NATO OTAN

10 YEARS ANS

Science & Technology Organization

Organisation pour la Science et la Technologie

S&T organization

2022 HIGHLIGHTS

SCIENCE AND TECHNOLOGY ORGANIZATION

EMPOWERING NATO'S TECHNOLOGICAL EDGE

WWW.STO.NATO.INT

FOREWORD

FOREWORD

Figure 1: Dr Bryan Wells, NATO Chief Scientist.

2022 has been marked by major geopolitical events, from Russia's invasion of Ukraine to the invitation to Finland and Sweden to join the NATO Alliance. The NATO Summit in June, close to the mid-point of the year, provided a significant opportunity for Allies and Partners to demonstrate their solidarity and unity, and also advance an ambitious forward agenda.

This "Highlights 2022" publication shows how the NATO Science and Technology Organization (STO) has been proactive in contributing to NATO's forward agenda, how it has been responsive to the changing circumstances, and how it is building resilience into its workforce.

Throughout the year, with a **proactive** approach, several initiatives were taken in order to expand the Organization's knowledge base and enhance its network of experts. The Science & Technology Board (STB) successfully identified a number of challenges for the Collaborative Programme of Work (CPoW) in areas where the research could be strengthened. Furthermore, the Office of the NATO Chief Scientist (OCS) in conjunction with the STO Centre for Maritime Research and Experimentation (CMRE) carried out several activities to identify crucial aspects of environmental transformation and study how climate change could affect NATO's maritime operations and security.

As a means to ensure a greater impact of STO influence across the Alliance, **responsiveness** lies at the core of our strategy. Following agreement of the new Strategic Concept at the Madrid Summit, which gives enhanced prominence to S&T, the STO is working to ensure that it is responding swiftly to the policy drivers set out in that document. The advancements in Distributed Synthetic Training (DST) by the NATO Modelling and Simulation Group (NMSG) are an example of how we contribute to the realisation of high-level initiatives, paving the transition from mature technologies to effective military capability whilst satisfying the Allied demand for expertise in the field.

Following the STO commitment to keeping the Organization fit for the growing demand for S&T from Nations and NATO, **resilience** has been of paramount importance. Therefore, we remain committed to encourage the participation of early career scientists, who keep nurturing our vibrant network through fresh and unconventional ideas, and create relevant networking opportunities for other members of the STO community. The events marking "70 years of S&T in NATO" and the celebration of the "STO 10th Anniversary" were two important occasions that brought our community together to enhance our scientific ecosystem. Our scientific Panels and Group also held their 50th Business Meetings this year, marking an important milestone in their ongoing engagement with their networks of world-class scientists, engineers, and analysts. The STO Panels and Group are the "powerhouse" of collaborative science and technology in NATO, and the bi-annual Business Meetings are a key opportunity for them to evaluate their work and decide on future activities.

The scale of our efforts is reflected in the statistics provided on our Programmes of Work. Over the year 2022, we have carried out more than 300 activities, which spanned the range of physical, information and human sciences and application over all five of NATO's operational domains (land, sea, air, cyber and space). This report demonstrates the quality of STO's work as it continues to nurture its vast network of experts, while advising leadership on potential future threats and anticipating the development of emerging and disruptive technologies.

Thus, this report shows how the STO Programmes of Work (PoW), and the Organization as a whole, continues to deliver the necessary solutions to face the security challenges of today and tomorrow while ensuring that Allies and Partner Nations maintain their scientific and technological advantage.

Dr Bryan WELLS

NATO Chief Scientist
STB Chairman

TABLE OF CONTENTS

"Emerging and disruptive technologies bring both opportunities and risks. They are altering the character of conflict, acquiring greater strategic importance and becoming key arenas of global competition. Technological primacy increasingly influences success on the battlefield."

NATO 2022 Strategic Concept, 29 June 2022

"With our [NATO] Chief Scientist, we are doing [AI] horizon scanning, and we're looking already to metamaterials and nano technologies."

NATO Deputy Secretary General Mircea Geoană, NATO Data and AI leaders conference, NATO HQ Brussels, 8 November 2022

"The STO scientists are the brightest of the brightest of NATO's ecosystem."

NATO Deputy Secretary General Mircea Geoană, STO 10th Anniversary celebration, NATO HQ Brussels, 19 September 2022

PROACTIVE

PROACTIVE

ANTI SUBMARINE WARFARE (ASW)

With more than 60 years of knowledge and experience in undersea research, the Centre for Maritime Research and Experimentation (CMRE) is a recognised centre of expertise in the Anti-Submarine Warfare (ASW) domain. The CMRE has also played an active role in assessing Emerging and Disruptive Technologies (EDTs) and their potential impact on defence capabilities and military operations.

Today, the CMRE ASW Programme encompasses the fields of advanced sensing, AI, autonomous systems, underwater acoustics, and operational analysis. The programme is supported by a dedicated sea-going capability, which facilitates cutting-edge maritime research in environments ranging from the Mediterranean Sea to the Atlantic and Arctic Oceans.

In 2022, the ASW team carried out two exercises off the Portuguese coast: Robotic Experimentation and Prototyping using Maritime Unmanned Systems (REPMUS22) and Dynamic Messenger (DYMS22). The team deployed the full CMRE unmanned passive ASW sensing capabilities on board Maritime Unmanned Systems (MUS), demonstrating their real-time detection, localisation and tracking capacities. These exercises marked the first-ever use of highly sensitive quantum magnetic sensors packaged in networked sea-bottom nodes, as well as the first real-time information exchange between MUS in order to autonomously improve detection performance and sensing opportunities. These milestones illustrate the rapid pace at which unmanned network systems are developing, and underscore their potential to dramatically enhance current ASW capabilities.

The programme's operational analysis examines the potential deployment of unmanned assets in order to determine optimum mixes of available platform types (including manned assets) – accounting for speed, detection range, endurance and logistical considerations. Analysis of the optimum results provides further insight into the critical limitations of certain asset types, and may de-risk future procurement.

CLIMATE CHANGE

NATO has recognised that climate change poses significant challenges to Alliance planning and operations, and to the security of Allied Nations. These challenges are particularly acute in oceanic and coastal regions, which face rising sea levels, more intense and frequent extreme weather events, and increased flooding, among other climate-related effects.

Successfully integrating climate change into the Alliance military planning and exercises requires an understanding of both climate dynamics in multiple contexts and specific military needs. Benefitting from the expertise of the CMRE, the STO is in a privileged position to help NATO understand and forecast how climate change is affecting the maritime environment, and to address its implications on the defence sector.

CMRE conducted a range of S&T activities related to climate change and security in 2022. Sponsored by Allied Command Transformation (ACT) and in collaboration with international partners, CMRE conducted the Northern Recognized Environmental Picture sea trial (NREP22), collecting oceanographic data, testing underwater acoustic communications, and introducing the use of autonomous aerial and underwater drones. It also published studies on how ongoing environmental changes in the Arctic region affect SONAR performances in future climatic scenarios. Recognising the Mediterranean Sea as a climatic hot spot, CMRE also tested novel technologies and sensoring capabilities, including the development of a "digital twin" of the Arctic and northern Atlantic Oceans, and the exploitation of advanced analytic techniques and AI-driven algorithms to understand and forecast the climate dynamics of the region.

In addition, CMRE provided important support to the NATO 2030 initiative, contributing to the drafting and updating of the Climate Change & Security Impact Assessment, which is the backbone of the NATO Climate Change & Security Working Group. Moreover, it conducted various outreach and communication initiatives, including dissemination activities targeting the general public and the NATO community, as well as a report for the NATO Climate Change and Security Centre of Excellence (CCASCOE) offering a prioritisation of S&T topics in the maritime domain to be tackled in the upcoming years.

ARTIFICIAL INTELLIGENCE AND BIG DATA IN WARFARE

Military operations have always relied upon good information, but ensuring access to quality information has become more challenging in the digital age. As the amount of data available to wartime military decision makers has increased, so too has the complexity of operations. In today's information-driven environment, information technology (IT) and the ability to apply data play an increasingly pivotal role in the performance of military tasks.

Data is a strategic resource. Artificial intelligence (AI) and big data (BD) have the potential to help militaries gain and maintain information dominance on the battlefield, and significantly increase the speed and quality of the Observe, Orient, Decide, Act (OODA) loop. Although they are not the only promising technologies on the horizon, AI and BD play a dominant role in driving automation and autonomous systems used to support and empower military units in dull, dirty, and dangerous tasks.

For militaries to become "AI ready", they must take actions to address certain precondition requirements. This necessitates working with interdisciplinary teams and in close alignment with the intended users of AI applications, such as warfighters. The NATO STO, through its CPoW, currently supports 27 multi-national and interdisciplinary activities that primarily focus on the preconditions and development of new AI technologies. This work is closely tied with numerous other NATO initiatives and organisations, especially NATO Allied Command Transformation (ACT) and the NATO Communications and Information Agency (NCIA).

In November 2022, NATO leaders convened their first-ever Data & AI Leaders Conference on BD and AI with a focus on building sound foundations for both governance and responsible use of these technologies.

Figure 2: Artificial intelligence and big data in warfare.

HYBRID WARFARE

Through its innovative use of well-known warfare methods, and with the help of new technologies, Russia's concept of operations in Crimea and Eastern Ukraine took many in the West by surprise. Analysts immediately searched for definitions for this "new" approach, with most falling within the West's theoretical framework. These include the Gerasimov Doctrine, hybrid warfare and hybrid threat, non-linear warfare, fourth generation warfare, and most recently, "grey zone" conflict. Yet in attempting to fit Russian strategy within Western theoretical constructs, rather than those within which it was developed, this approach has resulted in misconceived characterisations.

Figure 3: Hybrid warfare.

Russian military strategy and operational art are rarely valid beyond a single region and operational domain. Until now, Russia's main focus – especially as it concerns NATO – has been on non-kinetic instruments to achieve strategic objectives at the political level. These include cognitive warfare, with an emphasis on disinformation and psychological operations, and cyber-attacks, among other instruments. New technologies have made it easier to implement such hostile mechanisms, with Russia increasingly targeting the national fabric of its competitors to achieve its ultimate objectives in the political realm. Since this type of threat is multi-layered and targets a nation's very existence, war and defence should go beyond the armed forces and involve the whole of society.

The NATO STO helps the Alliance to overcome challenges in hybrid warfare research, primarily through work carried out by the NATO STO System Analysis & Studies (SAS) Panel and the NATO Modelling and Simulation Group (NMSG). This includes defining limits between the military and civilian domains; determining how deterrence works and types of new deterrence (e.g. coercion); understanding the effect of new technology on warfare; organising defence against hybrid warfare in a multi-layered and multi-domain environment; and assessing the willingness to defend one's country in case of non-kinetic and kinetic attacks.

ADVANCES IN ARTIFICIAL INTELLIGENCE AND INFORMATION FUSION FOR MARITIME SITUATIONAL AWARENESS

Artificial intelligence (AI) is already transforming a range of industries, and according to NATO's AI Strategy,[1] it is transforming the international security environment, as well. This transformation will only accelerate as AI technologies continue to evolve, and will be even more revolutionary when AI is combined with quantum processing technologies.

In this context, the Alliance has to constantly update, if not revolutionise, operational doctrines and capabilities, including in the maritime domain. Maritime Situational Awareness (MSA) is the core of maritime operations, and can leverage the most recent developments in AI and other Emerging and Disruptive Technologies (EDTs).

Figure 4. Workflow of next-gen Seabed-to-Space Situational Awareness (S3A) – all-domain – situation awareness C4-ISR, in the form of an automated OODA loop (Observe, Orient, Decide, and Act). Each block represents the main sub-systems composing the next-gen S3A based on distributed and decentralised AI decision makers controlling swarm of unmanned assets acquiring and fusing data/information, integrated with human operators and game theoretic models.

AI could streamline the processing of available data to improve decision making and deliver cognitive superiority, thereby bolstering operational effectiveness. AI and Information Fusion (IF) can easily process immense volumes of information fused from a variety of sources and generated from monitoring a very large number of assets, and use the learned knowledge to anticipate future behaviours and/or identify threats and critical situations.

Inspired by human cognitive abilities to automate routine tasks, NATO is fostering research that aims to develop and Advance Maritime AI and IF (MAI2F) in support of the cognitive processes of analysts and operators. Technological advances in MAI2F present the opportunity to transition MSA towards the holistic perspective of seabed-to-space situational awareness (S3A), also referred to as "all-domain situational awareness". This is a first step towards the concept of next-generation S3A systems, which is expected to be built around Multi-Domain Operations (MDO) and actively supported by AI technologies.

NATO ALLIANCE SMALLSAT CONSTELLATION EFFORT (ALLSAT)

Space is essential to NATO's collective defence missions, crisis response, disaster relief, counterterrorism and deterrence. Space services form the foundation of the Alliance's ability to navigate, track blue and red forces, share intelligence, communicate securely with partners, detect missile launches, and execute effective command and control. Research in space technologies and their military application has been an essential part of the STO Programme of Work for nearly 70 years, and this work has taken on new importance in recent years, in light of significant changes to NATO's approach to space. In 2019, for example, the Alliance declared space as a new operational domain, alongside air, land, maritime and cyberspace.

The NATO Alliance SmallSAT Constellation initiative is a research activity aimed at developing a 3-ball Nationally-owned satellite constellation as a testbed for collaborative S&T and experimentation in low-earth orbit. Each satellite in the proposed constellation would carry three S&T payloads – a space weather sensor, an optical sensor for space domain awareness and an optical communication payload for the ALLSAT constellation – and the entire system would be owned by Nations. Carried out under the STO Systems Concepts and Integration (SCI) Panel, ALLSAT builds upon several previous space S&T activities completed within the SCI Panel, as well as work carried out by the Applied Vehicle Technology (AVT) and Sensors and Electronics Technology (SET) Panels.

The development of the ALLSAT constellation is a critical first step to accelerating technology development within the Nations, and to ensuring the interoperability of future military capabilities that are essential for the Alliance. The activity aims to explore several key aspects of the space

Figure 5: Depiction of ALLSAT.

1 PO(2021)0350 – NATO's Artificial Intelligence Strategy.

domain, including operational standards, command and control, and interoperability. The system will also act as a multi-national technology testbed for low-power space-based sensing (e.g. space weather, space domain awareness, electronic intelligence, and remote sensing), on-board artificial intelligence, optical communications, novel propulsion, and payload/platform interoperability and resiliency. The system's proposed launch date is currently 2024.

CHALLENGING THE COLLABORATIVE PROGRAMME OF WORK

Built on an extensive network of national scientists and researchers, the Collaborative Programme of Work (CPoW) represents the STO's main contribution to developing modern interoperable capabilities.

In March 2022, the STB took stock of the current shape and content of the CPoW and discussed ways to strengthen it further. Taking into account the growing importance of emerging and disruptive technologies and recognising the indications for increases in national defence research budgets, the STB agreed on a new initiative: **Challenges to the CPoW**.

Particularly focused on programme development, each of these Challenges will promote one particular topic identified in line with Nations' medium-term funding priorities and championed by a Lead Nation. Within 12 months, each Challenge will deliver an overarching problem statement and a set of suggested research projects for the Panels and Group to take up. Taken together, these outputs will shape a forward-looking research agenda for that specific topic, driven by the Nations' most pressing needs, 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 give the lead time required for Nations to allocate their resources; and
- Establish cross-domain communities of interest that attract additional experts to engaging in and contributing to in the CPoW.

To launch this new initiative, the STB agreed on four pilot cases for immediate launch:

- For **Cognitive Warfare**, the Lead Nation Norway held a scoping workshop on November 2022, where participants generated 14 project drafts suggested to address cognitive warfare across four dimensions: situational awareness, cognitive effects, modus operandi and technological enablers.
- In December 2022, the Lead Nation Germany hosted a workshop on **Hypersonics (Technology Needs for Hypersonic Operational Threats – TecNHOT)**. Participants from a range of academic and operational backgrounds discussed 11 topics for further collaboration within the CPoW. The effort will be continued in a multi-disciplinary approach, involving all STO Panels and the Group.
- Canada is leading the **Climate Change and Security** Challenge through a series of virtual workshops that will culminate in a symposium in the course of 2023.
- For **Quantum Technology**, the allocation of national resources is nearing completion, with concrete work to commence in early 2023.

RESPONSIVE

RESPONSIVE

SYNTHETIC BIOLOGY

Synthetic biology is a multi-disciplinary science that facilitates the design and construction of biological components, systems or organisms that are not found in nature. By redesigning existing organisms and biological structures, or creating entirely new ones, biological engineers can create life forms and cellular components with novel properties that can be applied to a variety of issues.

Synthetic biology is expected to provide powerful defence and security capabilities over the next two decades, while reducing costs and increasing flexibility. Synthetic biology-based technologies will also assist Nations in meeting obligations arising from agreements and legislation on climate change. Work in this field will advance capabilities across a wide range of areas, including sensing; computing; materials and chemical production; materials protection and repair; agriculture and environment; energy storage and generation; human performance augmentation; medicine and pharmaceuticals; and chemical, biological, radiological, and nuclear defence. Although the applications of synthetic biology are expansive and promising, its acceptance and adoption will vary according to societal ethics and norms across Nations.

Synthetic biology has been identified as a focus area within the NATO STO, and is currently being examined by a Research Task Group (RTG) in the Human Factors and Medicine (HFM) Panel. The RTG (HFM-305) is investigating emerging opportunities and threats as they relate to the NATO defence structure, NATO's ability to prevent/assess, protect, and recover/mitigate during operations, and national security.

Figure 6: Representation of synthetic biology.

EDTS/EDT++

The STO remains committed to delivering a cutting-edge work programme while nurturing its network of national subject matter experts who are the foundation of the Alliance's knowledge base. The STO maintains technology watch and analysis capabilities, provides welcomed ideas and insights to the Defence Innovation Accelerator for the North Atlantic (DIANA) and provides direct advice to a wide public audience and senior leadership in NATO on current and foreseeable EDT developments. Over 2022, the STO explored new forecasting methodologies under the System Analysis and Studies (SAS) Panel, conducted a von Kármán horizon scan on artificial intelligence (AI), published new technology watch cards on various susbjects, discussed AI's malicious use, and began work on an update to the S&T trends report, last published in 2020. To expand the evidence base upon which this advice is given, the OCS has worked with NCIA to develop a technology watch dashboard known as the Science and Technology Ecosystem Analysis Model (STEAM). STEAM employs AI and big data analytics to help understand the development of EDTs and the innovation system that supports it. To complement this analysis, a detailed survey of the STO's network of nearly 5,000 scientists has provided unparalleled insight into the state, rate and military impact of EDTs. Publication of the associated S&T trends report is expected in early 2024.

VON KÁRMÁN HORIZON SCAN ON ARTIFICIAL INTELLIGENCE

Throughout 2022, the STO conducted a von Kármán Horizon Scan on artificial intelligence (AI) to assess the implications of AI on deterrence and defence. Named after Theodore von Kármán, the founding Chair of the NATO Advisory Group for Aeronautical Research and Development (AGARD), this particular type of technology forecasting project brings together experts with military, research and business backgrounds. In the scan on AI, experts from nine Allied and Partner Nations as well as NATO, shared their professional views and insights on the current state-of-play in AI and discussed plausible future development trajectories. Defence cases studies included intelligence, surveillance, and reconnaissance; missile defence; electronic warfare and drone swarms; and cyber defence. Key findings on risks and opportunities of AI-enabled defence systems are expected in the first half of 2023.

