work had an enduring impact, as the UK's SAPIENT architecture was adopted as a British Standard (BS FLEX 335 V1.0). Experimentation also raised new questions that were beyond sensor integration. Sensor tasking needs to include the context for the tasking, and common protocol language must be more robust. Achieving this would require moving away from an imagery-centric approach to allow

the use of all sensor modalities. NATO needs to investigate standards on multi-modal and smart sensors, and a common standard for raw data information is needed (draft STANAG 4789 goes a long way towards doing this). One obstacle to true interoperability is trust: how can we increase trust between multinational systems so that users can trust the tasking and data output? Part of the interoperability solution is policy driven, as well (e.g. "What can Nations share with other Nations directly? Data? Asset control? Distributed processing, tasking and workload?"). This can be addressed through a standing Concept of Operations for sensor interoperability.

> *"SET-256's experiment successfully addressed the challenge of sensor interoperability, while also raising new questions that follow-on SET or IST activities could address."* ***Susan Toth, 2023***

CONCLUSION(S)

SET-256's experiment successfully addressed the challenge of sensor interoperability, while also raising new questions that follow-on SET or IST activities could address.

Figure 18: The SET 256 technical team.

10TH MILITARY SENSING SYMPOSIUM (MSS) (SET-311)

The 10th Military Sensing Symposium (SET-311) took place at the Institute of Engineering and Technology (IET) in Savoy Place, London from 19–21 April 2023. It was hosted by the UK MoD's Defence Science and Technology Laboratory (Dstl) and co-chaired by Dr Ken McEwan and Dr Peter Harvey. The programme included seven keynote speakers, including the NATO Chief Scientist, and over 100 technical presentations split into three parallel tracks of four sessions each. The event attracted 245 participants from 20 nations, as well as representatives from academia, industry and other NATO bodies.

Dr Ken McEwan and Dr Peter Harvey, Defence Science and Technology Laboratory (Dstl)

BACKGROUND

The keynote speakers delivered informative briefings on both future S&T policy and strategy (e.g. NATO S&T trends, emerging security challenges, US chemical and biological challenges, and S&T for electromagnetic superiority) as well as key emerging technology areas (e.g. quantum, AI and reactive ISR). The contributed papers covered technological developments in both well-established sensing modalities (EO/IR, radar, RF sensing, LIDAR, acoustic and CBRNE) as well as emerging areas (e.g. quantum sensing). The symposium also encompassed advances in sensor management, sensor data exploitation and automatic target recognition.

> *"I suggest that new technology will give future military capabilities for our changing deterrence and defence four overarching characteristics, namely that they will be increasingly intelligent, interconnected, distributed and digital."* ***Dr Bryan Wells, NATO Chief Scientist***

MILITARY RELEVANCE

Throughout the symposium, a number of common themes emerged on the future of military sensing in order to meet the challenges of complex/contested battlespaces, a contested electromagnetic spectrum, increasingly sophisticated countermeasures, the emergence of AI and the erosion of laws of conflict. The requirement was also established for distributed, layered, adaptive, intelligent and heterogeneous sensor networks that are resilient and scalable, and that incorporate both traditional sensing modalities and emerging techniques.

OBJECTIVE(S)

The NATO Military Sensing Symposium provides NATO and partner nations with a unique opportunity to determine the state-of-the-art of military sensing and, crucially, to identify emerging trends for S&T development to best meet the Alliance's future military requirements.

S&T ACHIEVEMENTS

The symposium delivered unique educational benefits for participants and participating nations. Very few events focus on military sensing and offer the opportunity to share knowledge at the NATO Restricted classified level. The event allowed participants to publish and present work to a NATO audience, and the proceedings stand as an enduring reference document on state-of-the-art military sensing technology.

SYNERGIES AND COMPLEMENTARITIES

The symposium was hosted by the SET Panel, and included participants from the NATO Industrial Advisory Group (NIAG), the NATO Modelling and Simulation Group (NMSG), and the IST and SCI communities.

EXPLOITATION AND IMPACT

Awards for best papers were announced in the categories of RF technology, optical technology and multi-sensors and electronics, as well as awards for best overall presentation and best presentation by an early-career scientist. All presentations and papers were of very high quality, and the participation of early-career scientists was an especially encouraging sign for the future of NATO military sensing.

Figure 19: The SET Panel Young Scientist Award given to Michele Maxson.

CONCLUSION

The 10th Military Sensing Symposium was a huge success, despite being the first to be held in six years. In order to keep pace with the rapidly changing technological and geopolitical landscape, future symposia must be held more regularly. Planning for the next symposium, to be hosted by the US, is already underway.

Figure 20: Coffee break during Symposia.

STO ENGAGEMENT IN ALLIED COMMAND TRANSFORMATION'S TIDESPRINT 42

The spring 2023 TIDE Sprint S&T Track brought together scientists and military operators to exchange on key topics, brainstorm with experts, expand communities of interest, and, in the longer term, contribute to improving the upfront interoperability between NATO Nations by developing a common S&T culture.

Mr Thomas Bloor, STO CSO

BACKGROUND

TIDE Sprint is one of ACT and NATO's premier events for promoting the innovation and evolution of concepts and specifications that advance federate interoperability between NATO and partner nations' C2 capabilities and IT services. TIDE Sprint addresses interoperability from a people, process and technology perspective by encouraging operators, engineers and scientists from national governments, militaries, industry and academia to exchange ideas on current and future solutions. The STO led a sub track of the 42nd TIDE Sprint, bringing together researchers from across the CPoW to network with operators.

MILITARY RELEVANCE

Bringing together operators and researchers led to several developments of relevance to Allied Nations, ranging from use case validation for deployment of 5G within military formations, to the use of viruses to combat bacterial infections in affected military personnel.

OBJECTIVE(S)

The S&T Track aimed to:

- inform attendees about the work that the NATO S&T community conducts on the workshop topics, and what the STO collaborative business model offers;
- leverage attendees' experience and knowledge to fuel NATO S&T reflections on workshop topics; and
- attract valuable contributors who could continue reflections after the workshops and participate in NATO S&T activities (and STO activities in particular).

S&T ACHIEVEMENTS

TIDESPRINT proved an opportunity for collaboration between operators and researchers, thereby helping to improve the quality of CPoW research activities. The event allowed researchers to gather use case feedback from operators, explained how new researchers can join the collaborative network via an S&T 101, and facilitated contacts between NATO entities (e.g. COEs) and research activities.

SYNERGIES AND COMPLEMENTARITIES

Experimentation between Air Command, COEs and various NATO exercises with STO activities were earmarked for further development, including cooperative demonstrations of technologies and prototypes.

EXPLOITATION AND IMPACT

At joint sessions with the Medical Track, it was agreed that STO scientists should be invited to observe Exercise VIGOROUS WARRIOR 24, and that a cross-cutting research activity for additive manufacturing in medical operations should be established. In the joint 5G and Maritime Services sessions, feedback on the 5G use case was shown to be key to implementing next-generation networks to support multi-domain operations. The joint DS&AI sessions focused on emerging optimization techniques for ISR asset planning, and identified the demand for automation and intelligence cycle modelling tools across NATO.

CONCLUSION(S)

TIDE Sprint successfully introduced CPoW researchers to new audiences. The STO reached more than 500 attendees in total, briefing across 17 different activities, and created 5 follow-up events and invitations for future collaboration.

MILITARY ASPECTS OF COUNTERING HYBRID WARFARE: EXPERIENCES, LESSONS, BEST PRACTICES (SAS-161)

This activity aimed to inform the full spectrum of military planning at the Alliance and national level. The RTG developed functionally oriented analysis and country-specific case studies that touch all aspects of military effectiveness, and help inform collective efforts to account for the challenges of current (and expected future) characteristics of competition, warfare and warfighting.

Col Viacheslav Semenenko (Co-Chair), AFU; Mr Neil Chuka (Co-Chair), Defence Research and Development Canada (DRDC), Centre for Operational Research and Analysis

BACKGROUND

The SAS-161 RTG, co-chaired by Ukraine and Canada, is the second SAS activity conducted in collaboration with Ukraine. The work consisted of two distinct research streams. The first investigated, from Ukraine's perspective, Russian aggression and Ukrainian institutional responses up to the full-scale invasion of February 2022. The second research stream, undertaken by the non-Ukrainian members of the RTG, developed national-, subject- or mission-specific case studies investigating Russian behaviours in varying contexts.

MILITARY RELEVANCE

The close study of contemporary conflict and adversary behaviour is a fundamental component of military learning, adaptation, and innovation. Comparative analysis of the experiences of Ukraine, Allies and partners in countering Russian aggression yields insights into Russian approach to competition, warfare and warfighting, as well as the strategies they employ to attain their goals.

OBJECTIVE(S)

The research and analysis focused on understanding the military implications of all facets of Russian hybrid approach, prioritising the use of primary sources and applying a net assessment mindset. The team aimed to contribute to the professional development and training of military and civilian planners and analysts at the operational and strategic levels by contributing to a deeper understanding of Russian behaviours, as well as the strengths and weaknesses of Allies and partners that inform adversary approaches.

> *"It is imperative that each threat is studied in a way that respects the context of adversary decision-making and the specifics of threat behaviours applied to each target. A net assessment mindset applied to threat-based planning will result in greater understanding of threats, strengths, vulnerabilities, and risk."*
> ***Mr Neil Chuka, 2023***

S&T ACHIEVEMENTS

Five volumes of analysis investigated Ukrainian defence adaptation and planning activities, and support from the Alliance, where relevant, up to the Russian invasion of February 2022. It also investigated Russia's use of information and influence activities and economic instruments of power, and Russian activities targeting NATO Nations, partners, and NATO missions. The final volume details the military implications of the RTG's work.

SYNERGIES AND COMPLEMENTARITIES

The work reinforces that the Alliance and Ukraine can learn from one another to their mutual benefit.

EXPLOITATION AND IMPACT

Since 2021, the Zagreb Security Forum (ZSF) has played a pivotal role in cementing relationships and the testing of preliminary results. The ZSF has also facilitated additional bilateral and multilateral follow-on activity between RTG members and forum participants. The RTG's work is directly relevant to the NATO ACT Warfare Development Agenda (WDA), Allied SOFCOM, and the NATO S&T Line of Effort to "enhance Alliance decision-making" and the S&T priority target of emphasis on "planning and managing uncertainties."

CONCLUSION(S)

The work of the RTG details the characteristics of contemporary Russian behaviour. Regardless of the outcome of Russia's war against Ukraine, it is unlikely that the Russian government's behaviour will improve. NATO should expect to see, and must consistently prepare for, the type of behaviours described in this work.

STO Programme of Work

RESPONSIVE

ENERGY SECURITY IN THE ERA OF HYBRID WARFARE (SAS-163)

NATO's military logistics and supply chain systems are challenged by the tyranny of distance, near peer adversaries, and a tight energy market. Moreover, the ability to leverage technology for geopolitical gain against an adversary's vulnerabilities, broadly referred to as hybrid warfare, has become increasingly prevalent in the 21st century. This activity focused on energy security, given that the energy sector is the most vulnerable and possesses the greatest potential for societal destabilization. This study also included concepts for mitigating the impact on civilian and military infrastructure, as well as outlining countermeasures available to NATO Nations.

Dr Arnold C. Dupuy, Naval Postgraduate School; Dr Daniel Nussbaum, Naval Postgraduate School; Dr Sarah Lohmann, Army War College; Prof Gabriel Raicu, Constanta Maritime University; Mr Vytautas Butrimas, NATO Energy Security Centre of Excellence; CDR Georgios Giannoulis, Hybrid Centre of Excellence

BACKGROUND

The term "hybrid warfare" has been used to depict an ambiguous yet pervasive threat to state sovereignty and civil society. As the war in Ukraine has demonstrated, the energy sector is an inviting target for any adversary. SAS-163 was formed to gain a deeper understanding of this threat and its broader impact on NATO's military preparedness, the infrastructural resilience of NATO Nations, and, ultimately, the coherence of the Alliance itself.

MILITARY RELEVANCE

This activity drew attention to the dependence of NATO's military activities on the civilian energy infrastructure, and the ability of state and non-state adversaries to negatively affect military operations through a hybrid warfare posture. Specifically, the energy supply chains of NATO Nations are vulnerable to a variety of kinetic or non-kinetic threats, which fall within the purview of hybrid warfare. As a stakeholder in international security, NATO has a vital role to play in the nexus between energy security and hybrid warfare.

OBJECTIVE(S)

This activity aimed to address the operational and technological nature of the threat and raise awareness of the energy-hybrid warfare nexus by understanding its component parts. It also sought to identify the broader impact of hybrid warfare in the civilian and military realms; and to define courses of action to mitigate the impact on civilian and military infrastructure and interests, and develop countermeasures.