DISTRIBUTED SYNTHETIC TRAINING

Many Allied Nations are currently re-evaluating the live-synthetic balance of their operational training in order to address issues such as security, range/airspace limitations, asset availability, frequency, cost and environmental factors. However, the growing demand for distributed mission training in synthetic environments exceeds Allies' current training capabilities. NATO's vision for Distributed Synthetic Training (DST) is to establish a coalition-wide federation of national mission training capabilities powered by coherent architectures and security procedures, common standards and training objectives, and shared data. Effective DST capabilities would provide participating Nations with access to large- and small-scale coalition-level synthetic-enabled environments, as well as operational collective training across all operating domains, including cyber and, potentially, space.

The NATO Modelling and Simulation Group (NMSG) has developed and matured the technologies and policies required for establishing DST capabilities. A DST Working Group was formed in 2021, under Achieving and Accelerating Capability Development and Delivery (A2CD2): a joint initiative of the STB, Conference of National Armaments Directors (CNAD) and Allied Command Operations (ACO) / Allied Command Transformation (ACT). The working group brings together more than 100 members from 18 Nations and 15 NATO bodies and international organisations.

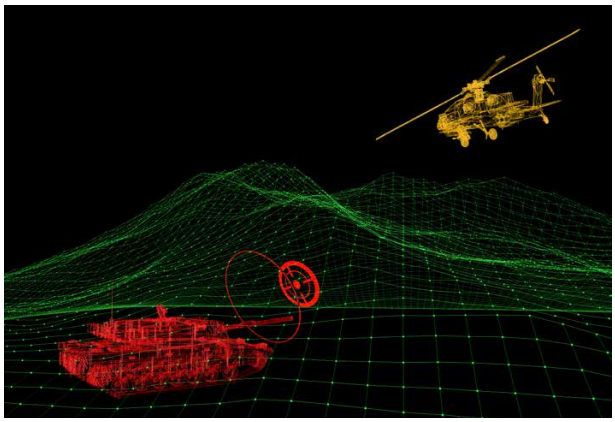

Figure 7: Depiction of distributed synthetic training.

COVID-19 DISINFORMATION

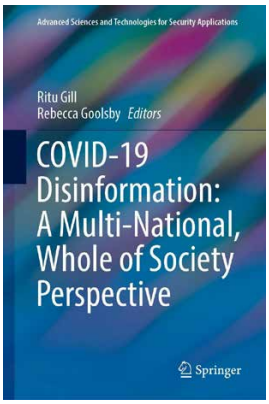

Figure 8: Book published on COVID-19 disinformation by STO scientists.

The COVID-19 pandemic has reaffirmed an understanding that has already been recognised over the years: a systematic and well-organised disinformation campaign can threaten peoples' lives, health and well-being. Cognitive conflict and the scourge of disinformation are now ubiquitous across the international security environment, as countries including Russia and China are conducting disinformation campaigns – especially against the backdrop of the illegal Russian invasion of Ukraine. Disinformation campaigns are hardly new and have long been a staple of geopolitical conflict. Nevertheless, the precision, breadth, volume and automation of such attacks during the COVID-19 pandemic were unprecedented. One of the ways that the NATO Alliance and the STO have countered these issues has been through the active use of S&T. The Human Factors and Medicine (HFM) Panel and the System Analysis and Studies (SAS) Panel are fully engaged in this research area through various activities such as the HFM-336 Specialist Team titled "Disinformation in relation to COVID-19". One of the outputs of their collective research is the recent publication of a book on disinformation and how to defend against it, notably through the lessons learned in countering the COVID-19 infodemic. The book is part of the Organization's wider efforts to support Allied and Partner Nations and help NATO maintain cognitive superiority and strengthen layered resilience. In the book, scientists from the HFM Panel and the Office of the Chief Scientist write about their work on topics such as the impact of emerging and disruptive technologies on COVID-19 disinformation, approaches to the detection and mitigation of COVID-19 disinformation, and how to defend against such actions. "This book shows the ability of the network of scientists who work in the NATO Science and Technology Organization to react rapidly and with agility and bring their expertise to bear on new crises in innovative ways," NATO Deputy Secretary General Geoană said. The book is available in hard copy and online at: https://link.springer.com/book/10.1007/978-3-030-94825-2.

TIDE SPRINT

In April 2022, the STO organised a track focused on science and technology (S&T) during the Spring 2022 Think-Tank for Innovation Decision and Execution Superiority (TIDE Sprint), held in Sopot, Poland. Organised in coordination with NATO Allied Command Transformation (ACT), this S&T Track brought together scientists and military operators to exchange views on key S&T topics affecting the Alliance, and their potential future impact. In the longer term, this track also contributes to developing a common S&T culture among Nations, thereby improving upfront interoperability. STO and ACT subject matter experts designed 10 workshops on topics of particular relevance to future NATO operational capabilities, including artificial intelligence, data science, quantum sciences, wargaming and space, among others. The workshop topics also align with NATO S&T priorities and ACT Warfare Development Agenda Lines of Delivery.

CSRRs (CHIEF SCIENTIST RESEARCH REPORTS)

The NATO Chief Scientist has two roles: first as scientific advisor to senior NATO leadership and second as Chair of the STB. This advice is sourced from the collective STO programmes and the underlying knowledge base, and then synthesised and integrated in a timely manner **for political and military decision makers**. Chief Scientist Research Reports (CSRRs) bring deep STO research together in a cross-panel perspective, focusing on communicating consolidated insights and results to decision makers at all levels on a specific topic of interest. Such an approach increases the impact of STO research on NATO decision making and operations. This year, CSRRs have been published on "The Impact of technological trends on Chemical, Biological, Radiological and Nuclear (CBRN)", "Autonomous Technologies", "Advancing the NATO Special Operation Forces (SOFs) Lifecycle", and "Artificial Intelligence (AI) Review". To increase the distribution of these reports, they have been made available on the STO website.

FINLAND AND SWEDEN: RESEARCH CAPABILITIES AND ENGAGEMENT WITH STO

FINLAND'S APPROACH TO SCIENCE AND TECHNOLOGY – COMPREHENSIVE RESEARCH IN THE ARCTIC DOMAIN[2]

Judging by where people actually live, Finland is the most arctic country in the world. Our operational environment is marked by three geographic facts: a 1,340 km land border between the EU and Russia; isolation from the rest of Europe by the Baltic Sea; and a geographic location at high latitudes.

Finland has four seasons, each with drastically different weather, sensor background signatures and terrain conditions. Soldiers must fight and their gear must remain operable in varied and extreme environments. The polar night lasts for 52 days straight in the northern part of the country. The lowest temperature measured is -51.5 °C and -40 is not a rare occurrence. At such temperatures, batteries die, diesel fuel solidifies, and military standard cables crack when bent.

Figure 9: Finnish military training is inherently arctic (Photo: Anna Kupsala/Finnish Defence Forces).

2 Author: Col. Jyri KOSOLA, Research Director, Defense Command, Finland.

Finland is mostly forests, swamps, and lakes. Lakes and swamps can be impassable for mechanised forces in the summer, but become ideal tank terrain when frozen. Frozen ground impedes mine laying and fortification, but enhances off-road mobility, until heavy snow falls. Sea ice poses a challenge for ship movement and sonar systems. Finally, due to Finland's location at high latitudes, communications and navigation satellites fly low on the horizon, but intelligence satellites pass by frequently.

Figure 10: Finland is the only country in the world where all harbours freeze during winter (Photo: Finnish Defence Forces).

Apart from its arctic climate and nature, Finland is defined by its people. Finland is both the happiest and the least corrupt nation in the world (*World Happiness Report* 2018 –2022, *Corruption Perception Index* 2021).[3] In 2019, we scored second in gender equality. This is a land and society worth defending.

The latest survey found that 88% of Finnish men will fight for their country, even if the situation seemed desperate. The Finns' will to defend is the highest in Europe. This attitude breeds resilience and is also reflected in conscription: each year, 74% of the men's age cohort begin their 6- to 12-month military service. As many as 600,000 Finns actively practise hunting and shooting, reinforcing skills acquired in military training.

With a population of only 5.6 million, conscription enables Finland to maintain an effective wartime strength of 280,000 soldiers complemented by a reserve of 870,000 militarily trained people. Finland has the strongest artillery in Europe among NATO Nations and a considerable number of main battle tanks and other heavy equipment. The highly motivated and educated population enables us to select and train the best of each age group to operate modern high-tech systems, such as F-35 fighters, GMLRS, NASAMS and Gabriel anti-ship missiles. At the same time, the bulk of our defence materiel needs to be simple enough for reservists to learn and inexpensive enough to be procured *en masse*.

As a small nation, Finland's approach to defence acquisition is to mainly procure mature systems. Consequently, research and development (R&D) in the Finnish Defence Forces focuses on integration of existing technologies, while prioritising carefully the technologies to be developed in-house. A specific technology would be developed, instead of procured, only when off-the-shelf solutions are not suitable for our environment or operations. Moreover, we may want to retain national control and technological sovereignty – or seek surprise and asymmetry, in which our own development is a *sine qua non.* Since most men have completed military training, when we procure R&D from Finnish companies, the work is done by people with a hands-on military understanding.

Finnish defence R&D strives to provide the scientific and technological base for solutions that are operable in an arctic environment. We build capabilities that can respond to a peer enemy threat and aim to create asymmetric advantage and surprise to avoid a war of attrition. For us, the NATO STO is a key forum for defence research – that is why Finland is so heavily engaged in the STO community.

SWEDEN'S APPROACH TO SCIENCE AND TECHNOLOGY – FINDING TALENTS IN THE SHADOW OF WAR[4]

The Challenges

The impact on the West due to the rapidly deteriorating security landscape has prompted Sweden to accelerate its efforts and spending in all domains of defence and security, including science and technology (S&T). However, the race to attract new talents to the defence S&T sector should be seen in the light of a number of other societal challenges where S&T will play a pivotal role, for instance climate change, energy and electrification, life science and health care, food security and many other areas. Although several of these areas are close to or even overlapping with defence and security interests, the particular restrictions surrounding work in the military domain, including intelligence, set it apart. The need for higher levels of security and processes to control information stand in sharp contrast with how successful academic institutions operate and train young scientists, and this is where we find our future experts and talents.

3 *World Happiness Report 2018-2022*, World Happiness Report; *Corruption Perception Index 2021*, Transparency International.

4 Author: Dr. Jens G. MATTSSON, Director General, Swedish Defence Research Agency (FOI), Sweden.

The scientists' playbook vs defence S&T

If you want to build a traditional academic career there are some basics that you need to follow: publish or perish (a logical and infallible mantra), secure funding, secure funding for independency, build a team, find the best talents (nationality is of less concern), move up in the academic roster, form international alliances and so on. In contrast, a career in defence S&T might seem very exotic: publish and you might perish, organisations are more closed, information is classified, titles are unfamiliar, there are restrictions concerning international collaborations, the agenda is defined by unfamiliar priorities, etc. At first glance, this suggests that a career in defence S&T might even seem like a limitation for an individual scientist. Consequently, talents might be reluctant to make a move or transition to the military domain. However, there are a number of reasons why our sector is attractive. Within defence S&T you work with exceptionally challenging problems, you work in multi-domain teams; you will have access to world-class and unique infrastructure, financial support is stable; you are allowed to explore areas that are out of bounds outside the military domain and most importantly, the impact of your work is something that truly matters. In this landscape, the NATO STO plays an important role in terms of international collaborations, not only enhancing national agendas, but also as a way for individuals both to find like-minded scientists and to boost careers.

In the future, a particular challenge will be to attract a larger proportion of women to defence S&T. One way might be to identify role models, but we will also have to look at ourselves in order to identify possible hurdles for women to work in the military domain, as well as strive to be modern and attractive future employers.

Final words

In a newly published poll among Swedish professionals in tech and cyber on the most attractive employers in 2022, the Swedish Defence Research Agency (FOI) and the Swedish Armed Forces ranked first and second, respectively. This is of course part luck and part hard work, but is also shows that a pool of talent is out there, ready to work in defence S&T. Hopefully we are ready to welcome them to a rewarding career that is beneficial for the individual, for Sweden and for our friends in other countries.

RESILIENT

RESILIENT

STO EARLY CAREER SCIENTIST EVENT

Attracting and developing young talent has always been a priority for the STO, NATO and its members. Young scientists make crucial contributions to maintaining NATO's competitive edge, and the STO remains committed to engaging with them. Working with the next generation of scientists on science and technology (S&T) and defence issues will ensure that NATO is equipped with the knowledge and expertise necessary to meet future challenges and maintain its pre-eminence.

As part of this engagement, the STO and the Norwegian Defence Research Establishment (FFI) held an Early Career Scientist Event in March 2022. Held as part of the Spring 2022 Science and Technology Board (STB) meeting in Oslo, Norway, the event brought together 26 exceptional young scientists, as nominated by NATO Nations, the Chairs of the STO Panels and Group, and the Centre for Maritime Research and Experimentation (CMRE). The scientists had the opportunity to present their research to the STB and to network with colleagues and peers from across the Alliance. Their presentations covered a wide range of technology areas that are relevant to NATO, including artificial intelligence, quantum computing, cognitive warfare, unmanned vehicles, laser radar, human systems integration, maritime surveillance, and additive manufacturing.

Cash prizes, sponsored by FFI, were awarded to the best presentation and the two best research posters. Ms. Eleri Lillemäe from Estonia received the best presentation award for her briefing on "Social Sciences and the Military". The prizes for best research posters were awarded to Dr. Pavel Zahradníček from Czechia for his research on "Effective Employment of Combat Unmanned Ground Vehicles"; and Dr. Andre Van Rynbach from the United States for his research on "Laser Radar Technologies for Advanced Target ID in Complex Environments".

Figure 11: Dr. Pavel Zahradníček and Dr. Andre Van Rynbach, awardees of the Best Research Poster at the 2022 Early Career Scientist Event, along with Dr. Bryan Wells, NATO Chief Scientist; CZE STB Principal Member, Dr. Pavel Zuna; and USA STB Principal Member, Mr. Jeffrey Singleton.

Figure 12: Ms. Eleri Lillemäe, winner of the Best Research Presentation award at the 2022 Early Career Scientist Event, along with Dr. Bryan Wells, NATO Chief Scientist, and the EST National Coordinator, Ms. Epp Leete.

Figure 13: Participants in the 2022 Early Career Scientist Event in Oslo, Norway in March 2022.

STO PANEL AND GROUP YOUNG SCIENTIST AWARDS

Every year, the STO Panels and Group grant the Young Scientist Awards to young researchers who have made exceptional contributions to the technical activities under the STO Collaborative Programme of Work (CPoW). This programme aims to encourage participation and networking among promising and talented young researchers in the STO community.

The 2022 Young Scientist Awards recognised the achievements of four scientists:

- Dr. Guillaume Grossir (FRA) – Applied Vehicle Technology Panel
- Dr. Mattia Fogli (ITA) – Information Systems Technology Panel
- Mr. Sean Havel (Canada) – System Analysis and Studies Panel
- Dr. Elisa Giusti (ITA) – Sensors and Electronics Technology Panel

The 2022 winners worked on research topics such as cognitive and synthetic radar imaging; machine learning; edge computing; Intermediate Force Capabilities (IFC); and hypersonics.

Figure 14: Dr. Elisa Giusti receives the NATO Sensors & Electronics Technology (SET) Panel's Early Career Scientist 2022 Award from Mr. Frank Van Den Bogaart, Chair of the SET Panel, at the SET Spring 2022 Panel Business Meeting held in Bled, Slovenia, 25 – 27 May 2022.

CMRE STEM ACTIVITIES IN 2022

The CMRE's Science, Technology, Engineering and Mathematics (STEM) educational and outreach programme, based on a framework agreement between the Centre and the Ligurian Regional School Office, aims to promote research and engineering among students at the local high schools, and to foster awareness and understanding of the CMRE as a world-class scientific research and experimentation facility.

With a clear focus on gender balance, all the activities carried out support and welcome the participation of female students as much as male students, with the objective to promote and develop an "environmental awareness" through scientific subjects such as physics, oceanography, acoustics, and robotics.

Part of this programme is the Giona Project through which CMRE and local schools are able to create multi-disciplinary activities involving students between the ages of 14 and 19. The topics range between bioacoustics, oceanography and climate change, engineering and oceanographic instruments, and underwater robotics. Thanks to this project, 34 local students who demonstrated excellence in STEM skills, had a chance to combine knowledge and practice with lessons and exercises conducted at sea, at school and online.

Figure 15: On board the Pandora schooner, CMRE staff showed the students how to use instruments to sample and analyse the water column (e.g. the CTD sensor).

Figure 16: Dr. Giovanni Sembenini, CMRE's Deputy Director, presented the role, organisational structure and governance of the CMRE and NATO to students.

MARITIME SCIENCE AND TECHNOLOGY EXPERTS COMMITTEE (MSTC) RECOGNISES CMRE'S DR. ENRICA D'AFFLISIO WITH EARLY CAREER AWARD

The NATO Maritime Science and Technology Experts Committee (MSTC) named Dr. Enrica d'Afflisio the recipient of the 2022 Early Career Award, in recognition of her outstanding scientific contributions to the STO Centre for Maritime Research and Experimentation (CMRE).

The Early Career Award recognises the achievements of early career scientists, engineers, and technologists working within, or in collaboration with, the CMRE to deliver high-quality science and technology to the benefit of NATO.

Figure 17: Dr. Enrica d'Afflisio, STO Centre for Maritime Research and Experimentation.

In acknowledging the overall impressive research and dedication that all finalists demonstrated through their work with the CMRE, the MSTC recognised Dr. d'Afflisio's excellence in developing "innovative statistical solutions to enhance maritime situational awareness, and developing novel maritime anomaly detection strategies with effective evidence in real-data world applications". The Committee also highlighted the important role young scientists play for their Nations and the organisations they represent in empowering NATO's technological edge today, and for decades to come.

70 YEARS OF SCIENCE AND TECHNOLOGY IN NATO

In 1952, Dr. Theodore von Kármán created the Scientific Advisory Group – an initiative that led to the creation of the Advisory Group for Aerospace Research and Development (AGARD), and effectively marked the beginning of scientific and technological collaboration in NATO.

The STO celebrated the 70th anniversary of this event in June 2022 with a special symposium held at the Organization for Cooperation and Development (OECD) in Paris, France, as well as a Heritage Reception at the Collaboration Support Office in Neuilly-sur-Seine, France. The Heritage Reception, held on 14 June, brought together former and current STO staff and leadership, including Dr. Michael Ihor Yarymovych, former Director of AGARD.

Bringing together high-level NATO officials, military leaders, policy experts and industry stakeholders, the symposium marked an occasion to reflect on the rich history of Science and Technology (S&T) in NATO, and the critical role it will continue to play in the future.

The symposium featured wide-ranging discussions and interventions from a number of speakers, including:

- General Philippe Lavigne, NATO Supreme Allied Commander Transformation
- Mr. Camile Grand, NATO Assistant Secretary General for Defence Investment
- Dr. Bryan Wells, NATO Chief Scientist
- Mr. John-Mikal Størdal, Director, NATO STO Collaboration Support Office
- General Eric Autellet, French Deputy Chief of Defence
- Mr. Dale Reding, Scientific Advisor to the Chief Scientist
- The Hon. Alan Shaffer, former Director of the NATO STO Collaboration Support Office
- Mr. Andrew Wyckoff, Director, OECD Science, Technology and Innovation Directorate
- Mr. Jeff Singleton, US Army Director for Technology
- Mr. Emmanuel Chiva, Director, Defence Innovation Agency, French Ministry of Defence

Figure 18: Current and former STO personnel and leadership at the Heritage Reception in Neuilly-sur-Seine, France (left to right): Ms. Ann Gok; MGen (Rtd) Albert and Ann Husniaux-Vermeire; and Ms. Anne Reboul.