S&T ACHIEVEMENTS

This work has raised strategic awareness of this topic within NATO's S&T community, as well as among NATO Nations and partners. This was accomplished through a series of workshops and lectures at conferences dedicated to the open exchange of ideas, as well as the use of methods and tools for operational analysis as applied to energy security and hybrid warfare. SAS-163 conducted both qualitative and quantitative analysis, case studies and table-top exercises in the course of events. The final report was delivered in December 2022.

SYNERGIES AND COMPLEMENTARITIES

This topic has resonated with many NATO Nations and Partnership for Peace (PfP) countries. Since beginning its work in 2020, SAS-163 made use of the data and outputs from the SAS-118 RTG on "Enhancing Strategic Awareness of Energy Security – a Holistic Approach." The SAS-163 organizing team also worked with members of the NATO S&T community, private sector subject matter experts, academic political science and security studies departments, and government/military entities. This includes organizations such as NATO's Emerging Security Challenges Division, the NATO Energy Security Centre of Excellence (ENSEC COE), the Cooperative Cyber Defence COE and the Hybrid Threats COE in Helsinki, as well as US-based institutions such as the Naval Postgraduate School and the Army War College.

EXPLOITATION AND IMPACT

The audience for SAS-163 ranges from NATO officials, Nations' civilian and military leadership, academics, private sector decision-makers, and security analysts. The results were delivered to decision-makers and policy specialists among the NATO Nations and partners. An interim preliminary findings report was published prior to the NATO Summit 2022, focusing on the strategic implications of energy security within the context of hybrid warfare.

> *"Critical energy infrastructure is an attractive target for any adversary."* ***SAS-163 RTG***

CONCLUSION(S)

NATO finds itself behind the front lines of a war that will provide both kinetic and non-kinetic challenges to its energy security. Russian hybrid warfare methods against NATO energy infrastructure will be a persistent threat, demanding a vigilant NATO response. NATO has taken positive steps to address both energy security and hybrid threats, including through the creation of organizations such as the Hybrid Challenges and Energy Security Section and the Energy Security Centre of Excellence. NATO will need to continue adapting to emerging and hybrid threats to energy critical infrastructure and energy security, which will require a continued emphasis on resilience, capability and interoperability.

AUTONOMOUS NAVAL MINE COUNTERMEASURES (ANMCM – SAC000E03/E04/E05)

The CMRE Autonomous Naval Mine Countermeasures (ANMCM) programme aims to tackle several MCM problems by developing novel and complementary approaches for the future of Naval Marine Warfare (NMW). In 2023, the programme focused on interoperability, novel sensing approaches, and the development of new tools and doctrines for unmanned systems.

Dr Yan Pailhas, Mr Thomas Furfaro, Mr Christopher Strode, GBR, CMRE

BACKGROUND

Given that the future of NMW will be unmanned, the CMRE focuses on developing and testing concrete and effective solutions in autonomy, AI-based tools, innovative sensing, and interoperability for NATO navies.

MILITARY RELEVANCE

NATO Nations have rapidly adopted autonomous systems, underscoring the need for advancements in autonomy, sensing and planning capabilities in the area of mine warfare (MW). This will improve the efficiency and effectiveness of MW operations efficiency by taking humans out of the minefield. To that end, CMRE works directly with the operational community to identify capability gaps, target relevant research, and quickly explore, test and validate novel concepts in operationally relevant scenarios.

OBJECTIVE(S)

The objectives of the ANMCM programme align directly with the NATO Future Naval Mine Warfare Vision Paper IMSM-0088-2021, focusing on the development of innovative, cutting-edge, interoperable and resilient NMW capabilities to enable joint and maritime operations.

S&T ACHIEVEMENTS

In 2023, the programme placed particular emphasis on interoperability with the further development of the CATL, enabling heterogeneous autonomous systems to effectively communicate during complex unmanned missions. Through co-chairing the STO SCI-343-RTG, the body governing CATL, the CMRE guides the next generation of standards promoting interoperability, as demonstrated during the REPMUS23/DYMS23 exercises. During the SUNFISH23 scientific trial, the CMRE demonstrated the capability for low-frequency systems to operate in complex environments where traditional high-frequency sensors perform insufficiently. The programme has also continued to investigate the use of AI-based tools to automatically characterize the environment. Further work has employed novel techniques such as a new evaluation mathematical framework based on possibility theory to improve the planning and evaluation (P&E) of MCM missions conducted by autonomous platforms.

> *"In the near future, MCM will be fully unmanned."* ***CDRE Ettore Ronco SNMCMG2***

SYNERGIES AND COMPLEMENTARITIES

The ANMCM programme, along with the MUSE programme, hosted the Interoperability Festival in May 2023, providing hands-on experience for partners and industry to develop and test their implementations of CATL and JANUS. The CATL track of the workshop acted as a de-risking activity for partners who also participated in REPMUS23/DYMS23. The partners include several Nations and leading industries including CSSN (ITA), DRDC (CAN), Dstl (GBR, with Seebyte), Evologics GmBH (DEU), NSWC (USA), THALES (FRA), and TNO (NLD).

EXPLOITATION AND IMPACT

The output of SCI-343-RTG will be integrated into STANAG 4817 on "Multiple Area Control of Unmanned Platforms" in 2024. This is a step forward to one of NATO's cornerstones – "day-zero interoperability" – for complex autonomous NMW operations conducted by a variety of unmanned systems. MARCOM has exploited P&E work for the analysis of real-world mine hunting performance during national exercises (MINEXs and Dynamic Messenger). The planning algorithms will be further exploited through the minimal viable product (MVP), which was successfully demonstrated during Exercise Dynamic Move.

CONCLUSION(S)

In tackling important military challenges and opportunities such as interoperability, novel sensing, and operational planning, CMRE offers concrete solutions for NATO Nations to efficiently transition to autonomous systems for future MCM operations.

The project Autonomous Naval Mine Countermeasures (ANMCM – SAC000E03/E04/E05) is financed by Allied Command Transformation (ACT).

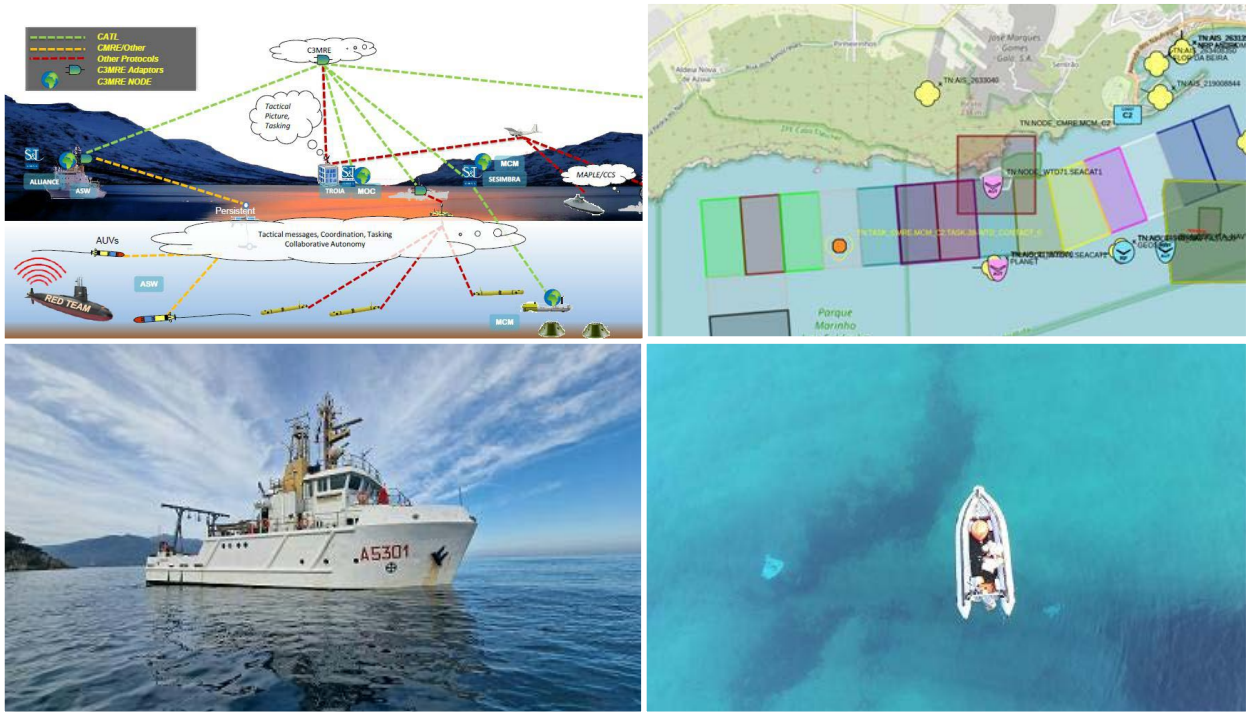


Figure 21: (top-left) CATL principles and mode of operation; (top-right) real-time maritime operational awareness provided by CATL messages; (bottom) CRV LEONARDO and CMRE RHIB at Elba Island during the SUNFISH23 experiments.

ALLIED INTEROPERABILITY AND STANDARDIZATION INITIATIVES FOR DIGITAL TWINS (MSG-ET-053)

In merging physical systems with digital simulations, digital twins offer the opportunity to enhance the performance of military systems throughout the Alliance. In order to reap their benefits for platform design, certification and mass production – through life support as well as decision support and analysis – digital twins should be interoperable and inter-connectable, just like the physical systems they mirror.

Mr Simon Skinner, Thales UK Ltd.

BACKGROUND

This Exploratory Team was formed to make the Technical Activity Proposal (TAP) suitable for a full research task, and gather a team of experts and contributing Nations.

MILITARY RELEVANCE

This work aimed to improve the Alliance's military capability within modelling and simulation by:

- effectively exchanging information (e.g. mathematical models, simulations, equipment and environmental data) between digital twins operating in different Nations;
- ensuring the security of information exchange and operation against adversarial penetration and attack in distributed networks and diverse computing and storage resources, using information that derives from military and commercial sources; and
- ensuring the coherent analysis, storage and discovery of the large quantities of data ingested and generated by operating digital twins.

OBJECTIVE(S)

Rapid approval of an RTG in under 6 months, assembling a team of 30 members and contributors from eight Nations/NATO organizations.

S&T ACHIEVEMENTS

The team clearly identified the problems that the RTG should address, and developed an improved TAP that clearly delineated the RTG's work. The group also shared best practices from Nations and their domestic industries, as industry plays a significant role in the digital twin space (e.g. end-users, integrators, and tool and component vendors).

> *"Digital twins have great capability to improve the military performance of NATO Nations, improving platform design, enabling easier testing and evaluation, and reduced maintenance costs through life."* ***Simon Skinner – Chair ET-053***

SYNERGIES AND COMPLEMENTARITIES

Through collaboration, the Exploratory Team identified many problems that were common across Nations, military domains, and the commercial space. They found interoperability standards in this field to be lacking, and determined that different modelling and simulation communities outside of the NMSG should be involved with the work.

EXPLOITATION AND IMPACT

Interoperable digital twins offer the potential to completely revolutionize military platform development and enhance multi-domain operations, through life performance and support, by making it much easier and quicker to develop and deploy advanced capabilities across the Alliance.

CONCLUSION

The Exploratory Team successfully identified existing use cases and capabilities from a variety of industry and government teams in NATO Nations. It made rapid progress in generating a TAP that resulted in an RTG with well-defined aims and objectives. Digital twins have the potential to greatly improve the military performance of NATO Nations by improving platform design, enabling easier testing and evaluation, and reducing maintenance costs through life. They offer the capability to improve decision support and analysis in complex, multi-domain environments, helping to build a modern force capable of addressing the challenges of the 21st century battlespace.

MODELLING AND SIMULATION STANDARDS SUBGROUP OF THE NATO MODELLING AND SIMULATION GROUP (NMSG-MS3)

The NMSG was officially named as the NATO's Delegated Tasking Authority for Modelling and Simulation by the Conference of the National Armaments Directors (CNAD). In that role, the NMSG is responsible for the production, management and maintenance of standardization documents in support of NATO modelling and simulation activities. In order to fulfil this essential function, the NMSG established the Modelling and Simulation Standards Subgroup (MS3), with the mission of providing support to modelling and simulation standardization activities across the Alliance.

Mr Lionel Khimeche , Directorate General of Armament (DGA), Mr Wim Huiskamp , TNO and Mr Adrian Voiculet, NATO STO.

BACKGROUND

The NATO Modelling and Simulation Master Plan (MSMP) calls for the application of modelling and simulation in support of operations, capability development, mission rehearsal, training and education, and procurement to improve Alliance operations. In this context, simulation interoperability and re-use are essential enablers, which in turn require appropriate open and common standards.

MILITARY RELEVANCE

Allied Heads of State and Government have decided that all Allies will ensure that their armed forces can operate together effectively, including through the implementation of agreed NATO standards. In the modelling and simulation domain, standards allow people working with different systems to cooperate in collective training, experimentation and many other areas. Moreover, standards reduce costs, including those associated with development, lifecycle, and implementer training. Standards are a natural way to share investments, avoiding duplication of efforts on new technologies while reducing risks linked to their use.

OBJECTIVES

The MS3 aims to develop policy and procedures for NATO M&S standardization activity; develop and maintain a NATO modelling and simulation standards profile (NMSSP); and establish a common understanding of the terminology associated with modelling and simulation standardization in NATO context.

S&T ACHIEVEMENTS

The MS3 produced and maintains the NMSSP, currently known as the AMSP-01 standard. It serves as an authoritative reference and guidance product for NATO and Nations on modelling and simulation standardization products and their applications. Under MS3 supervision, several NMSG technical activities developed other standards such as AMSP-02 "Allied Framework for M&S as a Service Concept of Employment," AMSP-03 "NATO Reference Architecture for Distributed Synthetic Training," and several more.

> *"Standards reduce costs, including those associated with development, lifecycle, and implementer training; standards are a natural way to share investments avoiding duplication of efforts on new technologies while reducing risks linked to their use"* ***The MS3 team***

SYNERGIES AND COMPLEMENTARITIES

In the framework of the Technical Cooperation Agreement between the NMSG and the Simulation Interoperability Standards Organization (SISO), multiple civil standards of interest to NATO developed by SISO are being adopted via Standardization Agreements (STANAGs) or Standardization Recommendations (STANRECs). One such example is STANAG 4855 that formalizes the adoption by NATO of the SISO standardization document SISO-REF-010-2023 "Reference for Enumerations for Simulation Interoperability."

EXPLOITATION AND IMPACT

The standardization products produced under MS3 supervision will facilitate the development of future military capabilities such as distributed synthetic training and modelling and simulation as a service (MSaaS).

CONCLUSION

Standardization in support of interoperability is not an end in itself, but a key enabler and important capability multiplier.

Figure 22: STANAG 4855 formalizing the adoption of a civil standard by NATO.

ANALYSIS OF ANTI-ACCESS AREA DENIAL (A2/AD) (SAS-147)

This activity investigated the challenges posed by adversary Anti-Access and Area Denial (A2/AD) strategies. Its work drew on a broad range of sources and experience, and was informed by simulations and war gaming, considering situations across pre-conflict, hybrid tactics and proxies, and collective defence, including maritime challenges in the Baltic Sea and High North. The unclassified discussion is amplified by classified sources and results.

Dr Eva Dalberg, Swedish Defence Research Agency (FOI), Mr Stian Betten, Norwegian Defence Research Establishment (FFI)

BACKGROUND

This study was initiated at a time when most NATO Allies and partners were starting to realise that a major war in or around Europe could no longer be ruled out. There was an urgent need to address Russian A2/AD strategy and find solutions and means to mitigate the threat.

MILITARY RELEVANCE

Russia's A2/AD strategy complicates decision-making and is intended to disrupt the Alliance's ability to fight by focusing on strategically important targets believed to be vital to the war effort. The SAS-147 analysis focuses on that threat through deterrence and defence.

> *"The mission of the group has been: Assessing the Consequences – Addressing the Challenge."*
> ***Dr Eva Dalberg, 2023***

OBJECTIVE(S)

The team aimed to address adversarial A2/AD challenges by identifying potential solutions encompassing technical, tactical, operational and strategic means.

S&T ACHIEVEMENTS

The scope of the study required multi-domain thinking, spanning geographic areas from local to regional, as well as various timescales. The team adopted a pragmatic approach using simplification in some areas (e.g. generic target types and simplified game cards), while not excluding detail in others (e.g. discussion of specific details during parts of the analysis). The group developed scenarios and vignettes, defined a simplified kill chain and created 40 technology or capability game cards. The utility was analysed in a wargame/scenario-based discussion, with invited participants providing important input to the group's final analysis. Particularly challenging situations were identified, as well as promising technologies or capabilities to mitigate the threat.

SYNERGIES AND COMPLEMENTARITIES

The wargame hosted by the Joint Warfare Centre in Stavanger, Norway served as a focal point for collaboration. The preparations, execution and post-event analysis demonstrate that a relatively small group with limited resources can still deliver significant outputs. The group, with participants from six Nations as well as ACT and NCIA, met physically six times, arranged the wargame, and held several virtual meetings.

EXPLOITATION AND IMPACT

The team provided a "smorgasbord" of solutions for the NATO and Nations to choose from according to their needs and situation. The study was designed to be shareable and useful, emphasising that solutions are possible and refuting the perception that A2/AD strategies are somehow unsolvable. The group's initial assessment of the most important capability gaps was revised based on feedback from the wargame participants. The final assessment is classified.

CONCLUSION(S)

The potential solution space for A2/AD is wide, and the group discussed a broad range of relevant themes when addressing A2/AD challenges. This resulted in 10 recommendations divided into capability- and concept-focused solutions where the Alliance is encouraged to take action.

Figure 23: Example of Game Card (from Annex F in the final report).

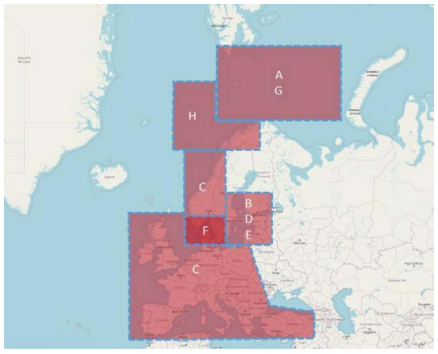


Figure 24: Overview of geographic location of the vignettes in the study. This is Figure 3-1 in the final report.

EO/IR COUNTERMEASURES (SCI-312)

Imaging mid-wave and long-wave infrared (IR) sensors are commonplace in both missile seekers and ISR platforms. Lasers are a disruptive technology to these sensors. The SCI-312 team developed and demonstrated a number of non-destructive methods to investigate laser impacts on these sensors in an effort to better inform procurement.

Dr Brett Garner, Naval Surface Warfare Centre, Crane, IR/RF Countermeasures Division

BACKGROUND

Most military imaging platforms such as missile seekers use advanced sensors in the mid- and long-wave IR. Representative sensors are costly, however, and many nations are unable to justify the risk of damaging state-of-the- art sensors or even precious missile hardware. This leaves researchers with three options when conducting research: use old laboratory equipment, use obsolete military equipment, or extrapolate effects from sensors operating in other parts of the spectrum. All of these options ignore aspects of current sensor capabilities.

MILITARY RELEVANCE

Imaging sensors are a vital component of military systems deployed in a battlespace. Friendly sensors act as a force multiplier, passing situational information to the war fighter such as enemy locations, force structure and movements. At the same time, adversaries employ sensors that increase the accuracy and lethality of their weapon systems. Laser technology may affect sensors operated by both friend and foe. It is therefore important to understand how to protect sensors from enemy lasers, while also employing lasers to disrupt the enemy's kill chain.

OBJECTIVE(S)

This team was formed to understand current IR imaging technology and develop a number of different non-destructive methods for investigating laser-induced effects on sensors.

S&T ACHIEVEMENTS

The group successfully demonstrated the use of a surrogate with sacrificial elements that were swapped as damage occurred, reducing the need to replace an entire optical system. Other methods developed included folding a projected scene of an aircraft with a laser, and a digital simulation technique for studying image noise and artefacts produced by a laser and the resulting effects on a sensor's ability to maintain a track.

SYNERGIES AND COMPLEMENTARITIES

Nine Nations across the Alliance participated in SCI-312, and the methods developed were integrated into three national facilities. Data collection and demonstrations were held at all three locations, providing close collaboration among the members.

EXPLOITATION AND IMPACT

Countermeasures refer to the steps required to protect coalition sensors from enemy lasers and the integration of lasers on coalition platforms to protect personnel and platforms from enemy weapons. The methods developed reduce research costs by ensuring that sensors are not damaged during the course of experimentation. Whether in a modelling and simulation environment or using lasers on an optical table, all Nations can investigate laser technology and its effects on sensors.

CONCLUSION(S)

The methods developed by SCI-312 provide researchers with tools to investigate the effects of lasers on sensors. The data developed using these methods will better inform platform requirements and procurement strategies for future capabilities.

> *"Today, no military platform is free from the risk of sensor track contamination by laser energy, particularly in low-intensity conflicts, where an immediate response may be limited."*
> ***Dr Brett Garner, 2023***

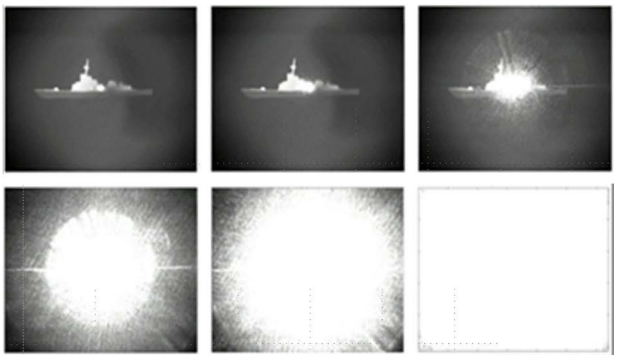


Figure 25: Projection of a generic frigate made with an IR mask, combined with a laser and presented to a mid-wave IR sensor on an optical table setup. EO/IR Countermeasures, NATO Science and Technology Organization, SCI-312 Final Report (2024).


STO Programme of Work
RESILIENT

CAPABILITIES FOR SENSING, SEARCH, AND SURVEILLANCE IN THE ARCTIC (SCI-329)

The SCI-329 Research Specialists' Meeting was held in Nuuk, Greenland from 19–21 June 2023, and hosted by the Danish Ministry of Defence Logistics and Acquisition Organization and the Danish Joint Arctic Command. The meeting provided a forum for increased awareness, dialogue, S&T recommendations, and improved basis for future procurements related to operations in the Arctic region.

Dr Ernst Krogager, Danish Ministry of Defence Acquisition and Logistics Organization (DALO); Prof Victor Lobo, Escola Naval (Portuguese Naval Academy)

BACKGROUND

The warming of the Arctic region, and the resulting increased access opportunities, call for extended presence with enhanced technological capabilities. Although previous NATO S&T activities have widely investigated sensor systems and technologies, comparatively little work has focused on Artic applications.

MILITARY RELEVANCE

Search and surveillance capability is of vital importance and hinges on appropriate sensing systems. The harsh Arctic environment, together with the limitations of satellite visibility in polar regions, demand adapted technical solutions in order to ensure essential C2 links and the optimum performance of systems of systems.

OBJECTIVE(S)

The meeting aimed to provide a forum for exchanging knowledge and raising awareness around technological solutions to the unique challenges that the Arctic region presents.

S&T ACHIEVEMENTS

The meeting brought together 39 participants from 12 NATO Nations and 3 NATO bodies, with high-quality contributions. It raised awareness of state-of-the-art and technological trends; fostered dialogue between the S&T community, military users and decision-makers; delivered recommendations for continued S&T efforts; and improved the basis for future capability procurements.

SYNERGIES AND COMPLEMENTARITIES

The meeting was held in Nuuk so as to coincide with the spring 2023 NATO ACT Innovation Challenge (IC) on "Monitoring the Arctic: from space to seabed," which was also held in Nuuk on 22 June.

EXPLOITATION AND IMPACT

The meeting was structured along five topical sessions: S&T strategy and international efforts; airborne and space-based capabilities; situational awareness and environmental monitoring; sensor systems and applications; and autonomous solutions, machine learning and disinformation. Presentations from the local S&T community in Greenland provided important perspectives and networking opportunities.

> *"This was the first STO event ever held in Greenland."* ***John-Mikal Størdal, CSO Director***

CONCLUSION(S)

Although Arctic sensing will continue to rely on space-based systems, aerial, ground and seaborne sensors are important complements and backups. Advances in signal processing techniques are crucial to help machine learning algorithms obtain useful and timely information. Meetings like SCI-329 foster awareness and networking among stakeholders.

Figure 26: Arctic Sea Ice Cover – Credit: NASA.

Figure 27: Morning gathering at Old Colonial Harbour on Greenland's National Day, 21 June 2023.