The event also featured a roundtable discussion on the future of science and technology among a panel of early career scientists, as well as another panel discussion on the role of industry in defence-related S&T.

In remarks opening the symposium, Mr. Størdal noted that the STO "has helped keep the democratic world on the cutting edge of technological development," and that "the torch is now ours to carry forward."

"We are on a deeply meaningful mission," Mr. Størdal said. "A mission for prosperity and peace; for the well-being of our societies and for the freedom of our citizens. That is what our endeavour is all about."

Videos from the symposium are available on the NATO STO YouTube page.

Figure 19: Mr. John-Mikal Størdal, CSO Director, and General Philippe Lavigne, NATO Supreme Allied Commander Transformation.

Figure 20: Some of the distinguished speakers and guests at the 70th Anniversary Symposium (left to right): Mr. David Van Weel; General Eric Autellet; Mr. François Chopard; Maj Gen Jean-Marc Vigilant; Dr. Giovanni Sembenini; Mr. Dale Reding; Mr. Eirik Lie; Ms. Jackie Eaton; The Hon. Alan Shaffer; Dr. Bryan Wells; Mr. Manfred Boudreaux-Dehmer; Dr. Michael Ihor Yarmovych; Mr. John-Mikal Stordal; Mr Philippe Duhamel; Mr. Jeff Singleton; Mr. Emmanuel Chiva; and Maj Gen (Rtd) Philippe Montocchio.

Figure 21: Early Career Scientist Panel at the 70th Anniversary Symposium (from left to right): The Hon. Alan Shaffer (Moderator); Dr. Dominika Kosárová; Dr. João Caetano; Ms. Eleri Lillemäe; and Mr. Sven Van Binsbergen.

Figure 22: Some of the CSO staff who supported the 70th Anniversary Symposium.

STO 10TH ANNIVERSARY

In addition to the "70 years of S&T in NATO" event, the STO celebrated its 10th anniversary on 19 September, bringing together representatives from Allied and Partner Nations, NATO civilian and military leadership, and members of the STO community for a special event at NATO Headquarters in Brussels, Belgium.

The event consisted of two parts: a poster exhibition and a conference.

At the poster exhibition, supported by the three STO executive bodies (the Office of the Chief Scientist, the Centre for Maritime Research and Experimentation and the Collaboration Support Office through the STO Panels and Group), Dr. Bryan Wells in his welcoming speech (see Figure 23) introduced the first OCS staff, including the first NATO Chief Scientist, Maj Gen Albert Husniaux, who played a key role in establishing the STO 10 years ago (see Figure 24).

The conference focused on how the STO has evolved over the past decade, and the work it does today to maintain NATO's technological edge.

In remarks delivered at the conference, NATO Deputy Secretary General Mr. Mircea Geoană highlighted the important role that the STO will play in meeting future challenges to the Alliance, and in implementing the NATO Strategic Concept 2022. He also described STO scientists as "the brightest of the brightest of NATO's ecosystem."

Dr. Wells emphasised the key role that STO members and staff have played in supporting the Alliance through enhanced cooperation and collaboration between Nations and Partners on defence- and security-related research.

Figure 23: Poster exhibition on the STO 10th anniversary event.

Figure 24: The first STO-OCS Staff (left to right) Mr. Nicolas Vandenabeele; Dr. Ulf Ehlert; Maj Gen Albert Husniaux; Maj Bart Houben; and Col Pierpaolo Dotoli.

> *"Over the last ten years the STO has delivered scientific excellence for the Nations and NATO. It has proved itself proactive in anticipating in anticipating new requirements such as climate change science, proactive in identifying emerging technical areas, and resilient to strategic shock such as COVID-19."*

The conference also featured insights from Dr. Catherine Warner, Director of the Centre for Maritime Research and Experimentation, on the "Evolution of CMRE Pogramme of Work in the last 10 years"; Mr. John-Mikal Størdal, Director of the STO Collaboration Support Office, on the "Evolution of the STO Collaborative Programme of Work in the last 10 years"; Prof. Dr. Maurus Tacke, former Director of the Fraunhofer Institute of Optronics, System Technologies and Image Exploitation, on "How science and the delivery of science has changed over the (last 10) years"; and Major General Albert Husniaux on "2012 – Establishing the STO".

A MILESTONE IN STO PANEL/GROUP BUSINESS MEETINGS

In Fall 2022, the Technical Panels and Group of the STO held their 50th Business Meetings, bringing together world-class scientists, engineers, and analysts, as well as national and NATO body representatives, to help shape the future of science and technology in the Alliance. The six Panels and one Group marked this milestone in a series of meetings held from 26 September to 21 October in various locations across the Alliance.

Known as the "powerhouse" of collaborative science and technology in NATO, the STO Panels and Group are responsible for proposing and managing the programmes of work in their respective scientific areas, providing both critical technical oversight as well as key links to military users and other NATO entities. Their bi-annual Business Meetings provide an opportunity for each Panel and Group to reflect on and evaluate recent work, and to decide on proposed future activities. The successful management of the Panels and Group are key to the successful delivery of the STO Collaborative Programme of Work (CPoW).

NATO STO PROGRAMME OF WORK

NATO STO Programme of Work

PROACTIVE

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 an energy market tighter than at any point since World War II. 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 project's focus on energy security is rooted in the pretext that energy is fundamentally the most vulnerable sector, and carries the largest potential to destabilise a society. This includes mitigating the impact on civilian and military infrastructure and interests, and developing countermeasures.

Dr. Arnold C. DUPUY, USA, Naval Postgraduate School; Dr. Daniel NUSSBAUM, USA, Naval Postgraduate School; Dr. Sarah LOHMANN, USA, Army War College; Assoc. Prof. PhD Eng Gabriel RAICU, ROU, Constanta Maritime University; Mr. Vytautas BUTRIMAS, LTU, NATO Energy Security Centre of Excellence; CDR. Georgios GIANNOULIS, GRC, 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 current war in Ukraine has demonstrated, the energy sector is an inviting target for any adversary. This project is dedicated to the deeper understanding of this threat and its broader impact on NATO's military preparedness, the member states' infrastructural resilience, and, ultimately, the coherence of the Alliance itself.

MILITARY RELEVANCE

Attention must be drawn to the growing 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 Member countries are vulnerable to a variety of kinetic or non-kinetic threats. As an actor in international security, NATO has a vital role to play in the nexus between energy security and hybrid warfare.

OBJECTIVE(S)

This activity aims to address the operational and technological nature of the threat and:

1. Raise awareness of the energy-hybrid warfare nexus by understanding its component parts;
2. Identify its broader impact in the civilian and military realms; and
3. Define courses of action to mitigate the impact on civilian and military infrastructure and interests, and develop countermeasures.

S&T ACHIEVEMENTS

The research has raised the strategic awareness of this topic within NATO's S&T community, as well as among NATO Member countries and partners. This has been 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. This activity will conduct both qualitative and quantitative analyses, case studies and tabletop exercises in the course of events.

SYNERGIES AND COMPLEMENTARITIES

This topic has resonated with many of the Alliance's Member or Partnership for Peace nations. Upon its kick-off in 2020, this activity leveraged the data and outputs from SAS-118 RTG on "Enhancing Strategic Awareness of Energy Security - A Holistic Approach". The activity's organising 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 organisations such as NATO's Emerging Security Challenges Division, Energy Security (ENSEC) Centre of Excellence (COE), Cooperative Cyber Defence COE, and Hybrid Threats COE in Helsinki, as well as US-based institutions such as the Naval Postgraduate School and the Army War College.

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

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.

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 organisations like the Hybrid Challenges and Energy Security Section and the ENSEC. NATO will need to continue adapting to emerging and hybrid threats to energy critical infrastructure and energy security.

Figure 25: Attacks on NATO fuel convoys in Afghanistan highlighted the importance of assuring energy supplies to military operations.

ANTI-SUBMARINE WARFARE (AASW) (CMRE)

As one of the core activities of the NATO STO CMRE, the Autonomy for Anti-Submarine Warfare (AASW) programme carries out scientific research and experimentation to validate and de-risk advanced ASW concepts, supporting NATO in improving maritime underwater situational awareness and addressing submarine threats.

Mr. Robert BEEN, NLD; Dr. Alessandra TESEI, ITA; Mr. Christopher STRODE, GBR, NATO Centre for Maritime Research and Experimentation (CMRE)

BACKGROUND

Advanced sensing technology (including quantum), autonomy, robotics, data science, edge processing and artificial intelligence (AI) hold promising potential for maritime unmanned systems in the field of ASW. Such emerging platform and sensing technologies require accurate evaluation in order to establish their performance and suitability.

MILITARY RELEVANCE

Addressing the submarine threat is critical for the safety of maritime operations and the security of NATO Nations. Research and experimentation validating advanced sensing, algorithmic, and autonomous platform concepts in operationally relevant scenarios will help identify the most effective technologies for countering submarine threats.

OBJECTIVE(S)

The AASW programme aims to develop, test and validate innovative, advanced platforms and potential deployment configurations for autonomous, networked ASW.

S&T ACHIEVEMENTS

The two main projects of the AASW Programme for ACT are Maritime Unmanned Systems (MUS) for ASW and ASW Decision Support. Under the MUS for ASW Project, scientists designed and tested advanced sensor suites and algorithms for the detection of submarine targets, and developed two low-power, long-endurance sea-bottom ASW nodes equipped with heterogeneous sensors for passive detection. These systems were deployed in concert with two Autonomous Underwater Vehicles (AUVs) during two exercises in Portugal: Robotic Experimentation and Prototyping augmented by Maritime Unmanned Systems (REPMUS22) and Dynamic Messenger (DYMS22). This cruise achieved important milestones in sensing, signal, and data processing, as well as autonomy.

The ASW Decision Support project developed advanced concepts for the performance assessment of heterogeneous manned-unmanned ASW through operations research, with an emphasis on improving planning algorithms for active sensing networks. In 2022, the project continued developing the linear programming optimisation framework to account for platform endurance and logistic considerations for a long-duration barrier. Its results underscore the importance of platform endurance and transit times required for recharging.

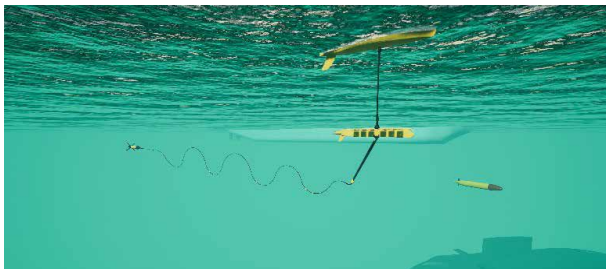

Figure 26: Visualisation of the synthetic world and models used to simulate CMRE's ASW missions.

SYNERGIES AND COMPLEMENTARITIES

The sea-going element of the programme includes participation in multi-national projects for the development and testing of advanced ASW concepts in a collaborative environment (e.g. DYMS22), as well as participation in NATO ASW exercises. The AASW Decision Support team provided acoustic performance predictions in support of NATO exercises, and collaborated with Allied Maritime Command (MARCOM)'s In-stride Debrief Team (IDT) to test advanced methods for exercise analysis. Further work seeks to exploit this data to define more advanced metrics for performance and comparison across geographic locations and time frames.

EXPLOITATION AND IMPACT

The outcomes of the AASW programme complement and enhance the ASW research and development activities of NATO Nations. De-risking advanced sensing technology, algorithms and maritime unmanned systems supports future procurement programmes.

CONCLUSION(S)

With more than two decades of experience in conducting unmanned system research and experimentation to improve NATO's ASW capabilities, the CMRE leads the way in advanced sensing, and algorithmic and autonomous platform concepts for ASW applications, demonstrating the potential of MUS for long-endurance, standoff operations. In 2022, significant steps were made towards ASW MUS integration and interoperability, in close collaboration with the MUSE Programme at the CMRE.

SUSTAINABLE AVIATION FUELS (SAF) IN A MILITARY CONTEXT (AVT-ET-221)

To reduce CO2 emissions, civil aviation will need to shift to alternative fuels. NATO and Nations must prepare for this change in order to maintain civil-military and military-military interoperability, but a great deal of work remains to be done. The AVT-221 Exploratory Team (ET) aimed to identify research topics to be addressed by a future AVT team starting in 2023, so that all NATO Nations will reach the same level of maturity and maintain interoperability.

Dr. Mickaël SICARD, FRA, Office National d'Etude et de Recherches Aérospatiales (ONERA); Prof. Patrick HENDRICK, BEL, Université Libre de Bruxelles (ULB); Mr. Steven GILLARD, GBR, Boeing Europe

BACKGROUND

Sustainable aviation fuel (SAF) is seen as a key component in reducing reliance on traditional carbon fuel sources. Destination 2050 sets forth an sustainability initiative by the European aviation sector to achieve net-zero CO2 emissions in European aviation by 2050; using SAF could reduce CO2 emissions by over 34% by 2050, compared to 1990 levels.

MILITARY RELEVANCE

Unlike the commercial aviation sector, national military airworthiness authorities insist upon an extra level of scrutiny above the American Society for Testing and Materials (ASTM) International's approval process. This has led to platform-specific approvals for SAF and a wide range of inconsistency across NATO. A substantial number of Nations have not yet approved the use of SAF in their platforms, even in cases where the same platform has been approved by other Nations. These differences are a serious risk to interoperability.

OBJECTIVE(S)

Industry success in using SAF needs to be translated into the military context. This ET sought to explore various research areas and garner support for a future RTG by bringing together industry effort and expertise to exploit SAF to the fullest extent for NATO Nations.

Figure 27: Industry success in using SAF needs to be translated into the military context.

> *"ASTM-approved Sustainable Aviation Fuel is fully interoperable with approved fossil aviation fuel."* ***AVT-ET-221 Team***

S&T ACHIEVEMENTS

This ET identified the following research topics that will be considered in the new AVT group starting in 2023:

- Clarify the complete terminology, e.g. e-fuels or the difference between 100% SAF and SBCs, and update on the emerging aviation fuels and pathways;
- Sustainability criterion analysis and definition;
- Differences between civil and military aviation certification process;
- Current status of National and OEM approvals of ASTM-approved fuels on platforms;
- Deployment status in Europe and Worldwide;
- Feasibility analysis for a technical demonstration of future sustainable defence operations up to 100% SAF.

SYNERGIES AND COMPLEMENTARITIES

Fifteen nations, 45 members and one NATO body participated in this ET group.

EXPLOITATION AND IMPACT

The continued expansion of Emerging Disruptive Technologies (EDTs) within NATO should include the challenge of integrating SAF onto NATO platforms. By incorporating the expertise of industry, academia and authorities, the next AVT group will start to set out a framework for the full adoption of SAF for NATO Member countries.

CONCLUSION(S)

The work carried out during this ET allowed for the establishment of a group of experts in the field of SAF which was able to identify topics to be covered in the next AVT in order to obtain the same level of information for the NATO Nations on this subject.

COMMUNICATION NETWORKS AND INFORMATION DISSEMINATION FOR THE TACTICAL EDGE (IST-185)

The IST-185 Research Specialist Meeting (RSM) facilitated information exchange and coordination between the Information System Technology (IST) Panel's communications and network activities that had a bearing on the Communications and Tactical Edge Syndicates of the Federated Mission Networking (FMN) organisation. This was the first step in establishing a firm relationship between the FMN community and the exploitation and direction of the broader IST work.

Mr. Simon BAKER, Dstl, GBR; Mrs. Mariann HAUGE, FFI, NOR.

BACKGROUND

FMN is a major initiative to enable "day zero" interoperability between Nations, forming an alliance for future multi-national deployed operations, and addressing major interoperability issues between Nations' IST systems in recent operations that took several years to resolve. This meeting was the first step in establishing a firm relationship between the FMN community and the exploitation and direction of the wider IST work, with both communities welcoming and supporting the initiative.

MILITARY RELEVANCE

Recent operations have struggled to achieve the communications and network interoperability necessary to support the tempo and interactions that effective military and security operations demand. The FMN initiative and supporting elements have planned and agreed many of the concepts and standards to provide Allied Nations with the tools to rapidly and confidently achieve secure interoperability upon future deployments. These concepts and standards aim to achieve interoperability on "day zero", thereby directly supporting the warfighter in establishing information superiority, including effective command, control, and synchronisation of available forces. Given that future planned spirals do not have the standards to support their goals and ambitions, recent IST activities help to inform standards and ensure that they reflect warfighters' needs within FMN. New activities are now being planned to address specific challenges.

OBJECTIVE(S)

This meeting aimed to educate the FMN and NATO IST communities on their respective work and challenges, and to foster discussions on how to better align activities and understanding for future mutual support.

S&T ACHIEVEMENTS

Twelve IST team activities relevant to the FMN syndicates participated in online discussions, joining more than 60 representatives from industry, academia, governments, NATO Bodies and the military, including some members who were already working effectively across the two communities. Findings from the meeting were briefed at the Spring 2022 TIDE Sprint STO Track and the Communications Track, where further support closer collaboration was expressed. The IST Panel is currently aligning outputs to FMN and initiating specific activities to directly address future FMN spiral challenges. This experience provides a framework for future FMN-relevant activities to be aligned with the FMN Spirals, and will drive new IST activities to address future spiral ambitions where standards are not currently available or foreseen, and concepts still need to be understood.

SYNERGIES AND COMPLEMENTARITIES

In addition to directly supporting the FMN exploitation, the meeting fostered an open exchange and understanding among the 12 IST activities briefed. This was recognised by the IST Panel leadership, which plans to ensure that future events enable a similar level of interaction to encourage stronger collaboration across IST and related activities.

> *"Communications, standardisation and interoperability are key – and that is exactly what this meeting addresses."* ***John-Mikal Størdal, CSO Director***

EXPLOITATION AND IMPACT

The exploitation of related IST activities, whether recent, underway, or planned, has been increased by this early exploration of FMN as a major exploiter of communications and networking activities with IST. The IST Panel and the FMN secretariat aim to formalise this collaboration and expand it to active IST participation in events such as TIDE Sprint.

CONCLUSION(S)

This meeting generated a new, large network of researchers, industrialists, NATO bodies and acquirers. It established a refreshed understanding of the potential value of this research, particularly where activities such as FMN have a long-term plan that the IST Panel can exploit to align with and actively address barriers, while maintaining and nurturing the close relationships that the meeting generated.