Figure 28: Tour on board HDMS Vædderen on Greenland's National Day, 21 June 2023.

ANTICIPE@STJU-23 (IST-192)

Modern, complex, multi-domain conflicts present dilemmas that are impossible for a human brain to address due to a constant deluge of data. Although some AI-based prototypes aim to assist commanders in their decision-making process, IST-192 is the first project to test a complete system in the most challenging and realistic scenario – a large, Article 5 NATO exercise.

Mr Hervé Le Guyader, School of applied cognitive sciences of the National Institute of Technology (ENSC)

BACKGROUND

The ANTICIPE system is an AI-native platform allowing for the autonomous extraction and distillation of critical information from all-domain information, thereby facilitating decision-making using a cooperative war gaming tool. Initially part of the award-winning "Human considerations in AI for C2" project (IST-157), ANTICIPE could not be experimented during previous editions of the STJU exercise due to the COVID pandemic and the war in Ukraine. The experiment was finally conducted at STJU-23, a NATO Secret Article 5 exercise involving 7,000 players. ANTICIPE passed all steps of the accreditation process and was experimented during the two weeks of the exercise by a NATO "Shadow HQ," under the supervision of the IST-192 experimentation team.

MILITARY RELEVANCE

There is a clear need to harness the power of AI in making valid military decisions, though this can only be done after conducting tests in the most realistic settings possible to evaluate the technology's technical readiness level (TRL) and human readiness level (HRL). IST-192 achieved this with ANTICIPE, which was also cited as an "AI-assisted decision-making" use case in the NATO AI Strategy.

OBJECTIVE(S)

The project aimed to explore how an AI-enabled prototype would affect decision-making in an operational setting, focusing on trust, situation awareness, human and systems integration, and the cognitive workload of operators. The team also conducted a thorough study on the system's user experience (UX) and possible impacts on the organization and battle rhythm of a given HQ. Its final report also provides updates to the IST-157 report.

S&T ACHIEVEMENTS

From a technical standpoint, STJU-23 allowed the ANTICIPE system to go from TRL 4 to TRL 6. From a more global perspective, the unique character of the experimentation – described as the largest NATO exercise since the Cold War – has significantly raised awareness among generals and flag officers, who saw the system in action and were briefed by the experimentation team.

> *"Modern, complex, multi-domain conflicts present dilemmas that are impossible for a human brain to address due to a constant deluge of data."* ***Mr Hervé Le Guyader, 2023***

SYNERGIES AND COMPLEMENTARITIES

Six Nations and two NATO bodies participated in this RTG. This diverse group contributed to the success of the activity and the high quality of the work. Synergies with the NATO AI Strategy were optimized.

EXPLOITATION AND IMPACT

While the "live" performance of the system was not perfect, its experimentation in such a demanding and challenging context has triggered two processes: ANTICIPE can now be further developed to reach higher TRLs and HRLs; and NATO decision-makers expect it to be tested it in future exercises.

CONCLUSION(S)

The IST-192 team overcame the challenge of accrediting ANTICIPE and integrating it into STJU-23, and the lessons learned during its experimentation will allow ANTICIPE to progress further. Moreover, the attention and interest that visiting generals and flag officers showed in the experimentation make IST-192 a clear success.

Figure 29: Military users getting familiar with the platform.

COMPARATIVE ASSESSMENT OF MODELLING AND SIMULATION METHODS OF SHIPBOARD LAUNCH AND RECOVERY OF HELICOPTERS (AVT-315)

Modelling and simulation of a helicopter landing on a ship could improve the effectiveness of costly and time-consuming clearance trials. To align the research approaches of different Nations, AVT-315 developed new common generic ship and helicopter platforms. These platforms were then deployed in a piloted flight simulation, modelling the air flow over a ship moving in heave, roll and pitch, to predict safe operational limits.

Prof Ieuan Owen, School of Engineering, University of Liverpool; Dr Richard Lee, National Research Council Canada

BACKGROUND

Military helicopters routinely operate to the landing deck of single-spot ships. The ship-helicopter operational limits (SHOL) are an envelope of maximum allowable wind conditions determined through sea trials in which test pilots conduct as many landing and take-off manoeuvres as possible. Several NATO Nations have been developing modelling and simulation methods to support trial planning and to estimate limiting conditions in advance; however, each Nation has its own ships and helicopters, thereby limiting research collaboration and comparison.

> *"A major aim of ongoing research in the helicopter-ship dynamic interface has been to develop modelling and simulation tools to support and inform SHOL trials, which are costly and time-consuming."* ***The AVT-315 team***

MILITARY RELEVANCE

Many Nations have naval fleets that support air operations at sea. Modelling and simulation has the potential to reduce the cost and improve the safety of flight testing for SHOL development and pilot training; it also has the potential to significantly improve the interoperability of a Nation's helicopters to the ships of other Nations.

OBJECTIVE(S)

This activity aimed to advance current research capability and collaboration by creating common ship and helicopter platforms; to increase the use of modelling and simulation in SHOL trials; and to improve the operational envelopes of shipborne helicopters. The new common platforms are the NATO Generic Destroyer (NATO-GD) and Generic Rotorcraft (NATO-GR).

S&T ACHIEVEMENTS

In addition to deploying the NATO-GD and NATO-GR in a full-motion flight simulator, the team demonstrated other simulation methods such as wind tunnel experiments and coupled computational fluid dynamics (CFD) simulations of a helicopter immersed in a ship's airwake. CFD methods have been developed for simulating the air flow over ships moving in pitch, roll and heave in realistic seaways. A baseline SHOL was established for the NATO-GR and NATO-GD.

Figure 30: A rendered image of the 150-metre-long NATO Generic Destroyer.

Figure 31: NATO Generic Rotorcraft approaching the NATO Generic Destroyer for a simulated deck landing.

SYNERGIES AND COMPLEMENTARITIES

AVT-315 brought together seven participating Nations and benefitted from advanced facilities (e.g. wind tunnels, flight simulator, high-performance computing) and expertise (e.g. large-scale unsteady CFD, helicopter and ship dynamics modelling, operational experience).

EXPLOITATION AND IMPACT

Several Nations are beginning to exploit modelling and simulation in support of their SHOL clearance processes. The NATO-GD is being made freely available, along with geometry, motion profiles and wind tunnel data, while the NATO-GR and available flight models have been specified. The outcomes from AVT-315 are also informing future collaboration in cross-deck helicopter operations from ships other than aircraft carriers (HOSTAC) operations and the deployment of unmanned shipborne aircraft.

CONCLUSION

Modelling and simulation for ship-helicopter operations now has common platforms for conducting future research and sharing outcomes. The AVT-315 team successfully demonstrated their deployment in a full-motion piloted simulator and new lines of research have been initiated.

DATA KNOWLEDGE AND OPERATIONAL EFFECTIVENESS (DKOE) (SAC000E08)

The Data Knowledge and Operational Effectiveness (DKOE) project aims to provide enhanced capabilities based on AI2F to enable cognitive superiority and achieve seabed-to-space situational awareness (S3A). The proposed vision is particularly relevant for supporting the monitoring and protection of CUI. The project is directly financed by Allied Command Transformation (ACT).

Dr Paolo Braca, Dr Leonardo M. Millefiori, CMRE

MILITARY RELEVANCE

In November 2023, NATO Secretary General Jens Stoltenberg met with EU Defence Ministers to discuss the protection of CUI and the importance of continued support for Ukraine. The Secretary General stressed that the sabotage of the Nord Stream pipelines last year, as well as the recent damage to the Balticconnector pipeline and cables, show that infrastructure is vulnerable, and that threats are real and developing. Since these incidents, NATO has stepped up air and naval patrols, and has increased its presence in the Baltic and North Seas. At the Vilnius Summit in July, Allies agreed to establish the new Centre for the Security of CUI at NATO's MARCOM.

OBJECTIVE(S)

The DKOE project aims to provide scientific research focused on AI2F to enable cognitive superiority and achieve S3A, with particular emphasis on CUI monitoring and protection.

S&T ACHIEVEMENTS

Building upon recent S&T achievements, the project has developed advanced multi-domain AI2F techniques and algorithms towards the S3A vision by exploiting diverse above-water and underwater systems extending to remote regions of the globe. The approach combines the use of an automatic identification system (AIS), satellite sensors, terrestrial radars, distributed acoustic sensing, and active/passive sonars, whether integrated into CUI or mounted on unmanned underwater vehicles. The techniques to achieve S3A also leverage the integration and analysis of contextual information, encompassing factors like bathymetry, weather data, and human and open source intelligence.

The DKOE project has delivered several significant contributions to top-tier scientific journals. The DKOE team has also informed the NATO Enterprise (primarily MARCOM and NATO HQ), as well as several Nations about modern CUI surveillance technologies and analyses related to recent events and sabotages.

SYNERGIES AND COMPLEMENTARITIES

The DKOE project benefits from many long-standing collaborations with recognised research institutions within the Allied Nations, such as the Massachusetts Institute of Technology (MIT) and the University of Connecticut, as well as governmental and international institutions, such as TNO, the Canadian Department of National Defence (DND), the European Space Agency (ESA), and the NATO Joint Analysis and Lessons Learned Centre (JALLC).

EXPLOITATION AND IMPACT

The agreed Warfare Development Agenda S3A Line of Delivery (LoD) applied to monitoring CUI allows for a timely understanding of the maritime activities possibly related to a sabotage (such as the one that impacted the Nord Stream pipelines last year) and the recent damage to the Balticconnector pipeline. The DKOE research aligns with MARCOM's needs and the operational activities of its new Centre for the Security of Critical Underwater Infrastructure.

> *"To hold the sea, he must take control of the situation."* ***Gnaeus Pompeius Magnus [CICERO, Letters to Atticus]***

CONCLUSION(S)

The CMRE's DKOE research and development (R&D) activities focus on the exploitation of disruptive technologies and the provision of cutting-edge research, based on AI, machine learning and information fusion, to help NATO achieve S3A and, ultimately, cognitive superiority.

The project Data Knowledge and Operational Effectiveness-DKOE (SAC000E08) is directly funded by Allied Command Transformation (ACT).

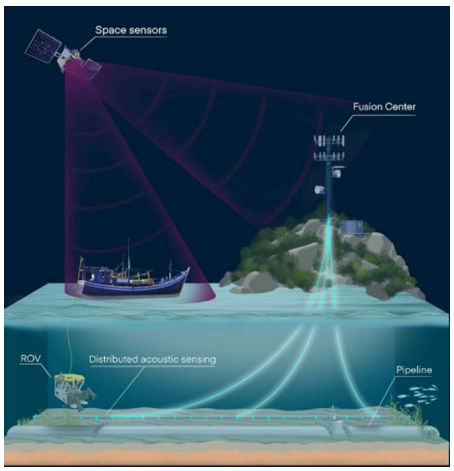


Figure 32: DKOE research activities aim to develop advanced AI2F technologies for S3A, with emphasis on CUI monitoring. These technologies encompass the use of data collected from multi-domain sensors (e.g. space sensors and distributed acoustic sensing systems), as well as contextual information.

ENVIRONMENTAL KNOWLEDGE AND OPERATIONAL EFFECTIVENESS (EKOE) (SAC000E06-E07)

The Environmental Knowledge and Operational Effectiveness (EKOE) programme assesses the impacts of the marine environment on naval operations, the mitigation of such impacts, and the optimization of the operational use of the environment. The scientific and technical approach is based on the development and exploitation of spatially distributed networks of autonomous platforms equipped with smart sensors to provide covert coverage across large expanses of the open ocean. Developments are applied to build up environmental understanding, with a dedicated focus on supporting ASW in the Arctic Ocean.

Dr Alberto Alvarez Diaz, CMRE

BACKGROUND

NATO's REA doctrine resulted from the paramount importance of expeditionary warfare in littoral seas during the post-Cold War era. Contemporary great power competition dictates naval doctrines to return to open seas. Scaling up expeditionary REA to blue waters is technologically challenging, particularly in the High North. Russia's great power competition in the Arctic Ocean presents a significant threat to NATO. Recovering and enhancing Arctic ASW capabilities requires regenerating environmental knowledge in the Arctic Ocean, where environmental conditions have changed significantly since the Cold War.

MILITARY RELEVANCE

The effectiveness of naval detection systems largely depends on the intervening medium where the carrier signals propagate. The environment introduces uncertainty in increasingly accurate sensors. Unravelling signals of interest (SoI) masked in background noise requires a deep understanding of the environmental perturbations. In addition, environmental fields can offer a basis for new, disruptive detection technologies.

OBJECTIVE(S)

In 2023, the EKOE programme aimed to: generate understanding of, provide insights into, or nowcast (descriptive) and forecast (predictive) environmental conditions in Arctic regions; assess the current levels of Arctic ambient noise; and further develop networked autonomous capabilities to conduct covert REA in contested regions.

S&T ACHIEVEMENTS

Underwater acoustic propagation under Arctic thawing conditions was evaluated in the sea trial Nordic Recognised Environmental Picture 2023, held from 20 June-11 July. The development of sound channels at specific depth under Arctic leads was numerically demonstrated. Moored oceanographic and acoustic sensors revealed the seasonality of underwater propagation channels at a greater depth in the Fram Strait area. Autonomous capabilities for the tactical determination of the acoustic properties of the seabed (underwater gliders) and sea ice thickness (aerial drones) were designed and developed. Finally, two innovative man-portable and fast-deployable 8-hydrophone arrays were built for tactical operations in harsh environments.

Figure 33: Drone take-off during NREP23 to build an aerial orthomosaic of the Arctic ice floe distribution.

SYNERGIES AND COMPLEMENTARITIES

Five Nations (FRA, GBR, ITA, NOR, USA) collaborated in the research conducted during NREP23. Collaborations increased the ambition and exploitation of the results.

EXPLOITATION AND IMPACT

Research activities in EKOE are exploited by publications and datasets, and through participation in NATO exercises.

> *"Know the enemy, know yourself; your victory will never be endangered. Know the ground, know the weather; your victory will then be total."* ***Sun Tzu- The Art of War.***

CONCLUSION(S)

Outcomes from the EKOE programme promote cognitive superiority for NATO forces through the collection and processing of environmental information and what it means, thereby helping them to operate effectively and gain tactical advantage on the battlefield.

The project Environmental Knowledge and Operational Effectiveness-EKOE (SAC000E06-E07)IiF is funded by Allied Command Transformation (ACT).

FACTORS AFFECTING ETHICAL LEADERSHIP (HFM-304)

Substantial research has explored the ethical behaviour of leaders and how their expectations influence the ethical behaviour of their followers. This activity found that strong ethical leaders have a firm foundation in values, can recognise and address an ethical dilemma, and believe that their institution shares these values. To support Nations' efforts to engender ethical cultures and sustain principled leaders, this activity offers insights and products to reinforce ethical decision-making, strengthen the selection of ethical leaders, and design training that promotes value-informed ethical leadership.

Dr Damian O'Keefe; Dr Allister MacIntyre

BACKGROUND

All leaders should be above reproach, avoid conflicts of interest, and be driven by principles, values and solid ethical reasoning. Some research suggests that the leader is the most important determinant in shaping an organization's ethical climate, which has a significant impact on the ethical behaviour of organizational members. However, little research has been conducted on dispositional and organizational factors that promote military leaders' ethicality.

MILITARY RELEVANT

Troops today are subjected to incredible public scrutiny, and unethical behaviour can have adverse consequences and generate vengeful motivations. To this end, NATO Nations owe it to their military leaders to understand critical ethical factors, and to consider these factors when selecting and training future leaders.

OBJECTIVES

The goals of this RTG included identifying individual and organizational variables that affect ethical leadership, collating best practices in military ethics education among NATO Nations and Partner for Peace (PfP) countries, and developing ethical leadership case studies for training.

S&T ACHIEVEMENTS

This RTG's findings show that strong ethical leaders can recognise an ethical dilemma (ethical sensitivity), address an ethical dilemma when it occurs (moral courage), have a firm foundation in values (benevolence), and believe that their institution shares these values. This suggests that ethical leadership reflects a broader, systemic dynamic where social and/or institutional principles are internalised by the leader. Tangible HFM-304 outputs include the identification of criteria that can be used when selecting leaders, and the development of ethical leadership case studies for training.

> *"Military leaders must do more than 'talk the ethical talk'; they must 'walk the ethical walk'."*
> ***Dr Damian O'Keefe, 2023***

SYNERGIES AND COMPLEMENTARITIES

Nine NATO and PfP Nations across six disciplines participated in HFM-304, and the team's diversity contributed to its success. This research was the first large-scale study investigating factors affecting ethical leadership among military leaders. It was the first time that NATO Nations and PfP countries collated educational/training documents relevant to the development of ethical leaders.

EXPLOITATION AND IMPACT

HFM-304's results highlight the importance of strong values, ethical sensitivity and moral efficacy in the promotion of ethical leadership amongst military leaders. Nations can use these results during the selection of future leaders and in the design of formal ethics training.

CONCLUSION

This research suggests that in order to engender ethical cultures, and attract, train and sustain principled leaders, military institutions must emphasise values, reinforce ethical decision-making and promote value-informed ethical leadership from the beginning.

REDUCING MUSCULO-SKELETAL INJURIES (HFM-283)

Human performance is impaired by musculo-skeletal injuries (MSI), which can affect all military personnel and new recruits, in particular. MSI range from muscle pain, resulting in days lost training, to stress fractures resulting in medical downgrading, or medical discharge.

The NATO military community recognises MSI as a significant problem. Although efforts have been made to reduce injury rates based on relatively coarse data, a better understanding of the incidence and causes of MSI, and the effectiveness of existing preventive measures, is necessary to decrease the number of personnel unfit for task and mission.

Mr Graham White, Defence Science and Technology Laboratory (Dstl); Dr Thomas Karakolis, Defence Research and Development Canada (DRDC)

BACKGROUND

MSI account for over half of all medical discharges, reducing both training and operational effectiveness, and increasing the demands placed on associated medical care provision. Published reports show that 20% to 59% of recruits are affected by MSI, with about 8% of recruits being discharged due to MSI. Generic interventions have been found to be ineffective. The frequency and quality of injury reporting varies within and between NATO Nations and partners.

MILITARY RELEVANCE

MSI remains a significant challenge for all NATO Nations. Tackling this challenge based on high-quality data will help to increase the number of personnel fit for task and mission.

> *"MSI can be reduced by considering military training as a dynamic system, a learning environment composed of three continuously interacting and changing subsystems: the organism (service member), the environment and the tasks."* ***Mr Graham White, 2023***

OBJECTIVE(S)

This RTG focused on primary preventive measures to reduce MSI by: promoting the sharing of information among participating nations; identifying the causes and associated risk factors for MSI; identifying existing and novel strategies/technologies which may reduce the injury burden; and linking to other ongoing STO activities.

S&T ACHIEVEMENTS

The team reviewed papers and reviews published since 2000 on potential risk factors for MSI in the military, leading to a review paper published in *Military Medical Research* (Sammito et al. 2021), and the development of a new model to assist with understanding risk factors and those that can be modified in a military setting. The team identified considerations for data collection in future research and assessed potential interventions. The final technical report details examples of successful and unsuccessful interventions, and provides recommendations to researchers, military leaders (commanders), trainers and medical personnel.

SYNERGIES AND COMPLEMENTARITIES

Early engagement with the HFM-252 RTG on "Aircrew Neck Pain Prevention and Management" guided the team's approach. The nine participating Nations shared unpublished defence-controlled data and reports, and the 12 group members worked together to reach consensus on interpreting the data and developing recommendations.

EXPLOITATION AND IMPACT

The published review paper has influenced policy changes aimed at reducing MSI in several participating Nations. The RTG members also organised a thematic session at the 2023 International Congress on Soldiers Physical Performance in London, UK, which was well attended. Several attendees said they would take the RTG's recommendations forward within their own military.

CONCLUSION(S)

The HFM-283 developed a model to assess the relative importance of MSI risk factors, and suggested interventions and considerations for data collection in future studies. It recommends that military leadership (commanders), trainers and medical professionals take a holistic view to include the personnel, military environment and tasks, and work together to reduce the incidence of MSI and improve rehabilitation measures. Several of the participating Nations have commenced implementation.

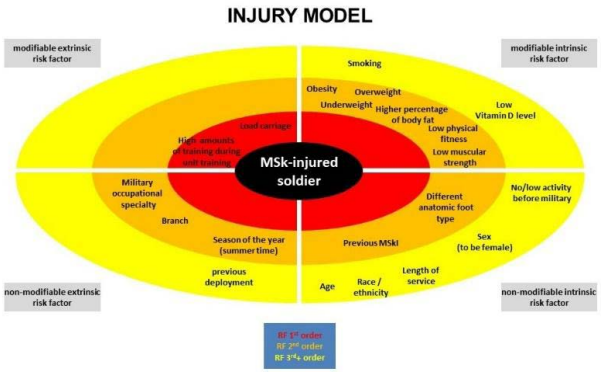


Figure 34: Injury model with a classification in 1st, 2nd and 3rd order, RF = risk factor (NATO-RTG-283 Reducing Musculo-Skeletal Injuries Final Report.

AIRBORNE BEYOND LINE-OF-SIGHT COMMUNICATION NETWORKS (IST-172)

As information technology advances, there is an increased need for distributed communications on the battlefield. NATO activities are multinational engagements that require communications between Allies and from the theatre of operations back to command centres. The IST-172 RTG investigated technologies for beyond line-of-sight (BLOS) communications other than high-frequency (HF) or satellites, creating links between disparate battlefield nodes. The study examined existing and emerging capabilities within the NATO Nations and their applicability to six representative scenarios.

Author Information

Mr Michael Rupar, US Naval Research Laboratory; Dr Erlend Larsen, Department of Strategic Analyses and Joint Systems (FFI); Dr Harun-Buğra Sağlam, Turkish Aerospace Industries, Inc.; Mr Julian Savin, Dstl Portsdown West; Mr Sami Pelotalo, Finnish Defence Forces Technical Research Centre; Mrs Nadine BRÜCK , Fraunhofer FKIE; Mr Ruben Bascuñana Blasco, Airbus Defence and Space SAU; Mr Christoph Prasse, Thales Deutschland; Mr Thorsten Lampe, Thales Deutschland

BACKGROUND

This RTG aimed to lay the scientific and technological foundations for the realisation of an airborne-hosted communication network to provide BLOS range extension for ground, maritime and air forces. An airborne-aided network provides a BLOS alternative for military networks that is possibly less vulnerable, more compatible with existing tactical radios, and more cost-effective, with less latency. The BLOS network was first envisioned in the final report from NATO IST-ET-102.

MILITARY RELEVANCE

BLOS communication plays a major role in connecting forces out-of-theatre, but it is also used for in-theatre communication. An airborne BLOS network provides an alternative to SATCOM or HF that does not require authorization or out-of-theatre approval for use, yet still provides more bandwidth than HF links. Airborne networks can be directed within the theatre, which may decrease the set-up time of tactical links for ground and maritime units. With multiple technologies, an adversary's countermeasures are less likely to impact the network. Having multiple airborne relay nodes adds resiliency in a hostile environment, allowing for redundancy in case some relays become unusable.

OBJECTIVE(S)

This report summarises the current state-of-the-art for BLOS alternatives to HF and to SATCOM, discussing atmospheric means of link extension, the various platforms available to relay/participate in BLOS networks, and the recent waveform and network developments that enable the modernization of NATO communications.

> *"There is an enormous number of considerations each operation must assess when implementing a BLOS solution that will: 1) Minimise additional investment; 2) Provide dependable link performance; and 3) Support networks involving different Nations."* ***Mr Michael Rupar, 2023***

S&T ACHIEVEMENTS

This study will enable NATO war fighters and planners to choose appropriate methods for airborne networking support for their situation. IST-172 produced a comprehensive technical report describing and discussing the possible solution sets available now to NATO. Recent developments in drones, tethered and untethered balloons, and troposcatter provide TRL 7–9 capabilities that were not present five years ago. The team's preliminary results were published in the *IEEE Communications Magazine,* and final findings were summarised in an *IEEE MILCOM 2022* proceeding.

SYNERGIES AND COMPLEMENTARITIES

The collaboration between the seven Nations was evident throughout the activity, as each participant contributed to the various solution sets, covering everything from cellular standards to tethered drone experimentation. The US, for example, provided results on troposcatter and Ka-band air-to-ground data exfil experimentation results; Norway and Germany provided insight on ETSI standards for UHF tactical radios and the emerging 5G use case; and the UK provided its results for tethered drones and troposcatter.

EXPLOITATION AND IMPACT

The options and discussion in this RTG's report will help improve the acquisition and fielding of BLOS technology, meeting current capability gaps in information exchange and communication resiliency.

CONCLUSION(S)

The development and advancement of airborne relay technology, together with networking techniques, provide NATO with multiple options for BLOS communications. This report outlines the trade-offs and recommends technology paths that leverage some or all of existing military hardware among NATO Nations.