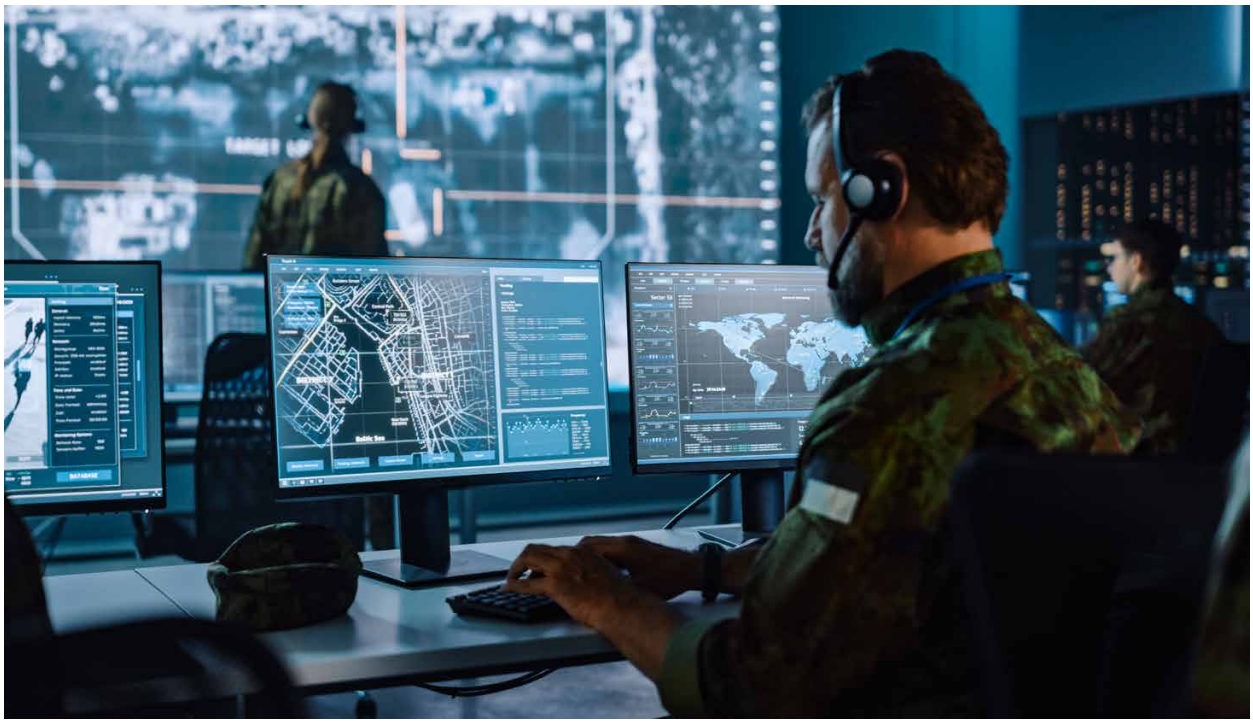

Figure 28: FMN is a major initiative to enable "day zero" interoperability between Nations, forming an alliance for future multi-national, deployed operations.

LESSONS FROM A HACKATHON TO APPLY AI AND DATA SCIENCE TOOLS TO A LARGE EXERCISE DATASET (SAS-IST-162)

SAS-IST-162 analysed how artificial intelligence (AI) and big data analytics are used to extract value from large military datasets, using a dataset collected during a major exercise (TRIDENT Juncture 2018) as a practical case study. The activity considered technologies needed to perform data exploration with a dataset of large volume, high velocity, great variety and, in some cases, imperfect veracity. It explored how data scientists, data analysts and military experts work with such a dataset to extract insights into the conduct of an exercise. Finally, the activity demonstrated that a structured data collection campaign is needed in order to collect quality data from exercises and fully exploit the potential of these technologies.

Mrs. Linda VAN DER HAM, NLD, Netherlands Organization for Applied Scientific Research (TNO); Dr. Michael STREET, USA, NATO Communication Information Agency (NCIA); Mrs. Ivana ILLIC MESTRIC, HRV, NATO Communication Information Agency (NCIA)

BACKGROUND

NATO military exercises are a crucial part of preparing NATO commanders and forces for operations in peace, crisis and conflict. They provide a means for the Alliance to test and validate its concepts, procedures, systems and tactics. They also offer an opportunity for militaries and civilian organisations to practice working together, and to identify both bottlenecks and best practices. Exercises like the 2018 TRIDENT Juncture yield huge amounts of data (big data) that the NATO Communications and Information Agency (NCIA) collects and analyses.

MILITARY RELEVANCE

A recent report from the NATO Defence and Security Committee stresses the need to increase both the quantity and quality of NATO exercises, in light of important changes to the security environment. There is therefore a strong need to effectively and efficiently reconstruct operational decision making, and to identify bottlenecks and understand their causes in order to strengthen the Alliance's fighting capability and meet NATO ambitions.

OBJECTIVE(S)

This specialist team was formed with three key objectives:

- Explore the potential of a data-driven approach for automatic reconstruction of operational decision making, lessons learned extraction and to drive machine learning;
- Build exercise-based taxonomies; and
- Develop a structured approach to exercise data analysis for use in future exercises.

S&T ACHIEVEMENTS

An earlier IST Specialist Meeting (MP-IST-178-01) identified multiple methods to help analysts extract valuable information from large document collections. Future analysis efforts would benefit from building on previous ones – either by providing findings or involving the same analysts, as was done in this case.

Three methods were commonly used during the hackathon to gain insight into the large datasets:

1. Time series visualisation and statistical analysis;
2. Clustering methods for correlating user groups, storylines and events; and
3. Natural language processing for extraction of keywords and summarising email contents.

Given the timeframe, visualisation of the dataset (e.g. dashboarding) was the most achievable.

SYNERGIES AND COMPLEMENTARITIES

This activity built upon previous NCIA analysis (NCIA Technical Report/2018/SPW03551/1), CMRE activities, and the findings of SAS-111 "Collection and Management of Data for Analysis Support to Operations"; SAS-136 "Optimisation of Investment in Simulation-Based Military Training"; and IST-160 "Big Data and Artificial Intelligence for Military Decision Making". It explored possible synergies with IST-141 (AI2S) "Exploratory Visual Analytics"; IST-163 (IWA) "Deep Machine Learning for Cyber Defence"; IST-169 (AI2S) "Robustness and Accountability in Machine Learning Systems"; and IST-178 "Big Data, Challenges: Situation Awareness and Decision Support", as well as SAS-139 "NATO Analytical War Gaming – Innovative Approaches for Data Capture, Analysis and Exploitation" and SAS-150 "Advanced Analytics and Artificial Intelligence for Defence Enterprise Resource Planning".

Figure 29: Members of SAS-IST-162.

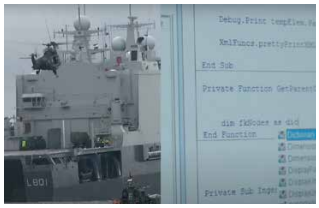

Figure 30: Sample datasets analysed by SAS-IST-162.

ABOVE WATER EO/IR SIGNATURE REQUIREMENTS FROM AN OPERATIONAL PERSPECTIVE (SCI-SET-323)

The NATO scientific community of subject matter experts (SMEs) on electro-optical and infrared (EO/IR) ship signatures hosted a two-day Research Specialists' Meeting (RSM) in Quebec City, Canada to facilitate technical exchanges between scientific communities and those tasked to acquire, build, and operate new naval ships. The two days were spent briefing naval, Ministry of Defence (MoD) and shipbuilding representatives on SET-269's proposed Standard Recommendation (STANREC) on "Defining Infrared Signature Requirements for Naval Surface Ships", and providing descriptions of the available tools and methods to design and assess IR signatures.

Dr. Karin STEIN, DEU, Fraunhofer Institute of Optronics, System Technologies and Image Exploitation

BACKGROUND

Every modern navy must include IR signature requirements when building a new ship. Developing common procedures for determining and specifying requirements reduces cost, expedites the process, and eliminates confusion between the navy forces and industry.

MILITARY RELEVANCE

The last several decades have seen a significant expansion in the use of EO/IR technologies in Anti-Ship Missile (ASM) seekers, surveillance sensors, and Intelligence, Surveillance and Reconnaissance (ISR) platforms. To counter these increasing threat capabilities, forces must optimise the design of naval platform signatures and signature management systems to reduce the ability of these new threats to detect, recognise, identify, and track maritime assets. SET-269 is leading the development of a NATO STANREC on "Defining Infrared Signature Requirements for Naval Surface Ships" to compile common knowledge generated in the scientific community and to share it with acquisitions and operational communities.
The event in Quebec City, Canada provided an environment for government and naval acquisition communities, shipbuilders and operators to be briefed on the initial STANREC draft, to learn of the tool sets developed to support the process, and to provide practical feedback on the initial draft of the STANREC.

OBJECTIVE(S)

There is often a knowledge gap between the scientific, acquisitions, industrial and operational communities. Expertise developed by one community is often not funnelled to other organisations in a timely manner. The RSM (SCI-SET-323) provided an opportunity for members of all of these communities to share their knowledge bases among other members of the NATO community.

S&T ACHIEVEMENTS

The RSM enabled members of industry to meet directly with NATO SMEs on EO/IR signatures and learn about current practices for generating ship IR signature requirements. The broader community guided the scientific community on missed concepts and how to improve the STANREC being prepared for publication in 2023/2024.

SYNERGIES AND COMPLEMENTARITIES

The design of the RSM allowed for the efficient, direct exchange of technical ideas by providing a forum for SMEs and front-end specification generators to engage with individuals who interpret complex requirements and deliver products that must undergo testing in dynamic environments.

EXPLOITATION AND IMPACT

Any document that simplifies and codifies complex analysis and procedures inherently reduces time, confusion and expense. The SET-269 STANREC will provide a reference for NATO navies to generate IR signature requirements, aide shipbuilders in interpreting the requirements and simplify the acceptance testing of new naval ships. The SET-SCI-323 RSM provided practical feedback from the end-user community on how to optimise the design of the document to improve its applicability outside of the scientific community.

> *"These roundtable discussions encouraged the scientific community to complete standardised recommendations on how NATO naval forces should specify ship IR signatures."* ***SCI-SET-323 Team***

CONCLUSION(S)

The NATO scientific community should frequently engage with operational and government agencies to ensure that scientific products fully meet the needs of stakeholders impacted by the work.

The SCI-SET-323 RSM provided such an opportunity to the NATO community involved with specifying, designing, building and accepting new naval vessels sailing in modern IR-threatened operational arenas.

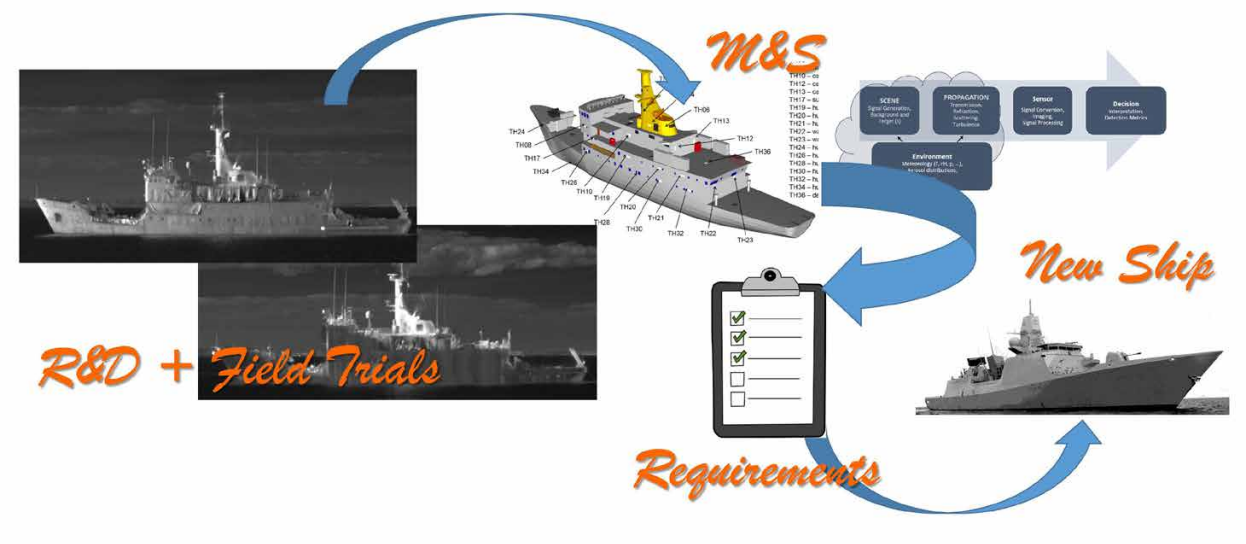

Figure 31: Images from FFI, TNO, and Davis Engineering (graphic source: Graphic.pptx).

SWARMS SYSTEMS FOR INTELLIGENCE SURVEILLANCE & RECONNAISSANCE (ISR) (SET-263)

SET-263 exploited an international effort that resulted in a high-level reference architecture, based on the NATO Architectural Framework (NAF), that identifies the swarm system as a promising NATO Agile Platform. This allows for the dynamic implementation of a swarm capability with the necessary elements and functions to support specific missions and different NATO forces.

Dr. Francesco FEDI, ITA, Leonardo S.p.A.

BACKGROUND

NATO adversaries are employing advanced Robotic and Autonomous Systems (RAS) to disrupt the military strength of NATO Joint Forces. This could increase risk to NATO forces.

MILITARY RELEVANCE

The adoption of agile swarm systems directly improves:

- The gathering of persistent ISR data on advisory actions;
- Force protection and interdiction; and
- Anti-access area denied operations.

The native agility of the swarm as a platform results in cost reduction, improved system resilience and adaptivity in uncertain, dynamic scenarios.

> *"Is swarming the future of conflict?"*
> ***Dr. Francesco Fedi***

OBJECTIVE(S)

SET-263 aimed to define a "High-Level Reference Architecture for Swarm System for ISR" by (i) analysing key research topics and (ii) focusing on the synergic integration of varying levels of autonomy under one robust and agile system architecture.

S&T ACHIEVEMENTS

- SET-263 addressed the swarm as a platform and defined its related high-level reference architecture, which is based on the NAF. This approach resulted in an agreed set of capability, operational, service, system and technical views.
- SET-263 defined a set of design guidelines for interoperability to address swarm as an open interoperable architecture.

The study also addressed the challenges raised by human-swarm interaction by providing a solution based on the symbiotic human-machine interaction, an Emerging Disruptive Technology (EDT) identified by the NATO STO.

SYNERGIES AND COMPLEMENTARITIES

SET-263 exploited an international effort where each partner addressed a specific research topic from different NAF views, namely: capability, operational, service, system and technical. The research topics addressed by each Nation are listed below in alphabetical order:

- ITA (Chair): Human-swarm system interaction, robot-robot interaction, data exchanges, interoperability;
- NOR: Swarm application;
- TUR: Networking, robot-robot interaction;
- USA: Swarm navigation and control.

EXPLOITATION AND IMPACT

The "High-Level Reference Architecture for Swarm System for ISR" paves the way for a standardisation process to address a promising NATO Agile Swarm Platform. The capability to deploy swarm systems composed of elements provided by different NATO Nations enables for an extensive exploitation of swarm capabilities, which results in information supremacy with very low risk for soldiers.

CONCLUSION(S)

SET-263 examined swarm as a platform and defined its High-level Reference Architecture, which (i) addresses key issues from different NAF views, and (ii) provides for design guidelines for a swarm interoperable open architecture. This paves the way for a standardisation process for a NATO Agile Swarm Platform, with clear advantages in terms of (i) cost reduction, (ii) resilience in dynamic, uncertain environments and (iii) the safety of forces.

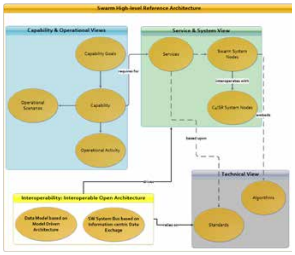

Figure 32: Key swarm concepts and high-level architecture views.

FLIGHT TESTING OF UNMANNED AERIAL SYSTEMS (UAS) (SCI-328)

Building on the success of a 2015 symposium on "Flight Testing of UAS", the SCI Panel held a second symposium on the same subject in Segovia, Spain in May 2022. The symposium brought together 115 participants from 17 Nations, with 23 papers presented in five different sessions.

Prof. Dr. Nafiz ALEMDAROGLU, TUR, Atılım University and the members of the SCI-358 Flight Test Technology Team

BACKGROUND

This is the second symposium that the SCI Panel's Flight Test Technology task group has organised, following a 2015 symposium held in Ottawa, Canada. UAS have become a popular and integral component of NATO armed forces. In terms of techniques and methodologies, flight testing of UAS is markedly different from that of manned aircraft. These aspects were discussed during presentations of the carefully selected 23 papers.

MILITARY RELEVANCE

UAS have become a game changer during recent conflicts. In addition to carrying out Intelligence, Surveillance and Reconnaissance (ISR), UAS are used for weaponised attacks, the suppression of enemy air defence, and as decoys for denial and deception purposes. UAS come in various sizes and capacities, ranging from miniature systems to large combat systems, depending on their military roles. They have become an integral part of the armed forces, with significant differences from manned aircraft – including around flight testing. This symposium helped to specify these differences.

OBJECTIVE(S)

The SCI-328 activity successfully achieved its goals during the five sessions of the symposium, which covered the following topics:

- Available UAS programmes and their operational applications;
- Major flight test facilities and establishments;
- Analysis validation and verification of UAS testing;
- New concepts and capabilities in UAS flight testing; and
- Regulatory environments for new and future UAS.

S&T ACHIEVEMENTS

Interest in UAS will continue to increase with rapidly advancing technology, and the SCI Panel has been studying flight testing of UAS for some time. Although this is the second symposium organised on this subject, a new Agardograph on flight testing of UAS will be published soon, and the subject remains very active.

SYNERGIES AND COMPLEMENTARITIES

A total of 115 participants from 17 NATO Nations attended the symposium, and 23 papers were presented over five sessions.

EXPLOITATION AND IMPACT

Each paper presentation was followed by extensive discussions and question-and-answer sessions, demonstrating the strong interest in the subjects presented.

CONCLUSION(S)

The symposium was very well received, given the high level of interest in the subject among NATO Nations, and was well attended (115 participants from 17 NATO Nations). A follow-on activity, SCI-338 Agardograph on "Flight Testing of UAS", is ready for publication, and the SCI Panel will launch future initiatives on similar topics, in line with the development of UAS technology and how it is used in the battlefield.

Figure 33: SCI-358 Flight Test Technology Team members attending the SCI-328 Symposium at the Academia de Artillería (Spanish Artillery Academy) in Segovia, Spain, 12 – 13 May 2022.

NATO STO Programme of Work

RESPONSIVE

AUTONOMOUS NAVAL MINE COUNTER MEASURES (ANMCM) PROGRAMME (CMRE)

The CMRE ANMCM programme aims to deliver technologies, methods, algorithms, standards and data that will enable CMRE and Allied navies to design, develop and test a network of securely communicating autonomous vehicles under realistic operational conditions for the localisation, detection, identification and neutralisation of naval mines.

Dr. Yan PAILHAS, FRA; Mr. Christopher STRODE, GBR; Mr. Thomas FURFARO, USA; LCDR Clifford HARRELL, USA, NATO Centre for Maritime Research and Experimentation (CMRE)

BACKGROUND

The ANMCM programme is oriented around three projects: Collaborative Autonomous MCM (CA-MCM), High-Resolution Low Frequency Synthetic Aperture Sonar (HRLFSAS) and Planning and Evaluation for MCM (P&E for MCM).

MILITARY RELEVANCE

Advancing autonomy, sensing capabilities and the planning of Naval Mine Warfare (NWM) activities enable Allied Nations to rapidly develop technologies that will "take the warfighter out of the minefield." Research and experimentation in operationally relevant scenarios help to identify the most effective technologies for countering mine threats. Working directly with the operational community allows CMRE to target future research on impactful solutions.

OBJECTIVE(S)

The CMRE ANMCM aims to maintain a credible, interoperable, adaptable, resilient and sustainable NMW capability that enables joint and maritime operations. This capability is ready to conduct defensive and offensive NMW in order to accomplish assigned missions.