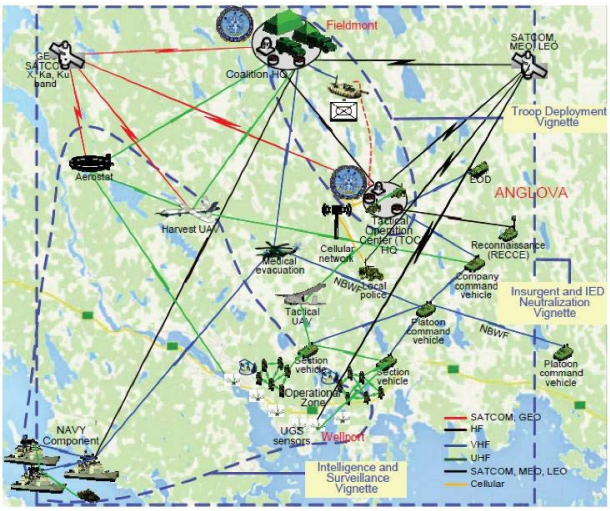


Figure 35: High-Level Operational View of NATO Scenario.

QUANTUM TECHNOLOGY FOR DEFENCE AND SECURITY (IST-SET-198)

This two-day research symposium featured high-quality position papers and S&T papers on a range of quantum technology topics, including: the implications of quantum technologies in defence and security, quantum PNT, quantum sensing, quantum imaging, quantum communication, and quantum information processing. The NATO Unclassified results from the symposium are accessible to NATO Nations, NATO bodies STO Enhanced Opportunity Partners (EOPs) (Australia, Japan, Sweden), and Switzerland.

Charlotte Rugers (Programme Chair), Prof Wolfgang Koch and Massimiliano Dispenza (Programme Co-Chairs); COMMITTEE MEMBERS: Dr Charlotta Bengston, Dr Felix Govaers, LtCol. Giuseppe Nifosi , Mr Harald Bongartz , Ms Jessica Park , Mrs Maran Van Heesch, Dr Martin Ulmke , Dr Michael Kunzer , Dr Per Jonsson. Mentors: Ms Tilly Driesenaar, Dr Bob Madahar (Award Chair)

BACKGROUND

Quantum technologies are developing rapidly in a number of areas, with a worldwide surge in R&D and investment. Although most of this R&D is at an early stage, global interest and technology trends may have a profound impact on the defence and security sectors. In light of this, Allied Nations and NATO, through the NATO STB and STO, have increased efforts to gain knowledge and understanding of the risks and opportunities that quantum technologies present.

MILITARY RELEVANCE

Several reports have outlined how the current surge in quantum technologies – termed the "second quantum revolution" – is unfolding. In the *Science & Technology Trends 2023–2043* report,[4] the STO, NIAG and ACT described how this revolution will affect different military areas, including sensors, communications and information assurance, PNT, computational power and information science.

OBJECTIVE(S)

The symposium aimed to present state-of-the-art updates on the development and application of quantum technologies from academic and industry professionals, and to gain more insight into how these technologies can be applied to real NATO operational issues.

> *"Unprecedented warfighting capability using quantum information science"*
> ***Chris Jay Hoofnagle and Simson L Garfinkel, 2022.***

S&T ACHEIVEMENTS

Forty-four papers and presentations were selected for the symposium, in addition to 12 posters. Seven keynotes and two invited talks were delivered by high-level national military officers and leading experts. The speakers expressed various – and sometimes diverging – perspectives on quantum technologies, including developments that may be on the horizon (e.g. quantum computing and quantum radar). A roundtable discussion focused on "Integrating quantum technology and mitigating its potential threats in the military domain", while panel discussions addressed various questions such as "will defence be early adopter of quantum technology?"

SYNERGIES AND COMPLEMENTARITIES

The symposium established strong synergies with a simultaneous CPoW Challenge on quantum initiated at the STB level and now endorsed across different SCTs.

CONCLUSION(S)

An unprecedented number of registrations and attendees joint the symposium from across NATO Nations and partners, with representation from more than 20 countries. The event also featured a rich mix of attendees and contributions covering a broad spectrum of disciplines from strategy and policy makers, to military staff and users, to deep specialists and industrial players, including start-ups.

4 To be found at https://www.nato.int/cps/en/natohq/news_213088.htm

MARITIME UNMANNED SYSTEMS ENABLERS (MUSE) (SAC000E09, SAC000E10, SAC000E11)

The Maritime Unmanned Systems Enablers (MUSE) programme at the STO CMRE addresses a number of fundamental enablers that will allow for the establishment of efficient multinational collaborative autonomous missions in the maritime domain. It investigates military problems and opportunities related to C2, modelling and simulation, underwater communications and quantum technologies.

João Alves, MUSE Dept. Head, CMRE

MILITARY RELEVANCE

Since its founding in 1949, NATO has recognised that interoperability and standardization are essential elements of effective multinational force integration, and fundamental enablers for the testing and rapid adoption of emerging technologies such as AI-driven autonomous systems. The introduction of EDTs such as autonomy and quantum are expected to deliver significant advantages in operational theatres.

OBJECTIVE(S)

In 2023, the MUSE programme aimed to continue developing data models and architectural frameworks for C2, modelling and simulation, and underwater communications that will support future system-of-systems autonomous maritime missions. It also worked to further expand the CMRE's knowledge on quantum technologies.

Figure 36: Interoperability Fest participants test their CATL and JANUS implementations

S&T ACHIEVEMENTS

MUSE further expanded the CATL and integrated it into the foundation of STANAG 4817. Additionally, the Command, Control and Communications for Maritime Robotic Exploitation (C3MRE) – CMRE's infrastructure for interoperability – enabled more than 30 institutions from 14 Nations to achieve a common operational picture during the REPMUS23 and Dynamic Messenger23 exercises. Modelling and simulation R&D on digital twins in the maritime domain introduced advanced 3D and virtual reality augmentation techniques and data analytics visualization to provide end-users with better situational awareness of maritime unmanned systems operations. Additionally, NATO's digital underwater communications standard (JANUS) to support responses to distressed submarines saw an incremental improvement, with several industries providing standardized solutions to harmonise a wide response to these critical situations. The CMRE also developed and published its Quantum Strategy, and organised the CMRE Quantum Science and Technology Workshop, further defining CMRE's research programme in this area.

> *"We are extending the frontiers of our knowledge, challenging old concepts, testing new ideas... In 'REPMUS', we join academics with industry and the military in a melting pot of innovation and creativity."* ***ADM Henrique Gouveia e Melo, PRT Chief of Naval Staff***

SYNERGIES AND COMPLEMENTARITIES

The work developed within MUSE is carried out in concert with STO Panel and Group activities, and with the direct collaboration of academia and national laboratories from NATO Nations. Additionally, CMRE subject matter experts actively interact with industry and end-users to facilitate the adoption of new interoperability solutions based on NATO standards. Modelling and simulation is another key area of cooperation within MUSE, as the team works closely with the NMSG. In 2023, MUSE organised a quantum S&T workshop, bringing together technological leaders and decision-makers to better inform next steps within the Alliance. MUSE also organised the Interoperability Fest where industry, research labs and academia met in La Spezia, Italy to test interoperability with CATL and JANUS.

Figure 37: Prof J. Thomsen delivers a keynote speech on the transition from quantum science to quantum technology

EXPLOITATION AND IMPACT

The outcomes of the MUSE programme include contributions to NATO standards; federated simulation capabilities, with digital twins supporting field experiments; and R&D at the cutting edge of digital underwater communications.

CONCLUSION(S)

The CMRE MUSE department addresses the enablers for a new era of autonomous maritime systems and missions. Informed by concepts such as the Digital Ocean and Multi-Domain Operations, MUSE aims to provide R&D-based solutions that can contribute to the rapid adoption of EDTs such as quantum and autonomy. New standards based on solid scientific studies will eventually provide the much-needed wide connectivity framework for an effective seabed-to-space multinational approach.

The project Maritime Unmanned Systems Enablers (MUSE) (SAC000E09, SAC000E10, SAC000E11) is fully financed by Allied Command Transformation (ACT).

COMPOSABLE HUMAN BEHAVIOUR REPRESENTATION IN CONSTRUCTIVE SIMULATION SYSTEMS (MSG-198)

This specialist team was established to consider methods and approaches for the representation, composition, deployment and integration of human behaviour in constructive simulation. This work aims to accelerate the achievement of reusable human behaviour modelling components. The nations involved in this work included Bulgaria, Netherlands, Sweden, USA and UK.

Mrs Naomi Betters, Defence Science and Technology Laboratory (Dstl)

BACKGROUND

There is a need for human behaviour to be represented in increasingly complex operating environments (e.g., own forces, adversaries, and civilian populations) and at different levels (e.g. individual, group, societal, etc.). Human behaviour models (HBMs) typically focus on modelling kinetic effects on human behaviour, but there is also a need to represent a wider range of effects, including non-kinetic effects. HBMs are currently composed for a specific situation and modelling and simulation application, and by a wide range of professional disciplines. Each professional discipline utilises unique language, perspectives and knowledge systems, resulting in different approaches to composing HBMs. This results in an inefficient and inconsistent approach to modelling human behaviour.

MILITARY RELEVANCE

Modelling and simulation is an important tool for NATO Nations and partner countries to enable effective and efficient joint, collective and coalition training, mission preparation and decision support. To sustain the asymmetrical advantage that simulation provides, there is a need to adopt a more consistent approach to composing HBMs – one that can be used and reused across modelling and simulation applications in a more effective and efficient manner.

OBJECTIVE(S)

This work aimed to review and define key components of human behaviour modelling; examine methods for composing human behaviour, tailoring models to meet user requirements; and examine the modelling of effects (both kinetic and non-kinetic) on behaviour.

> *"The common understanding, provided by the ABRM, better facilitates follow-on conversations about the composition and re-use of HBM components."* ***Aros, Betts and Robson, MSG-207***

S&T ACHIEVEMENTS

To support analysis of methods and approaches to composable HBR, the group developed a definition of human behaviour and an agent behaviour reference model (ABRM) to provide a shared understanding of HBM that transcends multi-disciplinary and cross-nation boundaries. The ABRM is designed to document the conceptual design of a simulation model. It is intentionally agnostic, detailing neither specifics about the context and model, nor the logic or methods comprise the internal information processing, and nor how effects are applied. A full account of this model can be found in the NATO MSG-198 report "Composable Human Behaviour Representation in Constructive Simulation Systems."

MSG-198 also found:

- Different approaches to the construction of HBMs were adopted, but it is not known which are the most effective.
- There are challenges in finding reliable data applicable to military operations to support the modelling of human behaviour and effects on behaviour.
- There is a prevalent focus on modelling the kinetic effects on human behaviour, and these effects are not represented in a consistent way.

SYNERGIES AND COMPLEMENTARITIES

Composable HBR is the future basis for enabling the re-use and interoperation of modelling and simulation systems across NATO Nations and partner countries, leveraging national expertise and knowledge in support of common goals. NMSG capabilities define aspects of how this can be achieved, which are relevant to the use of standards-based simulation supporting training, mission preparation and system evaluation activities.

EXPLOITATION AND IMPACT

This work provides a foundation for an activity on "Representing Human Behaviour and Decision-making in Modelling and Simulation" (MSG-222), which will test and revise the ABRM against a broad range of constructive simulation models involving different types of agents, behaviours, and effects on behaviour.

CONCLUSION

Using the ABRM as a common framework to support discussions, MSG-222 will be able to compare and contrast methods and approaches to determine the most effective. This, in turn, will facilitate follow-on conversations about the composition and re-use of HBM components.