S&T ACHIEVEMENTS

The CA-MCM Project uses robotics to deliver doctrinally relevant autonomy, collaborative autonomy and on-board machine intelligence. In 2022, the project improved the HFSAS ATR (Automatic Target Recognition) algorithms with the introduction of the single-stage detector classifier, along with prediction of auxiliary features and the implementation of environmentally targeted algorithms. In addition, the team developed data models for SAS and SSS images; carried out a study on generative adversarial networks; delivered automated mission reporting; and developed and validated the Collaborative Autonomy Tasking Layer (CATL). These capabilities were demonstrated during two exercises in 2022 (REPMUS22 and DYMS22).

The HRLFSAS Project aims to develop a prototype advanced sensor for the enhanced detection, classification and identification of objects that higher-frequency sonar systems cannot detect. In 2022, the team detected and characterised persistent scatterers and developed a 3D SAS micro-navigation algorithm with unsupervised machine learning. It also developed and validated a 3D FDTD viscoelastic numerical solver; refined requirements for an ultra-wideband low frequency system; and identified the benefits and disadvantages of underwater sensor types.

The P&E for MCM Project addresses the current deficiency in the planning and evaluation of mine hunting missions performed by AUVs, and in the evaluation of a system-of-systems tasked with a full MCM mission. In 2022, the project continued development of a novel planning framework for optimal mission planning; carried out a study on the multi-stage single vehicle problem; and provided support to MARCOM and ESP-N for MCM Performance Assessment during two exercises.

In parallel with the programme of work, two studies were carried out in 2022: one on quantum sensing for NMW, and one on countering drifting mines.

SYNERGIES AND COMPLEMENTARITIES

The ANMCM programme hosted the MCM Festival, which brought together scientists from the Nations to discuss advances in the field of MCM and enable future collaborations. ANMCM participation in the REPMUS22 and DYMS22 exercises also provided an opportunity for collaboration with several Nations and leading industries. In particular, CMRE garnered support from many Nations for the implementation and the testing of CATL.

EXPLOITATION AND IMPACT

The ANMCM programme's findings continue to advance MCM research within NATO Member Nations. Participating in events such as REPMUS and DYMS not only facilitates advanced collaboration in an operational environment, but allows CMRE to showcase technologies to operational end-users outside of the scientific community.

CONCLUSION(S)

R&D on sensors, adaptive-vehicle behaviour, improved P&E and underwater vehicles that overcome the constraints of surface MCM capabilities can greatly enhance NATO's MCM capabilities. The ANMCM programme works to increase effectiveness, efficiency and speed within the underwater realm, while leading greater interoperability efforts throughout the Alliance.

SYNTHETIC BIOLOGY FOR DEFENCE (HFM-305)

Synthetic biology combines microbiology and genetic engineering techniques with the principles of systems engineering, and is expected to drive disruptions and enable improvements in defence capabilities. In light of this potential, it is critical for NATO Nations to track advancements in the field, and to collaborate on mitigating threats, limitations and inherent barriers to implementation.

Dr. Peter EMANUEL, USA, Bioengineering US Army Futures Command DEVCOM Chemical Biological Center

BACKGROUND

Exploiting synthetic biology for defence can provide powerful enabling military capabilities, and can advance defence capabilities through applications in medicine; human performance augmentation; chemical and biological (CB) defence; sensing; agriculture; environmental management; materials; energetics, propellants, energy storage and generation; and coding and computers. Across NATO, Nations are now shifting their focus towards demonstrating the viability of bio-products in operational settings.

MILITARY RELEVANCE

The convergence of these technologies will provide new materials, sensors and therapeutics – many of which will have military applications.

OBJECTIVE(S)

This activity aimed to assess the potential for synthetic biology to contribute to Allied defence efforts and to recommend specific areas of collaboration among member countries.

S&T ACHIEVEMENTS

Synthetic biology and biomanufacturing have already begun transforming the way industry supplies the raw ingredients that both NATO militaries and the broader economy use to make textiles, plastics, lubricants, and other consumer goods. The RTG-305 study describes how this global transformation will profoundly impact Allied defence supply chains, and recommends that NATO pursue bilateral and multi-lateral collaborations to ramp up synthetic biology and biomanufacturing to an industrial scale. The convergence of biotechnology and material science also offers the opportunity to reduce the size, weight, power requirements and cost of sensing technologies, while increasing their detection capabilities. Such sensors can be the basis for reactive/responsive surfaces and coatings that will interact with the environment to continually sniff, measure and watch. The study recommends that NATO develop common guidance to maintain interoperability and ensure the smooth adoption of next-generation, low-cost sensors. In addition, biotechnology will transform medicine in future wars by removing many of the human body's current limitations, and NATO medical care will be vastly improved by new treatments and therapies. Through changes such as enhancing the human microbiome or creating brain-computer interface technologies for human-machine teaming, a warfighter's body will truly be transformed into a "human weapons system".

> *"Focus across NATO Nations is now shifting towards demonstrating the viability of bio-products in operational settings in order to reduce operational costs and increase operational flexibility."* ***HFM-RTG-305 Team***

SYNERGIES AND COMPLEMENTARITIES

Biomanufacturing efforts support Allied Nations' efforts to strengthen national security supply chains and reduce reliance on Russian energy exports. NATO has approved a follow-on Exploratory Team on biomanufacturing for national security materials.

Figure 34: Synthetic biology allows for the creation of vastly improved treatments and therapies that will enable NATO healthcare to treat a wider range of diseases and greatly augment our body's natural ability to heal from injury.

EXPLOITATION AND IMPACT

Bio-derived materials and microsensors are poised to have an immediate impact on NATO militaries. Biotechnologies will produce novel and previously unobtainable bio-materials that can bend light, store energy, shield defence systems and augment human performance.

CONCLUSION(S)

Coordination and cooperation between NATO Nations over the next 20 years will be crucial to ensuring that Allied defence forces benefit from the products of biotechnology, and that it is employed safely across the globe.

EFFICIENT GROUP AND INFORMATION-CENTRIC COMMUNICATIONS IN MOBILE MILITARY HETEROGENEOUS NETWORKS (IST-161)

The efficient and timely distribution of information is critical to successful military operations at the tactical edge. This Research Task Group (RTG) focused on group and information-centric communication capabilities, given that most of the information generated and exchanged at the tactical edge needs to be sent to many/all members. Experimental evaluations helped improve understanding of these protocols and led to performance optimisations.

Mr. Arjen HOLTZER, The Netherlands Organization for Applied Scientific Research (TNO), NLD;
Dr. Niranjan SURI, US Army Combat Capabilities Development Command (CCDC) Army Research Laboratory (ARL), USA

BACKGROUND

Whereas previous RTGs have focused on improving routing and network connectivity, this activity focused on efficient mechanisms for getting important information to nodes at the tactical edge, thereby ensuring that tactical nodes receive the information they need in a timely manner.

MILITARY RELEVANCE

The efficient dissemination of critical information at the tactical edge is important to ensuring successful operations. This group focused on experimentally evaluating different protocols for efficient group communication and helped improve a current standard implementation for information dissemination.

OBJECTIVE(S)

This RTG aimed to evaluate existing and novel capabilities for information dissemination at the tactical edge and to improve existing protocols, if possible.

S&T ACHIEVEMENTS

The IST-161 RTG conducted a comprehensive experimental analysis of 11 different information dissemination protocols using the Anglova scenario and identified the top performers. This work led to

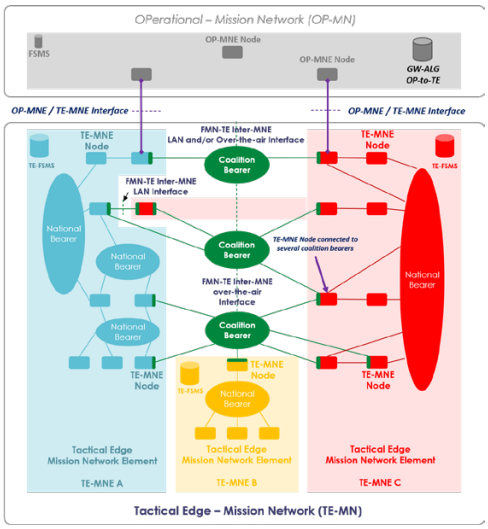

Figure 35: Tactical Edge-Mission Network (TE-MN).

> *"Efficient group and information-centric communications are key to distributing essential information at the tactical edge and to maintaining Situational Awareness."*
> ***IST-161 RTG Team***

improvements in the design and implementation of the protocols, including DisService (developed by the US Army Research Laboratory) and GDEM (developed by TNO). The activity also led to the creation of a detailed taxonomy of group communication protocols and the identification of limitations of novel communication paradigms such as Named Data Networking (NDN). In addition, the activity enhanced the open-source Anglova model by emulating Scalable Cooperative Broadcast (SCB) radio waveforms.

SYNERGIES AND COMPLEMENTARITIES

This RTG leveraged existing standards and ongoing work by the US Army Research Laboratory (DisService protocol), as well as the Anglova scenario initially developed by the IST-124 RTG.

EXPLOITATION AND IMPACT

The group had a close relationship with key interoperability initiatives, thereby facilitating a bi-directional exchange of information on requirements and solutions. It is anticipated that GDEM will be included in the relevant interoperability standards. The group also developed candidate solutions for decentralised chat, which is another important requirement for the tactical edge.

CONCLUSION(S)

The IST-161 RTG helped increase the scientific understanding of group communication protocols and new radio waveforms such as Scalable Cooperative Broadcast (SCB). It also developed a taxonomy of solutions and enhanced a standardised solution to provide better performance. Many commercial solutions do not work at the tactical edge.

DISTRIBUTED SYNTHETIC TRAINING (DST) WORKING GROUP (MSG-165; MSG-180; MSG-174; MSG-204)

NATO needs a persistent capability to provide distributed synthetic mission training and operational exercises across all roles in multi-domain operations. The NMSG and NATO International Staff Defence Investment are working together to transition S&T results from several NMSG efforts into a persistent, operational capability. The DST Working Group includes more than 150 experts from 18 Nations and several NATO bodies who work along four dedicated Lines of Efforts (LOE) to establish a persistent DST capability. The LOEs include updating relevant policy, establishing a DST infrastructure, coordinating with related NATO Capability Development programs (such as the Next-Generation M&S Capability) and organising DST exercises. Key milestones will be a nationally-led distributed synthetic exercise in late 2023 and the MARCOM-led synthetic exercise "DYNAMIC MIRAGE" in early 2024.

Mr. Arjan LEMMERS, NLD, Royal Netherlands Aerospace Centre (NLR); Dr. Robert SIEGFRIED, DEU, Aditerna GmbH; Mr. Wim HUISKAMP, NLD, TNO Defence Research

BACKGROUND

Allies lack the capabilities for frequent and regular multi-national, simulator-based training and exercises. As NATO and National leaders place greater emphasis on readiness and preparedness, such a capability is more needed than ever before.

MILITARY RELEVANCE

It is commonly accepted that "We fight as we train" and "Warfare is teamwork". Yet while missions are always executed as a coalition, NATO and Nations lack the capability to frequently train and exercise as a coalition. The DST capability will enable this, allowing Allies to carry out regular and frequent high-quality DST and exercises, while reducing their dependence on resource-limited, live training opportunities.

OBJECTIVE

The DST Working Group aims to establish a NATO-wide federation of national synthetic mission training capabilities powered by coherent architectures and security procedures, common standards and training objectives, and shared data; and to deliver regular and frequent access to high-quality, secure, immersive operational training opportunities at team, collective, joint and coalition levels.

S&T ACHIEVEMENTS

- Initial operational capability for NATO DST capability;
- Multi-level security approach for a NATO DST architecture;
- DST Reference Architecture and DST Handbook.

SYNERGIES AND COMPLEMENTARITIES

NATO DST will leverage existing NATO and National simulation assets, bringing together several NMSG efforts such as MTDS (distributed training for the air domain), LVC-T (distributed maritime training) and UCATT (distributed training for land domain). It also includes cross-cutting efforts such as M&S as a Service (MSaaS) and C2-to-Simulation connectivity.

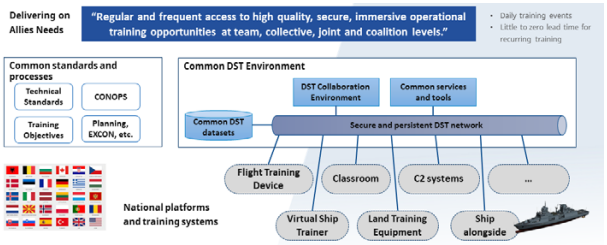

Figure 36: Illustration of Distributed Synthetic Training (DST).

EXPLOITATION AND IMPACT

Nations will use the DST Reference Architecture, the multi-level security solutions, and other results developed by the DST Working Group to implement DST-compliant training capabilities. Yearly tests, experiments and operational exercises aim to establish a persistent DST capability for joint and combined mission training. The NMSG is working closely with the NATO International Staff and International Military Staff to firmly anchor DST in relevant NATO policy.

CONCLUSION(S)

Allies need a DST capability to provide frequent and regular distributed mission training and operational exercises in all core roles related to multi-domain operations. The DST Working Group will incrementally build, exploit and maintain an initial DST capability in coordination with relevant DST exercises.

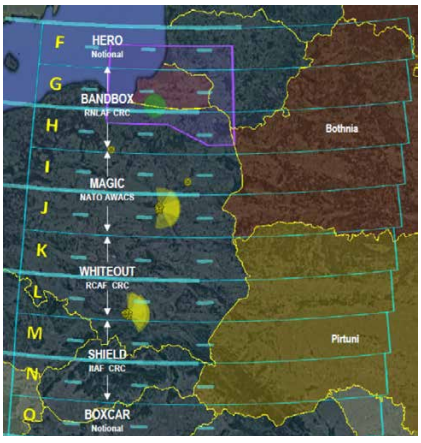

Figure 37: SPARTAN WARRIOR is a full up synthetic exercise, providing combat readiness training for participants.

SHORTWAVE INFRARED TECHNOLOGY: A STANDARDISED IRRADIANCE MEASUREMENT AND COMPATIBILITY MODEL TO EVALUATE REFLECTIVE BAND SYSTEMS (SET-246)

Recent advances in shortwave infrared (SWIR) technology show promising capability in some military applications. Although SWIR cameras and systems are proliferating, significantly more data is required to understand the highly variable irradiance levels and associated nightglow in the SWIR band, which is well understood and characterised in the Visible-Near Infrared (VNIR) bands.

Dr. Carolynn MOORE, USA, US Army DEVCOM C5ISR Center, Research and Technology Integration Directorate (RTI)

BACKGROUND

Today, SWIR systems can be used to "see through" obscurants. These systems are already used in manufacturing and quality control, as well as in the agricultural sector to monitor crop conditions and help farmers water more efficiently.

MILITARY RELEVANCE

Imagery in the SWIR band offers important advantages over the VNIR band. SWIR provides better visibility and target discrimination in haze-covered urban settings, and shows better resolution and more realistic imagery compared to thermal bands. A realistic estimate of SWIR illumination levels under varying low-light environmental conditions is necessary to realise these advantages. These illumination levels are well characterised in VNIR, but not SWIR. This information can be used to develop relevant military CONOPS and tactics, techniques and procedures.

OBJECTIVE(S)

SET-246 aimed to collect representative SWIR (night) sky data, and to develop models, algorithms and metrics for the SWIR band in order to develop a common language to identify irradiance values that soldiers are likely to experience in the SWIR.

S&T ACHIEVEMENTS

One crucial challenge to obtaining SWIR irradiance measurements is the lack of access to SWIR equipment for long-term data collection purposes. A sub-group of task members (CAN, NOR, SWE) designed and built a Commercial Off-The-Shelf (COTS) SWIR meter to test in a joint field campaign. To assess the usefulness of this system, the data it collected was compared to that from more expensive/specialised SWIR irradiance measurement units. This COTS system will allow many additional countries and organisations to participate in a follow-on campaign to collect large quantities of SWIR irradiance data.

> *"The need for geographically dispersed SWIR irradiance data leverages the advantages of working in a NATO collaboration, as researchers are already geographically dispersed."* ***SET-246 Team***

Figure 38: Left to right, the three COTS SWIR meters (SWE, NOR, CAN) and a commercial VNIR PR-745 spectroradiometer.

SYNERGIES AND COMPLEMENTARITIES

Most of the task group participated in a joint data collection in order to calibrate equipment and validate data collection and processing across all participants. The team chose a very dark site with little cultural illumination in the western United States. A number of participating countries acknowledged that they had SWIR calibration assets in their labs and that a round robin calibration exercise might be a better use of resources for this purpose in the future. Additionally, one team (FRA) is currently working on improving the SWIR irradiance models. A sub-group of task members (CAN, DEU, FRA) was able to collect additional geographically dispersed SWIR irradiance data. This reinforced the need for more data in a range of locations, and without being limited to season, portion of the lunar cycle, weather, and possible cultural lighting contamination. The need for geographically dispersed SWIR irradiance data leverages the advantages of working in a NATO collaboration, as researchers are already geographically dispersed.

EXPLOITATION AND IMPACT

A realistic estimate of SWIR illumination levels under varying low-light level environmental conditions is necessary to realise the advantages of SWIR technology. This information can be used to assess the illumination conditions under which SWIR imaging devices/systems can provide new surveillance and detection capabilities for target discrimination. Improvements in SWIR technology could include digital fusion with sensors in other spectral bands to provide increased situational awareness.

CONCLUSION(S)

Although the team made good progress on measuring and characterising SWIR irradiance, and developing new standards and models, there is much more work to be done in this area in order to bring it to the level of VNIR irradiance measurements. A larger dataset is needed to carry out a robust statistical analysis of SWIR irradiance data, particularly with respect to different weather, geographic and illumination (both natural and cultural) conditions.

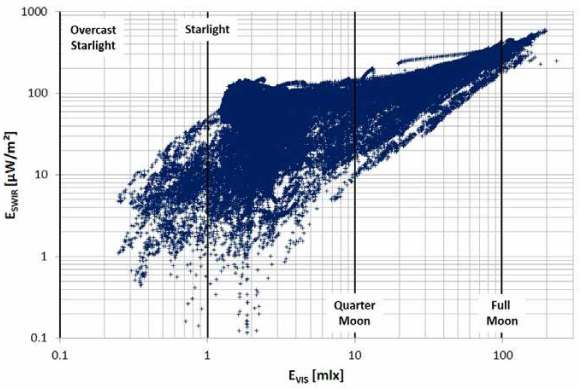

Figure 39: SWIR irradiance vs. visible illuminance, measured March – December 2019 (DEU). Overlaid are the defined visible illumination levels from the RCA Electro-Optics Handbook (1974).

SPACE SENSORS AND SPACE SITUATIONAL AWARENESS (SET-SCI-297)

The topic of space situational awareness (SSA) is fundamental to understanding all activities in space that may help or endanger NATO missions. Effort has been made within the Collaboration Support Office (CSO) in the direction of coordinating actions from NATO Members to create a common SSA picture. To emphasise the importance of the field and to stimulate cooperation in new activities, this Specialists' Meeting on "Space Sensors and Space Situational Awareness" was held from 10 – 11 October 2022 at Interlaken, Switzerland.

Dr. Laura ANITORI (NLD), Toegepast Natuurwetenschappelijk Onderzoek (TNO); Prof. Peter KNOTT (DEU), Fraunhofer FHR; Prof. Marco MARTORELLA (ITA), University of Pisa; Mr. Gregory HOGAN (USA), Massachusetts Institute of Technology Lincoln Laboratory (MIT-LL); Dr. Thomas NEFF (DEU), Deutsches Zentrum für Luft- und Raumfahrt (DLR)

BACKGROUND

Satellites in various orbits around the Earth are needed for a number of services that are nowadays crucial in several contexts, both in the civil and military spheres. They are used for communication, command and control, navigation, intelligence, surveillance and reconnaissance, and are a fundamental asset for supporting military operations. NATO operations heavily depend on such support systems in space. Therefore, it is in NATO's interest to ensure that space-based infrastructures are preserved, maintained and even improved.

MILITARY RELEVANCE

Given that NATO aims to make space a full operational domain – alongside land, sea, air and cyber – space sensors and SSA are of great importance to NATO's "Strategy for Space". Sensor networks constitute an integral part of the military force structure, providing critical information with sufficient accuracy and timeliness to support the manoeuvre of military forces and the targeting of their weapons.

OBJECTIVE(S)

This Specialists' Meeting aimed to bring together different stakeholders (space experts, military operators and users) as well as experts from different fields of research to discuss recent developments and future requirements in space sensors and space situational awareness. Results of related research activities from both SCI and SET Panels were presented, technology gaps discussed, and recommendations for future research and collaboration activities were identified.

S&T ACHIEVEMENTS

As an outcome of a previous joint panel activity highlighting the importance of SSA and the need for interdisciplinary cooperation, the meeting could now be conducted as companion event for the latest SET Panel Business Meeting. It is worthwhile to note that the event had an exceptional high attendance of 81 delegates, showing that space domain awareness is an important and timely topic.

Twenty-one papers were presented in different sessions covering "Technology and Capability Development for Space", "Improved Satellite Space Surveillance" and "Tracking & Reconnaissance", "Enhanced Sensor Network Capability", and "Threats to Space-Based Infrastructure". Two awards were given to the presenters of the best overall paper and to eligible young scientists (under 40 years old).

> *"Space domain awareness is of paramount importance for the operation and protection of our valuable space infrastructure and requires a joint global cooperation in research and technology development."* ***SET-SCI-297 Team***

SYNERGIES AND COMPLEMENTARITIES

There is a great number of synergies between both the SET and SCI Panels in the field of SSA, specifically in exchanging and fusing data and information from multiple sensors and catalogues. At a system level, new and/or improved existing capabilities at a sensor level - both in terms of technology and algorithms - are required. The diverse and complementary backgrounds of the partcipants contributed to the success of the activity and the high quality of the work.

EXPLOITATION AND IMPACT

The Specialists' Meeting aimed to identify the scientific state-of-the-art and way ahead, to find out highest-priority topics, and to define additional future (cross-) panel activities. In addition, the development of technology and techniques with enhanced sensitivity and imaging capability for future ISR missions is required, which is crucial for situational awareness, planning and decision making in support of blue force NATO missions.

CONCLUSION(S)

The SSA capabilities of NATO and partner countries must be expanded, improved, and combined to detect orbital hazards in all relevant orbital regions well in advance of an eventual collision. In addition to ground-based sensors, both ground and space-based systems need to be extended and improved to collect and track space object identification data for resident space objects without the disruption of weather, time of day and atmosphere. This capability will allow the Alliance to better understand the space environment and space events, and their effects across all domains.

Figure 40: Group picture of the SET-SCI-297-RSM.

NATO STO Programme of Work

RESILIENT

THE MARITIME UNMANNED SYSTEMS ENABLERS (MUSE) (CMRE)

The NATO STO CMRE MUSE department addresses a range of fundamental enablers for the establishment of efficient multi-national collaborative autonomous missions in the maritime domain. From data flow and information security, to modelling and simulation and underwater communications, MUSE addresses seabed-to-space interoperability through a series of S&T work strands.

Mr. João ALVES, PRT, NATO Centre for Maritime Research and Experimentation (CMRE)

BACKGROUND

The CMRE MUSE department seeks to enable the interoperability of heterogeneous autonomous assets including underwater communications, common tactical level situational awareness, and modelling and simulation tools for concept development and testing. Quantum technologies and their application to the underwater environment are a key focus, as well. The MUSE programme is carried out under the ACT Maritime Science and Technology Programme.

MILITARY RELEVANCE

Interoperability and standardisation are key to effective multi-national force integration, and fundamental enablers for the testing and adoption of emerging and disruptive technologies (EDTs), which could play a decisive role in operational theatres.

OBJECTIVE(S)

In 2022, the MUSE programme aimed to develop data models and architectural frameworks to support future system-of-systems autonomous maritime missions; expand and mature modelling and simulation tools to support such missions (e.g. through work on digital twin concepts and augmented sea trials); continue work on state-of-the art adaptive and secure underwater communications; and expand its work on quantum-key distribution and quantum navigation for underwater assets.

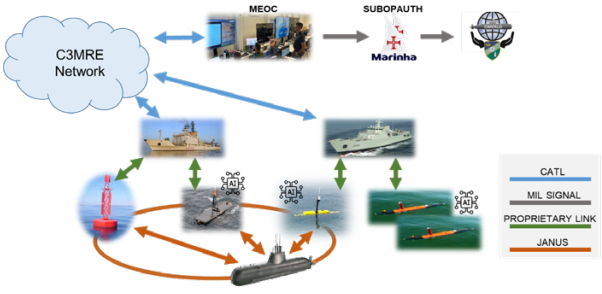

Figure 41: The Command, Control and Communications for Maritime Robotic Exploitation (C3MRE) data and messaging infrastructure deployed during the REPMUS22 exercise in Portugal in support of the distressed submarine scenario.

S&T ACHIEVEMENTS

The MUSE department contributed to the development and expansion of the Collaborative Autonomy Tasking Layer (CATL), an outcome of the STO RTG SCI-343, which is co-chaired by CMRE.

During the REPMUS22 exercise, the MUSE team deployed and demonstrated its Command Control and Communications for Maritime Robotic Exploitation (C3MRE) infrastructure, allowing more than 10 institutions and 100 nodes to exchange status and tasking messages. Modelling and simulation tools integrated into the C3MRE infrastructure allowed for the seamless integration of physical and simulation assets as a stepping stone towards the realisation of hybrid trials. C3MRE was also integrated for the first time in testing with JANUS, NATO's digital underwater communications standard, enabling real-time communication with a submarine in distress from anywhere in the world.

CMRE also organised a workshop on quantum technologies for the underwater domain and installed a proof-of-concept system for secure underwater communications based on Quantum-Key Distribution (QKD). In addition, the MUSE department delivered a study on the state-of-the-art and art-of-the-possible on quantum navigation for autonomous underwater vehicles.

SYNERGIES AND COMPLEMENTARITIES

The work in MUSE programme is carried out in coordination with STO Panel activities (e.g. SCI-317, IST-174 and SCI-343), and in direct collaboration with academia and national laboratories from NATO Nations. CMRE subject matter experts also engage with industry and end-users to facilitate the adoption of new interoperability solutions for digital underwater communications. In 2022, the department organised the first international underwater quantum S&T workshop and the 10th edition of the Underwater Communications and Networking (UComms) Conference.

EXPLOITATION AND IMPACT

Outcomes from the MUSE programme include data sets, contributions to NATO standards, models and simulators, and research and development at the cutting edge of digital underwater communications, in addition to conferences and workshops to accelerate exploitation.

Figure 42: Underwater QKD proof-of-concept system currently in operation at CMRE.

CONCLUSION(S)

The CMRE MUSE department addresses the enablers of a new era of autonomous maritime systems, and works to facilitate their adoption through modular, scalable modelling and simulation tools. MUSE is also working on quantum technologies in areas where they carry the most promise. New science-based standards will eventually provide the connectivity framework necessary for effective multi-national operations.

Figure 43: Dr. Giovanni Sembenini (CMRE Deputy Director) providing the opening remarks for the first Underwater Quantum S&T Workshop (24 – 25 May 2022).

AUGMENTED REALITY FOR ENHANCED SITUATIONAL AWARENESS FOR ARMOURED FIGHTING VEHICLE CREWS (AVT-334)

AVT-334 successfully designed, developed, integrated and demonstrated augmented reality (AR) solutions to enhance situational awareness for armoured fighting vehicle crews. The team built a robust understanding of military and human factor requirements for AR solutions and explored the benefits through virtual and live experimentations, laying the foundation for a future Standardized Recommendation (STANREC).

Dr-Ing Marcel C.A. BALTZER, DEU, Fraunhofer Institute for Communication, Information processing and Ergonomics (FKIE); Mr. Luke GALLANTREE, GBR, Defence Science and Technology Laboratory (Dstl)

BACKGROUND

Armoured vehicles operate in complex physical and technical environments, where crews require high levels of situational awareness to support decision making and ensure their efficient operation and survivability. AR provides the means to provide a crew with relevant and timely information in easy-to-exploit formats.

MILITARY RELEVANCE

The AR solution provides users with terrain, command, threat and friendly force information through visual, haptic and audible mediums. Trials have indicated a range of user benefits, including reduced chance of fratricide, faster threat detection and countering, reduced cognitive burden, improved target handover and safer manoeuvring.

OBJECTIVE(S)

AVT-290 sought to develop a requirements set for AR symbology based on defined use cases and to explore the display requirements. This included different user interface solutions, design and interaction patterns for AR, symbology requirements, and integration issues. AVT-334 built on the work of AVT-290 and implemented examples of the developed symbology set for virtual and live experimentation.

> *"The potential of AR to enhance the situational awareness and decision making of armoured vehicle crews, with resulting survivability and effectiveness benefits, has been effectively demonstrated and proven."* ***AVT-334 Team***

S&T ACHIEVEMENTS

The work exploited several AR design patterns from AVT-290 and instantiated them as an initial set of AR symbology. The team developed an understanding of display and integration requirements across a range of user interfaces (including head-mounted displays), and demonstrated the utility of AR using military crews and platforms. A technical report highlighting the achievements, recommendations and direction for future work will be published in January 2023.

SYNERGIES AND COMPLEMENTARITIES

The activity successfully convened a wide range of experts to address human factors, integration, hardware and software requirements to develop a holistic understanding of effective AR development. The work exploited international virtual and live experimentation capabilities to explore the effectiveness of AR solutions.

EXPLOITATION AND IMPACT

A viable minimum symbology set has been defined and already implemented on experimental live and virtual crew systems. This symbology set could form the basis of a STANREC. The work has also initiated a joint activity with HFM to further explore human systems integration associated with AR-enabling technologies and architectures. Further exploitation can be applied to the operation of robotic and automated systems.

CONCLUSION(S)

The work has developed and demonstrated the use of AR symbology and haptics to significantly enhance crew situational awareness and decision making. It is at the cutting edge of improving military capability for crews through novel technology methods and implementing hardware and software requirements for current and future military platforms.

Figure 44: CDT event in Meppen on 4 May 2022 showing the Boxer Joint Operational Demonstrator For Advanced Applications (JODAA) of the German Armed Forces, participants, and development crew.

MILITARY DIVERSITY: ETHNIC TOLERANCE AND INTOLERANCE (HFM-301)

The personnel of NATO multi-national forces strive to achieve cultural competence to enable effective interactions. The HFM-301 Research Task Group (RTG) developed a framework on ethnic intolerance – including the historical, political, economic, social, and socio-psychological factors that explain intolerant attitudes and behaviours – and a conceptual model that highlights the factors designed to cultivate a culture of ethnic diversity and inclusion. The RTG's findings and recommendations will inform NATO's strategic efforts, policies and programs to encourage greater ethnic diversity, inclusion, and improved military readiness and resilience.

Dr. Barbara WARUSZYNSKI, CAN, Department of National Defence

BACKGROUND

Ethnic intolerance continues to challenge NATO's efforts to promote "military diversity as a key transformational element" in overcoming cultural differences during multi-national military operations, coalitions and alliances. The HFM-301 RTG was formed to identify cross-national perspectives on the origins of ethnic intolerance through cultural, social and organisational behaviours found in diverse and pluralistic environments, and to explore the strategies, methods and tools that would foster greater ethnic diversity and inclusion.

MILITARY RELEVANCE

Securing peace and freedom through collective cooperation across NATO's Member countries is fundamental to NATO's mission. Changes in the security environment (e.g. weapons of mass destruction, cyber-attacks, and damages against infrastructure) have prompted NATO to exercise greater flexibility in promoting peace and security across its partner countries. Through enhanced education and training, NATO Allies have the opportunity to learn about ethnic intolerance and the strategies that would help to foster ethnic diversity and inclusion through positive culture change and leadership practices.

OBJECTIVE(S)

HFM-301 RTG aimed to identify the key factors attributed to ethnic intolerance; develop a conceptual model to explain ethnic diversity and inclusion; and offer evidenced-based educational programs to support inclusive organisational cultures in NATO and across multi-national defence organisations.

> *"NATO's efforts to promote 'military diversity as a key transformational element' will require its defence and security member-based organisations to foster greater cultural and ethnic diversity in multi-national military environments."* ***NATO Allied Command Transformation (2013)***

S&T ACHIEVEMENTS

Figure 45: Members of North Atlantic Treaty Organization (NATO) Exercise RAMSTEIN DUST visit Air Task Force-Romania (ATF-R) at the Mihail Kog-Iniceanu Airbase during Operation REASSURANCE–ATF-R on September 18, 2019 (Photo: LS Erica Seymour, 4 Wing Imaging, RP26-2019-0009-002, Canadian Forces Combat Camera, Department of National Defence; Reprinted with permission).

The team's work to leverage their synergies is detailed in a comprehensive Technical Report on ethnic intolerance and inclusion, and a book on "Team Diversity and Inclusion in Defence and Security: International Perspectives" (Springer, 2023), with co-editors Dr. Barbara Waruszynski, Dr. Yantsislav Yanakiev and Dr. Daniel McDonald. The RTG developed a framework on ethnic intolerance and a conceptual model on ethnic diversity and inclusion to help organisational leaders and military personnel foster greater ethnic diversity and inclusion in defence organisations.

SYNERGIES AND COMPLEMENTARITIES

Seven Nations shared national perspectives on ethnic intolerance and ethnic diversity and inclusion. Over a four-year period, the group's expertise, cohesion and commitment helped to achieve its objectives.

EXPLOITATION AND IMPACT

This activity will inform NATO's defence policies and programs, including a NATO STO Lecture Series on how to foster greater ethnic diversity and inclusion across multi-national military environments. Several RTG members also contributed to a book on "Team Diversity and Inclusion in Defence and Security: International Perspectives", with chapters devoted to ethnic diversity and inclusion, racism, unprofessional conduct and ideological extremism.

CONCLUSION(S)

The HFM-301 RTG developed a framework on ethnic intolerance and a conceptual model on ethnic diversity and inclusion to help the Nations foster greater cultural competence and relationships.

MULTI-FIDELITY METHODS FOR MILITARY VEHICLE DESIGN (AVT-354)

Rapidly evolving requirements for military vehicles demand new capabilities for their rapid and reliable design. The AVT-354 Research Workshop (RWS) examined the development, application and assessment of methodologies for multi-fidelity optimisation, which may enable the desired speed and accuracy for designing new platforms.

Dr. Philip BERAN, USA, Air Force Research Laboratory (AFRL); Dr. Matteo DIEZ, ITA, Consiglio Nazionale delle Ricerche (CNR); Prof. Melike NIKBAY, TUR, Istanbul Technical University (ITU)

BACKGROUND

As military requirements continue to evolve rapidly, next-generation weapon systems will need to be developed with significantly less time and effort, and with fewer problems arising late in their development. Meeting these needs requires new capabilities for the fast, accurate and thorough assessment of the design space.

MILITARY RELEVANCE

Earlier AVT efforts have consistently shown that there is a design benefit to coupling more engineering disciplines at higher levels of fidelity earlier in the development process. But there is no mathematical framework to determine which disciplines, level of coupling or level of fidelity are required to capture the physics most critical to a particular system's design. A better understanding of frameworks, architectures and methodologies for the adaptive selection of disciplines, fidelities and coupling is expected to decrease military vehicle development time and cost, increase system performance, generate new capabilities, and more quickly provide NATO decision makers with accurate information. These topics are a central focus of AVT-354 and the related Research Task Group, AVT-331.

OBJECTIVE(S)

AVT-354 aimed to build upon the achievements of AVT-331 by identifying and possibly extending the state-of-the-art associated with frameworks, architectures, and methodologies for the adaptive selection of different sources of information from data/models for the design of military vehicles.

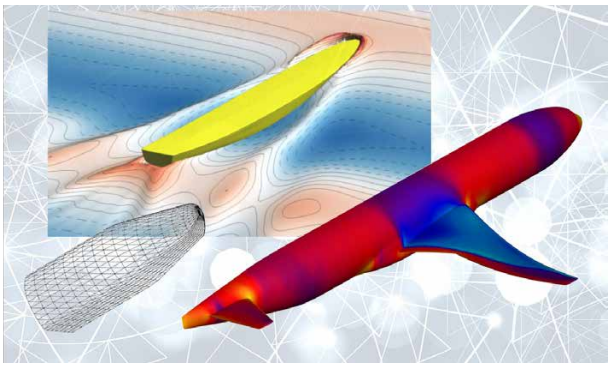

Figure 46: Air, space, and sea vehicle applications used to assess multi-fidelity methods.

> *"A better understanding of frameworks, architectures, and methodologies for the adaptive selection of disciplines, fidelities, and coupling is expected to decrease military vehicle development time and cost, increase system performance, generate new capabilities, and provide accurate information to NATO decision makers faster."* ***AVT-354 Team***

S&T ACHIEVEMENTS

The workshop covered a broad range of topics in the multi-disciplinary design optimisation of military vehicles, with a particular emphasis on how the incorporation of multi-fidelity methods in the design process can accelerate design procedures and enable more accurate physical analysis. Applications from the air, space, sea and ground domains were presented by experts from industry, government labs and academia, who brought complementary perspectives to the discussion. Multi-fidelity active learning approaches, as well as multi-fidelity gradient-based methods, provide the basis for the fast and reliable design optimisation of military vehicles. The penetration of these methods in industry is still marginal due to a number of factors (e.g. availability of solvers and frameworks, training time, etc.). Nevertheless, there is high interest in these methods, as they are seen not only as potential game changers, but also as sufficiently mature for adoption in the near future.

SYNERGIES AND COMPLEMENTARITIES

The information exchange carried out during the workshop provided AVT-331 with a pathway for multi-fidelity technology state-of-the-art (SoA) assessment with discussion on capabilities, opportunities, and future needs. As a separate RWS activity, this effort was closely coordinated with AVT-331 and benefited from the task group's technical activities. This RWS provided additional resources, expertise and a special focus on military vehicle design with cutting-edge contributions in the form of presentations, discussions and written papers by invited speakers to support AVT-331 objectives and outcomes.

EXPLOITATION AND IMPACT

The technologies discussed in this RWS will enable high-fidelity methods to be exploited in a cost-effective manner in the design and quantitative assessment of military vehicles. Methodologies will be further studied, developed and discussed in a newly proposed Exploratory Team on machine learning for military vehicle design, and in a dedicated Research Lecture Series, which will begin between 2023 and 2025.

CONCLUSION(S)

AVT-354 facilitated the identification of, and discussion on, promising extensions related to the current state-of-the-art of frameworks, architectures and methodologies for the adaptive selection of different sources of information from data/models for design of military vehicles. Vehicle design assessment and optimisation of military vehicles were found to benefit from the adoption of multi-fidelity methods, with respect to both the accuracy and efficiency of the overall process.

Figure 47: Attendees of the AVT-354 RWS.