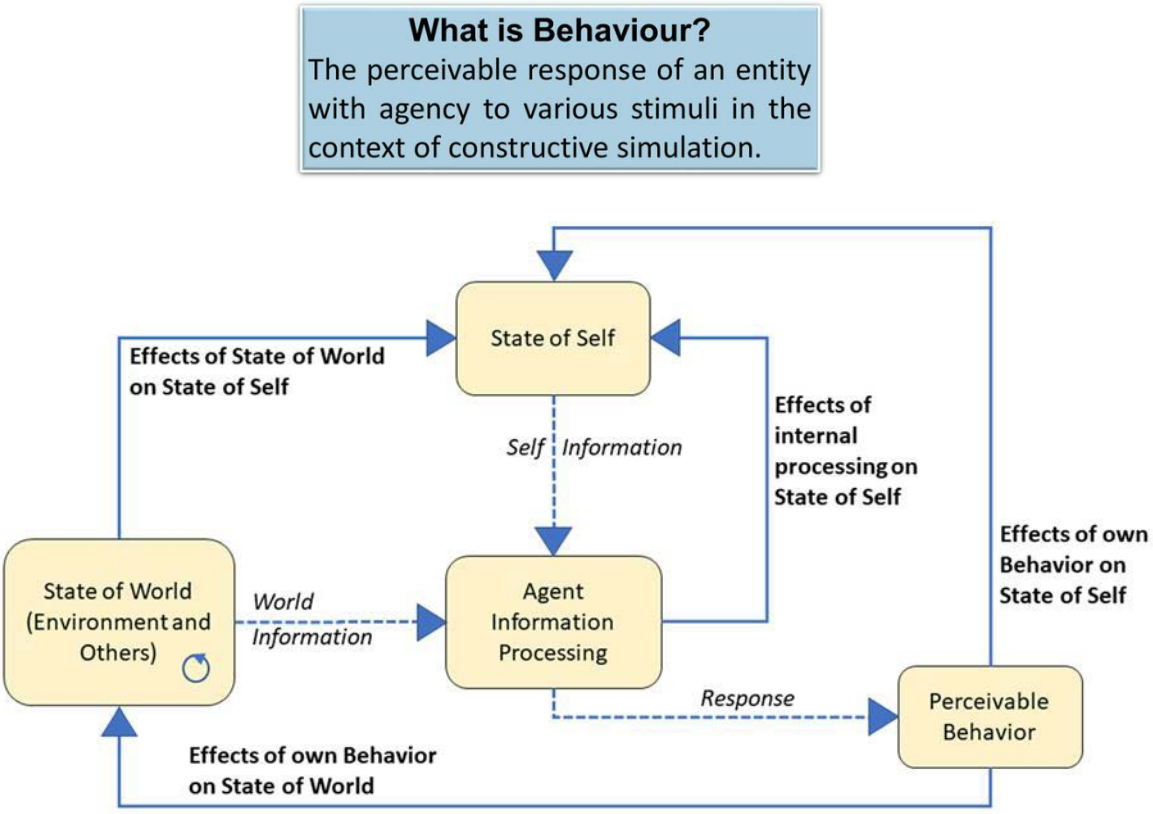


Figure 38: Human Behaviour and Agent Behaviour Reference Model.

ASSESSMENT OF EO/IR TECHNOLOGIES FOR DETECTION OF SMALL UAVS IN AN URBAN ENVIRONMENT (SET-260)

The SET-260 team organised a joint measurement campaign to collect signatures of UAVs and background simultaneously in bands covering visible to far infrared. The signatures were shared among the participating nations to compare the performances of the different technologies, and for the development and evaluation of detection and tracking algorithms.

Dr Marc Chateauneuf, Defence Research and Development Canada (DRDC);
Dr Karmon Stewart, Air Force Research Laboratory (AFRL)

BACKGROUND

Although mini-UAVs are widely used in many civilian applications such as security surveillance, surveying, filmmaking or simply for recreational use, they can also be used for hostile activities, such as spying, targeting, and carrying explosives or chemical/biological weapons. The operational community requires techniques to counter such UAV activities in order to defend and protect themselves against these emerging threats.

MILITARY RELEVANCE

Recent conflicts have shown how the use of unmanned vehicles (aerial, maritime or ground) is a game changer for tactics and force balance in military missions. Non-state organisations such as ISIS have carried out attacks with explosive-rigged drones rigged, and organised armies have used unmanned vehicles in Ukraine and the Nagano-Karabakth region. It is therefore critical that Allies have tools to efficiently detect and defend hostile unmanned vehicles in to protect soldiers and assets in a timely fashion. Detecting mini-UAVs is challenging due to their size and flight patterns, particularly in a complex environment with varying background clutter, such as urban environments.

> *"What we're observing in the ongoing war in Ukraine is a proliferation of drones of various shapes and sizes."* ***US Army Lt. Col. Paul Lushenko, Global News, Oct 2021***

OBJECTIVE(S)

This RTG brought together experts in electro-optical and infrared (EO/IR) detection among the NATO community to share knowledge and data on different EO/IR technologies for the detection of mini-UAVs in an urban environment. This was achieved by conducting a joint field trial.

S&T ACHIEVEMENTS

The team held a joint UAV urban field trial in June 2019 in France. The trial took place at the Urban Zone Combat Training Centre (CENZUB), a facility built for training French armed forces in urban warfare skills. Nine nations participated for a total of 13 teams, collecting UAV and background EO (VIS to FWIR) and acoustic signatures. More than eight different mini-UAV types flew in varying scenarios (including a night event) in the city centre of the training facility, as well as in the industrial zone. More details on the field trial can be found in the NATO video youtu.be/w12AZGCT65w.

SYNERGIES AND COMPLEMENTARITIES

The team organised joint meeting sessions with SET-245 RTG ("Radar-based UAV recognition") during the trial to evaluate the potential of collaborative work. Both teams agreed that sharing expertise, knowledge and equipment to organise a joint trial would be beneficial, and that a co-collect could give researchers the data of a fused or integrated detection system. A joint trial was planned but ultimately abandoned due to COVID.

EXPLOITATION AND IMPACT

The gigabytes of data acquired during the trial were shared and can be exploited by Nations for further development work. Tens of NATO and open literature publications were produced. A research symposium on detecting and defeating mini-UAVs was organised in Copenhagen, Denmark from 9-10 October 2023. The data will also be available for the new SET-ET-128 data and sharing hub (DASH).

CONCLUSION(S)

The detection of mini-UAVs is a complex problem that is most effectively addressed through collaboration among Allies. A TAP for a new RTG was prepared in collaboration with SET-307 to exploit the synergy of both technologies.

Figure 39: Example of clutter urban environment in the visible band. A DJI Mavik 3 can be seen in the middle of the image, which can be difficult to distinguish from the birds.

ANNEXES

OFFICE OF THE CHIEF SCIENTIST

The Office of the Chief Scientist (OCS) is the STO executive body closest to the senior political and military leaders at NATO Headquarters. As the senior advisor to NATO leadership, the Chief Scientist, Dr Bryan Wells, plays a vital role in advising on the science and technology underpinning the next generations of military capability. The OCS supports the Chief Scientist in two of his essential functions: as Chair of the Science and Technology Board (STB), and as senior scientific advisor to NATO leadership. In addition to providing executive support to the STB and its responsibilities, the OCS acts as the focal point for the STO programmes of work (PoWs) and its users represented at NATO Headquarters. To this end, the OCS works with the S&T results generated through STO PoWs and promotes their use in the political and military context. Involving committees and staff at NATO Headquarters and beyond, the OCS coordinates the generation of an overview of NATO S&T programmes across the Alliance to selectively highlight the most relevant and recent S&T results that are available to inform NATO decision-making. In addition, the OCS staff supports the Chief Scientist in providing analysis of significant S&T trends and developments, while conveying an in-depth assessment of the potential impact of S&T and security EDTs on Alliance objectives.

In 2023, the OCS continued to prioritise forward-thinking initiatives and anticipate future trends. These efforts resulted in the publication of the *Science & Technology Trends: 2023–2043* report, which provides evidence-based analysis of EDTs. Furthermore, the OCS co-organised multiple activities regarding the impact of climate change on defence and security.

This year, the Fall STB meeting was held in Helsinki, Finland, marking the first NATO committee held in the country since it joined the Alliance in April 2023. Another notable event took place in October 2023, when the NATO Chief Scientist and the Managing Director of NATO Defence Innovation Accelerator for the North Atlantic (DIANA) signed a Memorandum of Understanding, marking an important milestone in the STO's partnership with DIANA.

Throughout the year, the NATO Chief Scientist led the STO's work to leverage the S&T impact for Nations and NATO, and, under his direction, the OCS reinforced strategic communication on that matter. The Chief Scientist, as a member of the Innovation Board, upheld his advisory role to senior leadership by giving regular briefings, providing guidance on EDTs, encouraging innovation, and preserving the Alliance's unique technological and strategic position. The Chief Scientist also briefed the North Atlantic Council, Military Committee and senior committees such as the Resilience Committee. Furthermore, Dr Wells played a key role as a member of the DIANA Board of Directors, which is responsible for the organizational and strategical governance of DIANA, which works to accelerate cooperation on key technologies by bringing together NATO work and academia for rapid development. There is rapidly increasing demand for evidence-based and scientific expertise across the Alliance, as the importance of maintaining NATO's technological edge becomes ever clearer. Together, the Chief Scientist and OCS staff are fully invested in meeting this demand.

COLLABORATION SUPPORT OFFICE (CSO)

Directed by Mr John-Mikal Størdal, the Collaboration Support Office (CSO) provides executive and administrative support to the STO Collaborative Programme of Work (CPoW). The CPoW is delivered through a collaborative business model whereby NATO Nations and partner countries contribute their national resources to define, conduct and promote cooperative research and information exchange. The CSO plays a critical role in managing and overseeing the CPoW through supporting the business of the STO Science and Technical Committees (STCs), facilitating all collaborative activities, maintaining an active network of scientists, budget planning, and managing the publication of activity reports. The CSO also carries out outreach efforts to ensure that S&T findings from the CPoW reach key audiences, leveraging IT tools such as the STO website, the "Science Connect" collaborative space, various social media platforms, and a database managing the collaborative effort. Taken together, all of these tasks help to ensure that the CPoW delivers high-quality results and that the STO garners widespread recognition for its work to strengthen the Alliance.

THE COLLABORATIVE PROGRAMME OF WORK (CPOW)

The strength of NATO's collective defence ultimately rests upon close cooperation and interoperability among Nations, and the coalescence of national capabilities. Within the STO, NATO Nations and partners benefit from a collaborative framework to address S&T issues and challenges of common interest. Through the CPoW, NATO aims to equip all Nations with the S&T they need to develop the interoperable, cutting-edge capabilities that ensure battlefield success.

Encompassing all cooperative scientific activities and research undertaken by NATO and partner Nations, the CPoW is built upon a collaborative business model that brings together 5,000 of the best and brightest scientists and engineers in government, industry and academia from across the Alliance. They work closely together in more than 400 carefully selected activities in areas of critical importance to NATO militaries: cyber, space, sensors, weapons, command and control, human-machine interface, modelling and simulation, and operational analysis. Working together, sharing technology and knowledge, they can do far more – and at far lower cost – than they could on their own. Nations benefit from access to the world's largest defence collaborative scientific network, while also multiplying the impacts of their S&T investments – in the short, medium and long term, and in ways that often extend beyond the realm of defence.

Nations leverage this work to develop capabilities that enable them to defend against new and emerging threats. Knowledge generated from the CPoW is also used to advise decision-makers on capability development within Nations, thereby ensuring interoperability across the Alliance, while strengthening the industrial and technological base at the national level. With a deeper S&T knowledge base, Nations can make smarter investments in developing or acquiring capabilities, putting scarce resources to more efficient use.

Through participating in the CPoW, Nations of all sizes can come together to share, discuss and develop collaborative solutions to increasingly complex challenges. At a time of growing geopolitical instability, and amid rising competition in the race for technological primacy, the CPoW provides Nations with a robust and cost-effective, cooperative mechanism to maintain their collective technological edge – today, and for decades to come.

The following Scientific and Technical Committees (STCs), commonly known as the Panels and Group, address the total spectrum of this collaborative effort:

- Applied Vehicle Technology (AVT) Panel
- Human Factors and Medicine (HFM) Panel
- Information Systems Technology (IST) Panel
- System Analysis and Studies (SAS) Panel
- Systems Concepts and Integration (SCI) Panel
- Sensors and Electronics Technology (SET) Panel
- NATO Modelling and Simulation Group (NMSG)

Known as the "powerhouse" of the collaborative model, the STCs carry out scientific activities that, collectively, comprise the CPoW. In addition to providing critical international S&T management and scientific oversight, they provide opportunities for coordination and cooperation with military users and other NATO bodies.

Technical Teams formed within and across the STCs carry out scientific work on specific research topics. The Technical Teams can take a variety of forms – including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series, and Technical Courses – and have a defined duration (typically from one to three years). Results from each activity are published as scientific papers, with some featured in scientific peer-review journals. Activity results are frequently publicized through technology demonstrations, as well.

With 393 Technical Activities conducted in 2023, the Collaborative Programme of Work (CPoW) has increased its efforts by 70% since 2012 (see Figure 41). All information on the status of the CPoW can be found in the 2023 CPoW Annual Report at www.sto.nato.int/public/NATO-STO-CPoW-2023.pdf (see Figure 40).