DATA-ENVIRONMENTAL KNOWLEDGE AND OPERATIONAL EFFECTIVENESS (D-EKOE) (CMRE)

The CMRE D-EKOE programme contributes to NATO's maritime cognitive superiority and enhanced decision making through observation, comprehension and near-future forecasting within physical and cognitive dimensions, with the overarching aim of supporting integrated multi-domain operations.

Dr. Alberto ALVAREZ, ESP; Prof. Aniello RUSSO, ITA; Dr. Paolo BRACA, ITA; Dr. Leonardo M. MILLEFIORI, ITA, NATO Centre for Maritime Research and Experimentation (CMRE)

BACKGROUND

In recent years, the CMRE has begun applying advanced artificial intelligence (AI), machine learning (ML) and information fusion (IF) techniques to extract knowledge from data and information in order to support naval decision making. In 2021, these strands of work were combined to form the D-EKOE programme under the ACT Maritime Science and Technology Programme, funded by NATO's Supreme Allied Commander Transformation (SACT). This integration aims to address the challenges of a defined future warfare in a multi-domain battlespace with merged physical and non-physical dimensions.

MILITARY RELEVANCE

The D-EKOE programme supports NATO's Maritime Joint Intelligence, Surveillance and Reconnaissance (M-ISR) requirements. It aims to improve the Alliance's ability to operate in the maritime domain (on surface and underwater), through a greater understanding of the operating environment for decision making.

OBJECTIVES

The D-EKOE programme aims to assess emerging and disruptive technologies (EDTs) for implementation within distributed intelligence solutions for the near-real-time surveillance and prediction of marine environments, and to bring forward AI and information fusion (AI2F) techniques to enable cognitive superiority in the maritime domain.

S&T ACHIEVEMENTS

In 2022, environmental knowledge researchers within the D-EKOE programme numerically evaluated the tactical capability to assess the sea ice bottom roughness and draft with drones equipped with ground penetrating radars. The team implemented a high-resolution ocean model for the Barents Sea, and integrated new autonomous platforms for environmental monitoring within autonomous Anti-Submarine Warfare (ASW) networks.

The Nordic Recognized Environmental Picture (NREP22) sea trial in the Greenland Sea/Svalbard region aimed to collect data to assess the impact of environmental conditions on Allied Arctic ASW operations. Twenty-seven conductivity-depth-temperature (CTD) and 24 expendable bathythermograph (XBT) casts were collected during the sea trial, and 22 hours of acoustic transmissions were sent from an acoustic source on board the NRV Alliance and moored receivers. The performance of innovative technologies for autonomous acoustic surveillance from gliders and drifters were tested, as well.

The data knowledge branch within the CMRE D-EKOE programme focused on processing as much (heterogeneous) data as possible from sensory measurements and contextual information to achieve cognitive superiority. Its 2022 activity involved a line of efforts around the application of MSA-derived concepts and techniques in MCM/ASW scenarios, with a special emphasis on the processing and fusion of multi-intelligence sources. Data science, predictive analytics and anomaly detection techniques also played a prominent role in revealing and monitoring the activity of suspicious vessels close to underwater critical infrastructures. The techniques were applied in an offline analysis of surface vessel traffic before the Nord Stream sabotage, and the analysis was repeated for the Shetland Islands incident and other underwater critical infrastructures.

SYNERGIES AND COMPLEMENTARITIES

The NREP22 sea trial was funded by ACT and involved a range of external collaborators from academic and military research institutions across the Alliance. Additionally, D-EKOE staff participated in a successful Passing Exercise (PASSEX) Technical Demonstration together with the Standing NATO Maritime Group 2 (SNMG2). Deep learning long-term prediction methodologies were tested during sea trials carried out as part of the Horizon 2020 project PROMENADE ("imPROved Maritime awarENess by means of AI and BD mEthods").

EXPLOITATION AND IMPACT

Products and solutions developed by the D-EKOE programme are transferred to the operational framework through their implementation in support of NATO exercises. In 2022, the programme contributed to the REPMUS and DYMS exercises, conducted in September 2022 off the coast of Portugal.

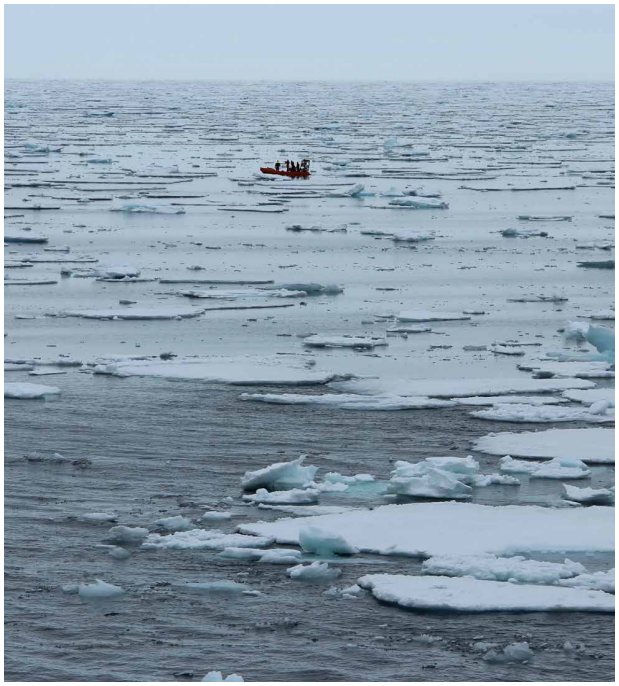

Figure 48: Workboat operations during the Sea Trial NREP22.

CONCLUSION(S)

Activities carried out under the D-EKOE programme focus on disruptive environmental monitoring technologies, numerical modelling, advanced AI and IF techniques, which are applied to data of different volume, velocity, variety and veracity. Such tools and techniques convert collected data and information into actionable knowledge to enable maritime information dominance for NATO forces.

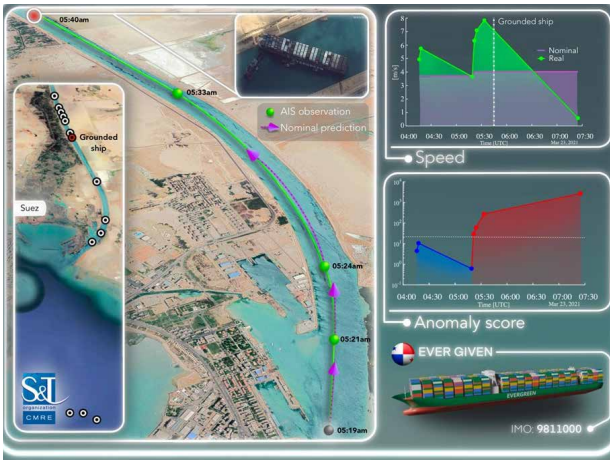

Figure 49: Overview of the automatic anomaly detection tool applied to the real-world scenario of the Suez Canal blockage. The Ever Given trajectory reported by AIS from 23 – 29 March 2021 is displayed on the left. In the middle panel, the nominal trajectory and the AIS observations are depicted right after the entrance of the canal and before the grounding. On the right panels, the anomaly score is reported as well as the nominal and the real speed of the ship. The alarm is triggered (red dots) when the score is above the threshold (white dotted line), while the nominal condition is declared (blue dots) when the score is below the threshold.

SEXUAL VIOLENCE IN THE MILITARY (HFM-287)

Sexual harassment and violence affect unit cohesion, morale, and operational effectiveness. This insidious behaviour is destructive for victims, and damaging for organisations that do not address it. This Research Task Group (RTG) developed culturally sensitive ways of defining and identifying sexual harassment and violence, and made suggestions for more targeted training.

Prof. Matt FOSSEY (GBR), Director, Veterans and Families Institute for Military Social Research, Co-Director, Centre for Military Women's Research, Anglia Ruskin University; Dr. Sanela DURSUN (CAN), Director General Military Personnel Research and Analysis, Department of National Defence

BACKGROUND

Sexual violence remains a pervasive problem in many NATO militaries, despite numerous initiatives to end it. The lack of progress stems from the complexity of the issue. Effective strategies and programs to end sexual violence require a deep understanding of these complexities.

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. Furthermore, public perception and trust in NATO is at some risk through damaging media stories about sexual violence and harassment among its members, especially on operations. The corollary of these behaviours is the potential impact on retention and recruitment at a time when many militaries are struggling in these areas.

OBJECTIVES

HFM-RTG-287 aimed to investigate the approaches that different NATO militaries have taken to eradicate sexual harassment and violence within the military, and to gain a common understanding of the mechanisms and challenges involved. It also aimed to provide the command structure with the tools to address and minimise the problem, thereby improving effectiveness and operational readiness.

S&T ACHIEVEMENTS

The RTG reviewed and compared the approaches to address sexual harassment and violence among all 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 these insidious behaviours. This instrument has been translated into seven NATO languages. The RTG also suggested approaches to training, including the use of scenarios to stimulate discussion and action.

> *"Sexual violence and harassment have no place in NATO militaries, and the work of HFM-295 will contribute significantly to the understanding and eradication of these serious and damaging behaviours."* ***HFM-287 Team***

SYNERGIES AND COMPLEMENTARITIES

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

EXPLOITATION AND IMPACT

In addition to a NATO Technical Report, the RTG is producing a special edition of *Military Behavioural Health* that explores the range of issues that have emerged from this research. This will include technical details of the survey instrument so that it can be exploited by audiences beyond the military community. The RTG will also work with NATO leaders to integrate the group's definitions of sexual harassment and violence into NATO policies and frameworks, alongside the validated survey instrument. In December 2022, the panel reported on its findings at an international conference on military sexual violence, held in Cambridge, UK.

CONCLUSION(S)

Sexual violence and harassment have no place in NATO militaries, and the work of this RTG will contribute significantly to the understanding and eradication of these serious and damaging behaviours. The insights, tools, and recommendations that it produced will be critical in assisting the NATO community in achieving this important goal.

Figure 50: Sexual violence remains a pervasive problem in many NATO militaries, despite numerous initiatives to end it.

M&S SUPPORT FOR CRISIS AND DISASTER MANAGEMENT PROCESSES AND CLIMATE CHANGE IMPLICATIONS (MSG-147)

Our moral and ethical values reflect the appraisement of our society. The response to disaster relief is highly humane, and completely aligns with NATO's ideals. MSG-147's research explored this area further. MSG-147 developed technology independent concepts and transformed it into life-saving capabilities.

COL Dr. Orlin NIKOLOV, BGR, Crisis Management and Disaster Response Centre of Excellence (CMDR COE); LTC Massimo FRANGELLA, ITA, Modelling and Simulation Centre of Excellence (MS COE); Dr. Rachid EL ABDOUNI KHAYARI, DEU, IABG; CDR. Harold PIETZCHMANN, DEU, Bundeswehr Office for Defence Planning

BACKGROUND

The responsibility for crisis management and disaster response, as well climate change influences, are different for every nation and may involve several ministries and agencies. It is also a core task of the Alliance. Today, the Alliance is able to make decisions in crisis and emergency situations, and to act under significant threats and time pressure. NATO develops capabilities to be ready, on a case-by-case basis and by consensus, to contribute to effective crisis and disaster prevention.

MILITARY RELEVANCE

While MSG-147's work has implications for civil society resilience, the project's concept, research and technical deliverables are mainly military focused. The work relates to "smart" wargaming, in the case of risk management during operation planning or disaster management when troops are deployed. The process can be either straight (brute-force computing) or flexible, but in each case it delivers the optimal course of action and mitigation measures.

OBJECTIVE(S)

The project's main objective was to develop a closed-loop schema supporting the decision-making process in case of disaster. The innovative challenge in practical implementation involved the building of an open, self-adjusted framework, combining and orchestrating different tools and applications. The developed Crisis Management and Disaster Response (CMDR) IDE is capable of analysing threats, generating a dynamic response plan, testing the plan to assess effectiveness and efficiency, training staff, and assessing the readiness for plan application.

S&T ACHIEVEMENTS

The team identified important gaps, such as the lack of High-Level Architecture (HLA) standards for disaster-related information exchange. (Such a standard is under development.) It also created an algorithm for adequate dynamic plan generation, which involved breaking Standard Operating Procedures (SOPs) down to rudimentary measures and enhancing them with metadata for further filtration.

SYNERGIES AND COMPLEMENTARITIES

Synergies were at the core of MSG-147's creation, with the team finding that the synergy effect is proportional to the difference in capabilities of the networked components. At the same time, the effort necessary to achieve coherent coordination depends on the developed collaborative framework. The technical architecture – Crisis Management and Disaster Response (CMDR) IDE – is an orchestrator in this regard.

Figure 51: CMDR COE awarded as Firefighter of the Year by Sofia Municipality for supporting their disaster management.

EXPLOITATION AND IMPACT

The built schema and its practical implementation (CMDR IDE) support the decision-making process in a fast, adequate and objective way. It is applicable during NATO joint operations and is also valuable for each Nation. It provides new capability and leverages the creativity of the decision maker. The CMDR IDE is currently managed and controlled by CMDR COE, but there are plans to industrialise it at the level of brigade headquarters and relevant civil structures.

CONCLUSION(S)

The CMDR IDE successfully proved the concept and theory that MSG-147 developed, and this was achieved with support from industry and the scientific community. Companies like IABG and MASA recognised the value of the project, and contributed their time and effort.

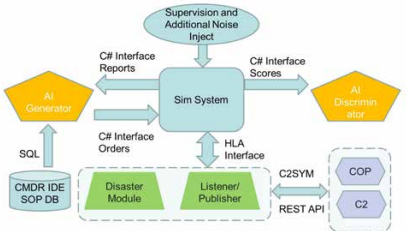

Figure 52: Decision-making support with two AI engines (generative adversarial networks).

SOLDIER WEAPON EQUIPMENT ASSESSMENT TOOL (SWEAT) – RECOMMENDATIONS FOR PERFORMANCE TEST AND EVALUATION (SAS-145)

Across NATO Nations, soldier systems are typically assessed in a purely technical manner, with little consideration for the human operator. SWEAT aims to address this gap by developing an operationally relevant course that provides an overall assessment of a soldier system in terms of lethality, mobility and survivability. The SWEAT framework provides a standardised approach for understanding the tradespace between lethality, mobility and survivability, and in so doing, a more direct measure of soldier combat effectiveness and efficiency.

Ms. Stephanie BROWN, USA, US Army Combat Capabilities Development Command Soldier Center; Dr. Mike TOMBU, CAN, Defence Research and Development Canada (DRDC)

BACKGROUND

In order to maintain their technological advantage over potential adversaries, NATO Nations are constantly striving to ensure that their personnel are equipped with the best possible weapons and equipment. Until now, most test and evaluation focused on the performance of materiel in a purely technical manner, usually within a narrow performance domain, and with little consideration for the human operator. Although this concept of testing yields a set of results that are both objective and comparable, it omits the effect of tested materiel on soldier combat effectiveness and efficiency (SCEE).

MILITARY RELEVANCE

It is well understood how to test a rifle and ammunition in isolation, but not how to assess soldier in the loop performance as part of the soldier system and relate it back to operational effectiveness. Effective soldier in the loop operational performance assessment is crucial for operational readiness and mission success. The proposed assessment framework can be utilised across the spectrum of materiel developers and science and technology communities, as well as training and doctrine organisations. This assessment framework will allow NATO to quantify soldier system lethality, mobility and survivability, and thus optimise investments.

OBJECTIVE(S)

The goal of SWEAT is to provide an overall assessment of a soldier system (soldier, weapon and equipment) in terms of lethality, mobility and survivability. Although the isolated measures of performance will continue to be important, the integrated testing is also critical for understanding the soldier in the loop operational performance impacts. Rather than replacing individual technical tests and evaluation, the integrated SWEAT tool serves to supplement the human-system integration aspects of system assessments in the acquisition process.

S&T ACHIEVEMENTS

SWEAT represents a first step in the development of a comprehensive soldier-system assessment tool. Although extensive multi-lateral discussions and limited field testing went into the development of SWEAT, it remains a work in progress, and it is expected that future iterations will yield an improved course based on lessons learned from earlier implementations. As currently implemented, SWEAT provides a framework for objectively assessing the impact of dismounted soldier, weapon and equipment factors on SCEE, incorporating commercially available equipment and data collection hardware/software and high-quality research design considerations for informed decision making on test outcomes.

> *"Bringing lethality, survivability and mobility into a course that comprehensively tests soldier systems throughout NATO will increase interoperability."* ***SAS-145 Team***

SYNERGIES AND COMPLEMENTARITIES

NAAG LCGDSS; D14; STANREC 4513; STANAG 4512

EXPLOITATION AND IMPACT

This assessment methodology can be utilised across the spectrum of materiel developers, science and technology communities, and training and doctrine organisations. This assessment methodology will allow NATO to optimise SCEE and thus optimise investments. The new methodology will help quantify capabilities within soldier-system lethality, improving understanding of the data, information and range of effects that can be achieved.

CONCLUSION(S)

The primary item identified as a gap across the NATO Nations represented is the need for a standard comprehensive course that holistically assesses a new system's impact on operationally realistic performance when utilised in conjunction with the full soldier kit and equipment. The SWEAT recommendations provide a standardised blueprint for test and evaluation, and are customisable for application based on organisation/country assessment needs.

Figure 53: Live firing exercise tests conducted at Salisbury Plains, UK (Photo; courtesy of Dstl).

EXCELLENCE IN NATO SCIENCE AND TECHNOLOGY

EXCELLENCE IN NATO SCIENCE AND TECHNOLOGY

Every year, the NATO Science & Technology Board (STB) recognises outstanding achievements in international collaboration on science & technology (S&T) within the NATO framework. In order to motivate individuals and teams alike to continue providing exceptional contributions to the benefit of the STO community and the Alliance writ large, the STB presents two types of awards: the von Kármán Medal and the STO Excellence Awards.

VON KÁRMÁN MEDAL

The von Kármán Medal is awarded to highly accomplished individuals with a lifetime dedication to international S&T collaboration in NATO. Through exemplary service, recipients repeatedly delivered significant contributions to STO activities over a long period of time. They combine an internationally recognised career in S&T with leadership and vision to advance the S&T collaboration among the Allied Nations. Typically, the STB awards only one von Kármán Medal per year.

Figure 54: Von Kármán Medal.

2022 VON KÁRMÁN MEDAL RECIPIENT – DR. HENRICUS (RIC) SCHLEIJPEN (NLD)

In spring 2022, the STB awarded the 2022 von Kármán Medal to Dr. Henricus "Ric" Schleijpen (NLD). For almost 20 years, Dr. Schleijpen has consistently demonstrated exemplary service to the NATO STO as a member of the Systems Concepts and Integration (SCI) Panel.

Dr. Schleijpen is a preeminent scientist in the domain of electronic defence, having made significant contributions to the field, with an emphasis on electronic warfare. As a result of his research contributions, the Electronic Defence Department at the Netherlands Organization for Applied Scientific Research (TNO) has become a global leader in its field.

Within the NATO community, Dr. Schleijpen has represented the Netherlands in the SCI Panel with exceptional commitment, having participated in over 40 activities and publications. Dr. Schleijpen acted as Chair of an activity eight times before becoming Vice Chair and ultimately serving as Panel Chair from 2016 – 2018.

His exceptional work with the STO is evident by his past accolades. As the Chair of SCI-192 on "Advanced Electro-Optical Countermeasure Concepts", he received a Scientific Achievement Award. Dr. Schleijpen was also a member of SCI-239 on "CM concepts against future IR.EO threats", for which he received an SCI Panel Excellence Award. In 2018, his final year as Chair, he received the SCI Panel Chair Service Award.

Dr. Schleijpen has demonstrated exceptional S&T leadership and vision within the SCI Panel. His introduction of "Tech Watch Cards" increased focus on new areas of interest, and resulted in the effective acceleration of SCI's ability to identify and address emerging technologies. During his tenure as Chair, Dr. Schleijpen ensured that SCI became a leader in the field of autonomy, resulting in a significant impact on cross-panel activities on this topic.

Dr. Schleijpen has continuously served the NATO S&T community with excellence and professional integrity.

Figure 55: Dr. Henricus "Ric" Schleijpen receiving the 2022 von Kármán Medal from the NATO Chief Scientist, Dr. Bryan Wells.

STO EXCELLENCE AWARDS

The STO Excellence Awards recognise exceptional accomplishments in recent STO activities conducted and completed during the last four years. Recipients delivered high-quality original work of considerable military relevance and benefit, while achieving a significant degree of international collaboration. The STO Excellence Awards can be granted to teams and to individuals. The STB typically presents several such awards every year.

The 2022 STO Excellence Awards were granted to the following team and individual:

- Design and Analysis of Compressive Sensing Techniques for Radar, ESM and Electro-Optical (EO) Systems" (SET-232 / SET-236)
- Dr-Ing Michael Wunder (IST Panel, DEU)

DESIGN AND ANALYSIS OF COMPRESSIVE SENSING TECHNIQUES FOR RADAR, ESM AND ELECTRO-OPTICAL (EO) SYSTEMS (SET-232 / SET-236)

Led by: Dr. Todd Du Bosq, USA; Dr. Laura Anitori, NLD; and Prof. Marco Martorella, ITA

Current military operations are facing new challenges, such as spectral congestion, intelligent jamming and the need for multi-function systems. While traditional approaches seem to be insufficient in effectively tackling these challenges, the relatively novel concept of compressive sensing enables efficient information extraction from sensors, which leads to enhanced performance at lower cost.

The joint work of SET-232 and SET-236 has made a major contribution to the progress and the success of the Sensors and Electronics Technology (SET) Panel by investigating and demonstrating new techniques for electro-optical (EO) imaging, radar, and electronic support measures (ESM) systems.

Figure 56: The Co-Chairs of SET-232/SET-236 joint Research Task Groups (Dr. Laura Anitori, Dr. Todd Du Bosq, and Prof. Marco Martorella) receiving the 2022 STO Excellence Team Award from the NATO Chief Scientist, Dr. Bryan Wells.

SET-232 demonstrated how new spectral bands, and the exploitation of other properties of light to obtain information that cannot currently be measured, will enable warfighters to react faster to threats and to gain a tactical advantage. It also enables advanced imaging capabilities to be introduced at lower echelons, including individual warfighters. This would enable a major increase in overall situational awareness and targeting capability. SET-236 has shown how key performance metrics can be used to form the basis for specifications of future systems which incorporate Compressive Sensing. This tool is particularly beneficial to support radar and ESM designers as well as procurement offices. Radar manufacturers are now taking the results of SET-236 into consideration when designing their next generation of radars (e.g. in order to improve angular resolution when detecting and tracking individual drones in a swarm). The work of both teams brought together 36 scientists from 12 Nations, and led to the organisation of a successful Lecture Series and Specialists' Meeting in 2019.

Figure 57: Members of the SET-232 Research Task Group.

Figure 58: Members of the SET-236 Research Task Group.

DR-ING MICHAEL WUNDER (IST PANEL, DEU)

For more than a decade, Dr. Ing Michael Wunder has made outstanding contributions as a member of the Information Systems Technology (IST) Panel. His work in support of NATO's collaborative research efforts and exemplary leadership has contributed to the continual success of IST Panel and cross-panel activities. Dr. Wunder's overall focus has been on emerging technologies and developments that can improve interoperability in the evolving threat landscapes of the future.

As the leader of a number of IST Research Task Groups (RTGs), Dr. Wunder made notable technical contributions related to the use of modelling languages to develop frameworks for shared ontologies, ensuring semantic interoperability across domains. He recognised the potential impact of this research on cross-panel and NATO-wide activities, spearheading a number of IST Panel activities on big data (BD), artificial intelligence (AI), and machine learning (ML).

Dr. Wunder has noted the importance of maintaining a collaborative community comprised of scientists and military alike. He organised the influential Research Specialists Meeting (RSM) IST-160 on "BD and AI for Military Decision Making". This event brought together approximately 300 participants, including junior and senior scientists from NATO Nations and partners, industry experts, and academics. The success of IST-160 initiated the push towards an increase in cross-panel activities and the development of broader communities of interest.

Figure 59: Dr.-Ing. Michael Wunder receiving the 2022 STO Excellence Award from the NATO Chief Scientist, Dr. Bryan Wells.

Another seminal IST Panel event led by Dr. Wunder was IST-RSM-190 on "BD and AI, ML for Hybrid Military Operations". This virtual meeting attracted 300 participants, influenced the future road map for collaborative research activities, and emphasised NATO responsiveness to complex hybrid military operations.

Dr. Wunder's technical expertise and dedicated leadership to IST Panel activities make him a highly deserving recipient of the individual 2022 STO Excellence Award. His positive impact and exceptional contributions to defence and security collaboration are evident through his involvement in more than 40 NATO research activities.

NATO SECRETARY GENERAL RECOGNISES CMRE'S MR. LUIGI TROIANO WITH NATO MERITORIOUS SERVICE MEDAL (MSM)

Mr. Troiano was awarded the NATO Meritorious Service Medal in recognition of his readiness to undertake two major unplanned tasks in 2021, while successfully completing all his scheduled duty activities as head of the Acoustic Section within the Engineering Department at the CMRE.

Firstly, the CMRE received an urgent request for technical assistance from a NATO Nation industrial partner developing a novel ASW acoustic array for a NATO navy. Mr. Troiano analysed data from the sonar and subsequently wrote a proposal addressing the issues identified, suggesting corrective actions. The proposal was followed up by two on-site visits by Mr. Troiano, where he provided technical expertise to engineers, helping to characterise and remediate the problems.

Figure 60: Mr. Luigi Troiano.

Secondly, the unexpected departure of the key engineer working on design and implementation of the three "Deep Diver" multi-channel acoustic recorders left the project in disarray. Mr. Troiano took on the responsibility of completing and testing the three systems, and subsequently organising and implementing the deployments from RV Leonardo. Mr. Troiano's timely actions ensured the successful execution of a project of great reputational importance to the CMRE and the STO.

ANNEXES

THE OFFICE OF THE CHIEF SCIENTIST (OCS)

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 has played a vital role in advising on the science and technology (S&T) underpinning the next generations of military capability. The OCS supports the Chief Scientist in two essential functions: as Chairman of the Science and Technology Board (STB), and as senior scientific advisor to the NATO leadership. In addition to providing executive support to the STB and its responsibilities, the OCS acts as the focal point for the STO work programmes (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 staffs 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 emerging and disruptive technologies (EDTs) on Alliance objectives. In 2022, the COVID-19 pandemic reduced its effects, and the STO work sought to return to normality as virtual and hybrid meetings continued to be used extensively. After more than two years, the Spring STB meeting was held physically again, in Oslo in March, as well as the STO Plans & Programmes Workshop (PPW), in February in Paris. Over the year, several Strategy Sub-Group (SSG) meetings have been held. Some were hosted virtually, while three took place in Oslo (Norway) on the occasion of the Spring STB meeting, in Paris (France) over the summer, and the last one in Brussels (Belgium), at the time of the Fall STB meeting. On 19 September 2022, the STO celebrated its 10th anniversary with a special event at NATO Headquarters in Brussels. Additionally, the 2nd and 3rd Distributed Synthetic Training (DST) Workshops were successfully held at NATO HQ by the NATO Modelling and Simulation Group (NMSG), in coordination with the OCS and the Defence Investment Division. As NATO's leadership became increasingly interested in innovation, and EDTs in particular, the 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, providing guidance in dealing with EDTs, encouraging innovation, and preserving the Alliance's unique technological and strategic position. Furthermore, Dr. Bryan Wells played a key role as a member of the DIANA Board of Directors, which is responsible for the organisational and strategical governance of the Defence Innovation Accelerator of the North Atlantic (DIANA) that is in charge of accelerating cooperation on key technologies as well as bringing together NATO work and academia for rapid development. Due to the rising awareness of the critical importance that maintaining a technological edge poses for the Alliance, the demand for evidence-based advice and scientific expertise that the STO can bring to NATO HQ is rapidly increasing. Together, the Chief Scientist and OCS staff are fully invested in satisfying this demand.

COLLABORATIVE PROGRAMME OF WORK (CPOW)

The strength of NATO's collective defence ultimately rests upon close cooperation and interoperability amongst 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 Collaborative Programme of Work (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 300 carefully selected activities in areas of critical importance to NATO militaries: cyber, space, sensors, weapons, command and control, human-machine interface, modelling & 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 Panels and Group address the total spectrum of this collaborative effort:

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

Known as the "powerhouse" of the collaborative model, the Panels and Group carry out scientific activities that, collectively, comprise the CPoW. They are made up of a network of approximately 5,000 national representatives, including world-class scientists, engineers and information specialists. In addition to providing critical international S&T management and scientific oversight, they provide coordination and cooperation opportunities with military users and other NATO bodies.

Technical Teams formed within and across the Panels and Group 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-reviewed journals. Activity results are frequently publicised through technology demonstrations, as well.

With 309 Technical Activities conducted in 2022, CPoW has increased its efforts by 60% since 2012 (see Figure 61). In 2022, 40% of the CPoW activities were related to at least one EDT. All information on the status of the CPoW can be found in the 2022 CPoW Annual Brochure:

https://www.sto.nato.int/public/NATO-STO_CPoW_2022_FINAL.pdf

Figure 61: 2022 CPoW Annual Report.

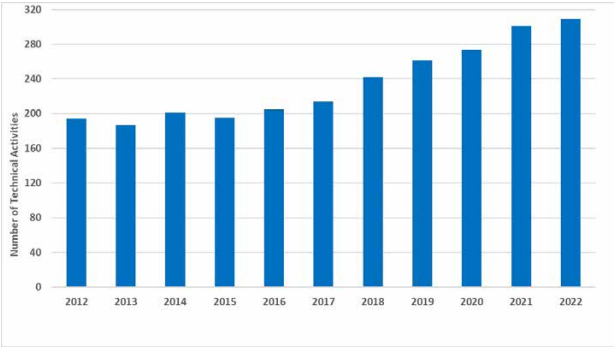

Figure 62: NATO STO CPoW Activities per year.

THE 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). In its areas of expertise, the CSO also provides assistance and support to the STB and the Office of the Chief Scientist. The CSO plays a critical role in managing and overseeing the CPoW, through supporting the business of the six STO Panels and the NATO Modelling & Simulation Group, 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 CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION (CMRE)

ABOUT NATO STO CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION

Directed by Dr. Catherine Warner, the NATO 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 science and technology solutions to address defence and security needs of the Alliance.

Building on over 60 years of knowledge and experience, CMRE supports NATO's technological advantage in the maritime domain by strengthening the science and technology network, accelerating the development of critical capabilities within the Alliance, and building science and technology 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 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-ton 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

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 yools, and artificial intelligence and deep learning. 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- Environmental Knowledge and Operational Effectiveness: 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 (MCM): Strengthening NATO's ability to counter naval mines through networks of securely communicating, adaptive autonomous systems.

Maritime Unmanned Systems (MUS) Enablers: Providing capabilities for the development of unmanned system of heterogeneous systems with a high level of interoperability, security and persistence.

The ACT-funded programmes are supplemented by projects funded by the European Commission and the Nations.

INTERNATIONAL EXERCISES

In 2022, CMRE participated in a number of NATO and international exercises, including the International Maritime Exercise (IMX), and the Robotics Experimentation Prototyping for Maritime Unmanned Systems (REPMUS) and NATO Dynamic Messenger exercises held in Portugal. During IMX22, CMRE contributed to the "Digital Ocean", demonstrating the use of buoyancy gliders for wide area patrol and anomaly detection in the US Navy Fifth Fleet's landmark unmanned systems exercise. For REPMUS and Dynamic Messenger, 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 MUS for ASW, MCM, and Rapid Environmental Assessment (REA), demonstrating their utility in an operational context with front line operators. In addition, CMRE conducted an analysis of MUS performance in the exercise vignettes.

In addition to facilitating CMRE's participation in exercises, the NRV ALLIANCE was the platform for the execution of three scientific experiments in the High North. In early summer 2022, CMRE – along with other partner organisations – conducted the Northern Recognized Environmental Picture (NREP) sea trial, studying the effects of climate change. The NRV ALLIANCE remained in the High North for the Italian Navy NREP cruise in July, and returned to the polar region again in October to support the US Office of Naval Research's (ONR) Northern Ocean Rapid Surface Evolution (NORSE) sea trial.

LIST OF ACRONYMS AND ABBREVIATIONS

AASW	Autonomy for Anti-Submarine Warfare
ACT	Allied Command for Transformation
AFRL	Air Force Research Laboratory
AGARD	Advisory Group for Aerospace Research and Development
AI	Artificial Intelligence
AIS	Automatic Identification System
ALLSAT	NATO Alliance SMALLSAT Constellation Effort
ANMCM	Autonomous Naval Mine Counter Measures
AR	Augmented Reality
ASM	Anti-Ship Missile
ASTM	American Society for Testing and Materials
ASW	Anti-Submarine Warfare
AUV	Autonomous Underwater Vehicles
AVT	Applied Vehicle Technology
BD	Big Data
CA	Collaborative Autonomous
CAN	Canada
CATL	Collaborative Autonomy Tasking Layer
CB	Chemical and Biological
CCASCOE	Climate Change and Security Centre of Excellence
CCDC	Combat Capabilities Development Command
CDR	Commander
CM	Countermeasure
CMRE	Centre for Maritime Research and Experimentation
CNAD	Conference of National Armaments Directors
CNR	Consiglio Nazionale delle Ricerche
COE	Centres of Excellence
CONOPS	Concept of Operations
COTS	Commercial Off-The-Shelf
CPoW	Collaborative Programme of Work
CRV	Coastal Research Vessel
CSO	Collaboration Support Office
CSRR	Chief Scientist Research Reports
CTD	Conductivity-Depth-Temperature
DEVCOM	United States Army Combat Capabilities Development Command
DIANA	Defence Innovation Accelerator for the North Atlantic
DST	Distributed Synthetic Training
DYMS	Dynamic Messenger
EDT	Emerging and Disruptive Technologies
EO	Electro-Optical
ESM	Electronic Support Measures
EST	Estonia
ET	Exploratory Team
FFI	Norwegian Defence Research Establishment
FHR	Fraunhofer Institute for High Frequency Physics and Radar Techniques
FKIE	Fraunhofer Institute for Communication, Information Processing and Ergonomics
FMN	Federated Mission Networking
FOI	Swedish Defence Research Agency
FRA	France
GBR	United Kingdom of Great Britain and Northern Ireland
GDEM	Generic Data Exchange Mechanism
HFM	Human Factors and Medicine
HLA	High-Level Architecture
HRLFSAS	High-Resolution Low Frequency Synthetic Aperture Sonar
IDT	In-stride Debrief Team
IFC	Intermediate Force Capabilities
IMX	International Maritime Exercise
IR	Infrared
ISR	Intelligence, Surveillance and Reconnaissance
IST	Information System Technology
IT	Information Technology
JODAA	Joint Operational Demonstrator For Advanced Applications
LOE	Lines of Efforts
LVC-T	Distributed maritime training
M&S	Modelling and Simulation
MARCOM	Maritime Command
MDO	Multi-Domain Operations

ML	Machine Learning
MoD	Ministry of Defence
MSA	Maritime Situational Awareness
MSaaS	Modelling and Simulation as a Service
MSTC	Maritime Science and Technology Experts Committee
MTDS	Distributed training for the air domain
MUS	Maritime Unmanned Systems
MUSE	Maritime Unmanned Systems Enablers
NAF	NATO Architectural Framework
NATO	North Atlantic Treaty Organization
NCIA	NATO Communication Information Agency
NDN	Named Data Networking
NLD	Netherlands
NLR	Netherlands Aerospace Centre
NMSG	NATO Modelling and Simulation Group
NMW	Naval Mine Warfare
NORSE	Northern Ocean Rapid Surface Evolution
NREP	Northern Recognized Environmental Picture
NRV	NATO Research Vessel
OCS	Office of the NATO Chief Scientist
OECD	Organization for Cooperation and Development
OEM	Original Equipment Manufacturers
ONERA	Office National d'Etude et de Recherches Aérospatiales
ONR	Office of Naval Research
OODA	Observe, Orient, Decide, Act
P&E	Planning and Evaluation
PASSEX	Participated in a Successful Passing Exercise
PoW	Programmes of Work
PPW	Plans and Programmes Workshop
PTSD	Post Traumatic Stress Syndrome
QKD	Quantum-Key Distribution
RAS	Robotic and Autonomous Systems
REA	Rapid Environmental Assessment
REPMUS	Robotics Experimentation Prototyping for Maritime Unmanned Systems
RSM	Research Specialist Meeting
RTG	Research Task Group
RWS	Research Workshop
S&T	Science and Technology
SACT	Supreme Allied Commander Transformation
SAF	Sustainable Aviation Fuels
SAS	System Analysis & Studies
SBC	Synthetic Blend Components
SCB	Scalable Cooperative Broadcast
SCEE	Soldier Combat Effectiveness and Efficiency
SCI	Systems Concepts and Integration
SM	Specialists' Meeting
SMALLSAT	Small Satellite
SME	Subject Matter Experts
SoA	State-of-the-Art
SOF	Special Operation Forces
SOP	Standard Operating Procedures
SSA	Space Situational Awareness
SSG	Strategy Sub-Group
SSS	Side-Scan Sonar
STANREC	Standardized Recommendation
STB	Science & Technology Board
STEM	Science, Technology, Engineering and Mathematics
STO	Science and Technology Organization
SWEAT	Soldier Weapon Equipment Assessment Tool
SWIR	Shortwave Infrared
TIDE	Tank for Innovation Decision and Execution
TNO	Toegepast Natuurwetenschappelijk Onderzoek
UAS	Unmanned Aerial Systems
UCATT	Distributed training for land domain
ULB	Université Libre de Bruxelles
US	United States of America
VNIR	Visible-Near Infrared
XBT	Expendable Bathythermograph

LIST OF LINKS/CONTACT DETAILS

OFFICE OF THE CHIEF SCIENTIST (OCS)

Twitter: @NATO_STO_OCS

LinkedIn: NATO STO OCS Office of the Chief Scientist

YouTube: NATO STO OCS Office of the Chief Scientist

Website: https://www.nato.int/sto

Address: NATO STO-OCS, NATO HQ-Blvd. Léopold III, B - 1110 Brussels- Belgium

Email: mbx.sto@hq.nato.int

COLLABORATION SUPPORT OFFICE (CSO)

LinkedIn: NATO Science and Technology Organization (CSO)

YouTube: NATO Science & Technology Organization

Website: www.sto.nato.int

Address: NATO STO -CSO, BP 25, 92201 Neuilly sur Seine – France

Email: mailbox@cso.nato.int

CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION (CMRE)

Twitter: @sto_cmre

Facebook: NATOSTOCMRE

Linkedin: NATO STO-CMRE

Website: https://www.cmre.nato.int

Address: NATO STO-CMRE, Viale San Bartolomeo, 400 19126 La Spezia (SP) - Italy

Email: pao@cmre.nato.int


ALLIANCE
A 5345