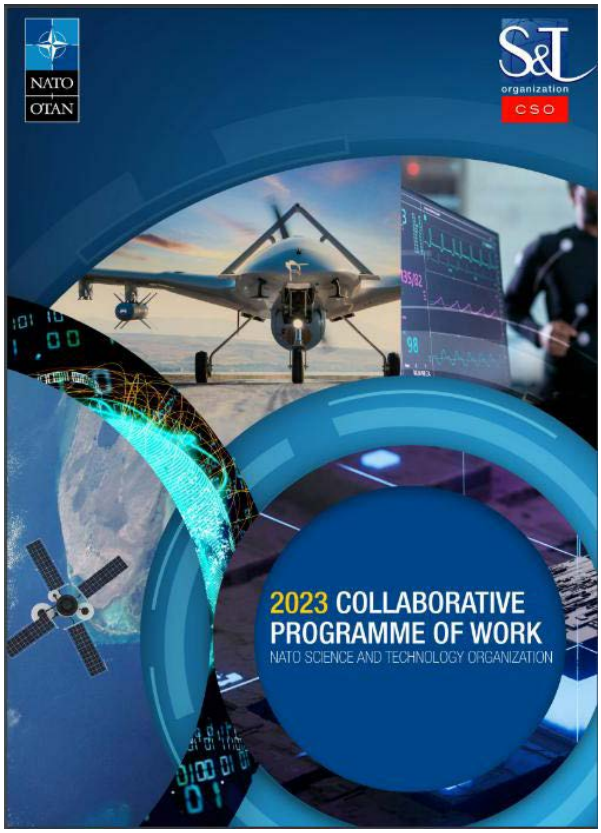


Figure 40: 2023 CPoW Annual Report.

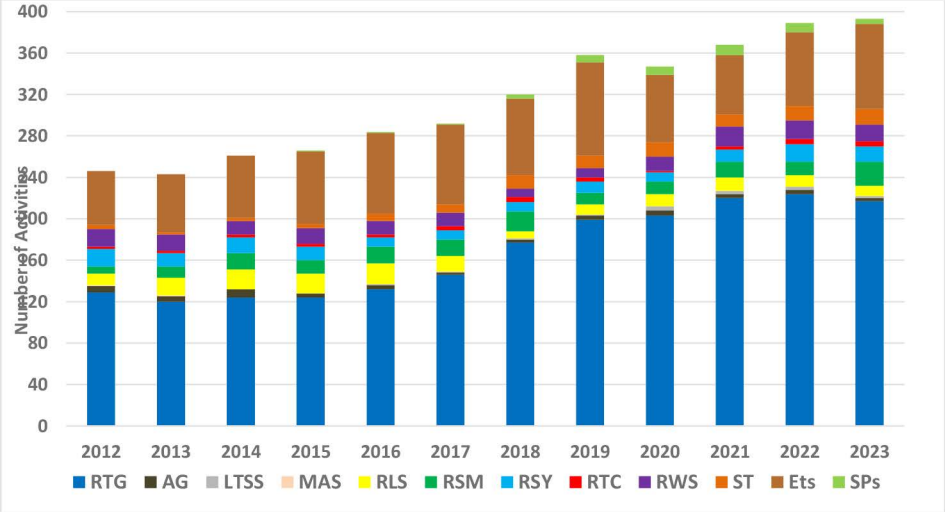


Figure 41: STO CPoW Activities per year.

THE CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION (CMRE)

Directed by Dr Eric Pouliquen, the STO Centre for Maritime Research and Experimentation (CMRE) is a world-class scientific research and experimentation facility focused on the maritime domain. The Centre delivers innovative and field-tested S&T solutions to address the Alliance's defence and security needs. Building on over 60 years of knowledge and experience, CMRE supports NATO's technological advantage in the maritime domain by strengthening the S&T network, accelerating the development of critical capabilities within the Alliance, and building S&T capacity through partnerships. The Centre provides an outstanding at-sea research environment, enabling internationally recognised scientists and engineers from all NATO Nations to deliver results more effectively than would be possible by individual Nations.

RESEARCH VESSELS

Two NATO-owned research vessels are key capabilities for CMRE's experimentation programme. Both ships, flagged and crewed by the Italian Navy, have modern facilities and are complementary, providing a flexible capability from the near shore, to the deep ocean, to the Arctic.

NATO RESEARCH VESSEL (NRV) ALLIANCE

One of the world's quietest ships, the NRV ALLIANCE is an ice-capable, global class vessel designed to minimise noise radiating from the ship into the water. The NRV ALLIANCE is an excellent platform for sonar testing and other types of research where a quiet platform is essential. The 93-metre, 3,180-tonne, open ocean research vessel offers 400 square metres of laboratory space and state-of-the-art navigation and communication equipment.

COASTAL RESEARCH VESSEL (CRV) LEONARDO

Launched in 2002, the CRV LEONARDO is the smallest research vessel in the world that is fitted with dynamic positioning and substantial deck handling equipment. The CRV LEONARDO is a 300-tonne coastal vessel suitable for inshore operations, in particular research experiments with autonomous underwater vehicles and port protection. If you are interested in chartering a vessel, please contact: smo@cmre.nato.int.

PROGRAMME OF WORK

The CMRE conducts cutting-edge maritime scientific research and experimentation, ranging from concept development to prototype demonstration at sea. Today, the Centre's research scope encompasses technological trends focused on collaborative autonomy, big data analytics and decision support tools, and AI and quantum technology. The CMRE's main scientific programmes are funded by NATO Allied Command Transformation (ACT) and are designed to address future defence requirements of the Alliance in the maritime domain.

Autonomy for Anti-Submarine Warfare (ASW):

Improving the Alliance's ability to counter submarine threats through networks of securely communicating autonomous systems with adaptive behaviour.

Data Knowledge and Operational Effectiveness (DKOE):

Using data science techniques to improve maritime situational awareness and information exchange among NATO Nations and enhancing the Alliance's ability to operate in the maritime domain through greater understanding of the operating environment.

Autonomous Naval Mine Countermeasures (ANMCM):

Strengthening NATO's ability to counter naval mines through networks of securely communicating, adaptive autonomous systems.

Maritime Unmanned Systems Enablers (MUSE):

Providing capabilities for the development of unmanned system of heterogeneous systems with a high level of interoperability, security and persistence.

Climate Change and Security (CC&S)

In 2023, the STO CMRE, sponsored by the OCS, developed a unique and forward-looking S&T line of research focused on Climate Change and Security (CC&S).

INTERNATIONAL EXERCISES

In 2023, the CMRE participated in a number of NATO and international exercises, including the Robotics Experimentation Prototyping for Maritime Unmanned Systems (REPMUS) and NATO Dynamic Messenger exercises held in Portugal. During REPMUS and Dynamic Messenger, the CMRE deployed over 70% of its research staff and the NRV Alliance as an autonomous vehicle command and control (C2) platform to further the development of maritime underwater systems enablers for ASW, mine countermeasures (MCM), and rapid environmental assessment (REA), demonstrating their utility in an operational context with front-line operators.

In addition to facilitating CMRE's participation in exercises, the NRV Alliance was the platform for the execution of scientific experiments in the High North. From 20 June-11 July, the CMRE, along with other partner organisations, conducted the Nordic Recognized Environmental Picture (NREP23) sea trial, studying the effects of climate change in the Fram Strait.

LIST OF ACRONYMS AND ABBREVIATIONS

AASW	Autonomous Anti-Submarine Warfare
ABRM	Agent behaviour reference model
ACT	Allied Command Transformation
AFRL	Air Force Research Laboratory
AFU	Armed Forces of Ukraine
AFV	Armoured Fighting Vehicle
AGARD	Advisory Group for Aeronautical Research and Development
AI	Artificial intelligence
AIS	Automatic identification system
ANMCM	Autonomous Naval Mine Countermeasures
ASW	Anti-submarine warfare
AVT	Applied Vehicle Technology
BLOS	Beyond line-of-sight
CATL	Collaborative Autonomy Tasking Layer
CCASCOE	Climate Change and Security Centre of Excellence
CC&S	Climate change and security
CFD	Computational fluid dynamics
CFI	Connected Forces Initiative
CMRE	Centre for Maritime Research and Experimentation
CNAD	Conference of the National Armaments Directors
COE	Centres of Excellence
CPoW	Collaborative Programme of Work
CS	Compressive Sensing
CSO	Collaboration Support Office
CUI	Critical underwater infrastructures
DALO	Defence Acquisition and Logistics Organization
DASH	Data and sharing hub
DEVCOM	US Army Combat Capabilities Development Command
DGA	Directorate General of Armament
DIANA	Defence Innovation Accelerator for the North Atlantic
DKOE	Data Knowledge and Operational Effectiveness
DND	Department of National Defence
DRDC	Defence Research and Development Canada
EDT	Emerging and Disruptive Technologies
EKOE	Environmental Knowledge and Operational Effectiveness
EO/IR	Electro-optical and infrared
ESA	European Space Agency
EU	European Union
FAMOS	Framework for Avionics MissiOn Systems
FFI	Norwegian Defence Research Establishment
FKIE	Fraunhofer Institute for Communication, Information Processing and Ergonomics
FOI	Swedish Defence Research Agency
FMN	Federated Mission Networking
HBM	Human behaviour models
HEL	High-energy laser
HEPS	Hybrid-electric propulsion systems
HF	High-frequency
HFM	Human Factors and Medicine
HOSTAC	Helicopter operations from ships other than aircraft carriers
HRL	Human readiness level
IC	Innovation Challenge
IED	Improvised explosive device
IET	Institute of Engineering and Technology
ISAR	Inverse synthetic-aperture radar
ISIS	Islamic State of Iraq and the Levant
ISR	Intelligence, surveillance and reconnaissance
IST	Information Systems Technology
JALLC	Joint Analysis and Lessons Learned Centre
LIDAR	Light detection and ranging
LoD	Line of Delivery
MARCOM	Maritime Command
MASINT	Measurement and signature intelligence
MCM	Mine countermeasures
MEC	Munitions and explosives of concern
MINEX	Mine exercise
MIT	Massachusetts Institute of Technology

ML	Machine Learning
MOSA	Modular Open Systems Approach
M&S	Modelling and simulation
MSaaS	Modelling and simulation as a service
MSI	Musculo-skeletal injuries
MSMP	Modelling and Simulation Master Plan
MUS	Maritime Unmanned Systems
MUSE	Maritime Unmanned Systems Enablers
MVP	Minimal viable product
MW	Mine warfare
NACO	NATO Arctic Climate undersea Observatory
NCIA	NATO Communications and Information Agency
NGNRMM	Next-Generation NATO Reference Mobility Model
NIAG	NATO Industrial Advisory Group
NMSG	NATO Modelling and Simulation Group
NMSSP	NATO modelling and simulation standards profile
NMW	Naval Marine Warfare
NRV	NATO Research Vessel
OA	Operations analysis
OCS	Office of the Chief Scientist
OR	Operations research
OSA	Open systems architectures
OSUS	Open Standards for Unattended Sensors
P&E	Planning and evaluation
PDD	Public Diplomacy Division
PED	Processing, exploitation and dissemination
PfP	Partnership for Peace
PNT	Positioning, navigation, and timing
PoW	Programmes of work
PRU	Principles of Responsible Use
PTSD	Post-traumatic stress disorder
R&D	Research and development
REA	Rapid environmental assessment
REP	Rapid Environmental Picture
REPMUS	Recognised Environmental Picture augmented by Maritime Unmanned Systems
RF	Radio Frequency
RTG	Research Task Group
S&T	Science and technology
SACT	Supreme Allied Command Transformation
SAPIENT	Sensing for Asset Protection with Integrated Electronic Networked Technology protocol
SAS	System Analysis and Studies
SATCOM	Satellite communications
SCI	Systems Concepts and Integration
SET	Sensors and Electronics Technology
SHOL	Ship-helicopter operational limits
SISO	Simulation Interoperability Standards Organization
SOFCOM	Allied Special Operations Forces Command
SoI	Signals of interest
SSA	Space Situational Awareness
STANAGs	Standardization Agreements
STANREC	Standardization Recommendation
STB	Science and Technology Board
STC	Science and technical committees
STEAM	Science and Technology Ecosystem Analysis Model
STEM	Science, Technology, Engineering, and Mathematics
STJU	Steadfast Jupiter
STO	Science and Technology Organization
TAP	Technical Activity Proposal
TIDE	Think-Tank for Information Decision and Execution Superiority
TNO	Netherlands Organisation for Applied Scientific Research
TRL	Technical (technology) readiness level
UAV	Unmanned aerial vehicles
UHF	Ultra High Frequency
UX	User Experience
vKHS	von Kármán Horizon Scan
VTOL	Vertical take-off and landing
WDA	Warfare Development Agenda
WG	Working Group
ZSF	Zagreb Security Forum

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