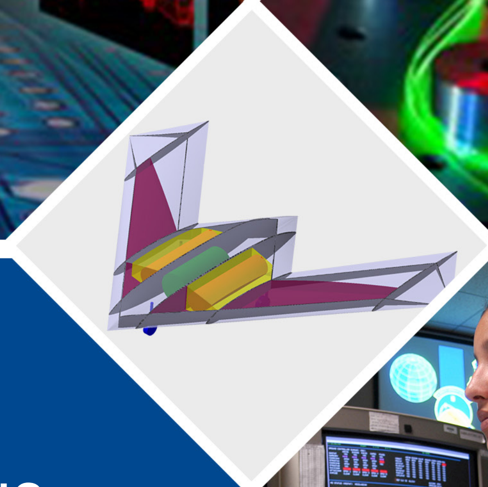
NATO OTAN

S&T organization

2019 HIGHLIGHTS

SCIENCE AND TECHNOLOGY ORGANIZATION



EMPOWERING THE ALLIANCE'S TECHNOLOGICAL EDGE

www.sto.nato.int

NATO SCIENCE AND TECHNOLOGY ORGANIZATION HIGHLIGHTS 2019

FOREWORD

FOREWORD

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

Dr Bryan Wells, NATO Chief Scientist.

The London Declaration, issued by NATO Heads of State and Government in December 2019, made clear the importance of science and technology to Alliance defence and security. In this Declaration, leaders stated that the Alliance was "addressing the breadth and scale of new technologies to maintain our technological edge, while preserving our values and norms."

This statement by NATO leaders goes to the heart of the mission of the NATO Science & Technology Organization (STO). Our role is to maintain NATO's scientific and technological advantage by generating, sharing, and utilizing advanced scientific knowledge, technological developments, and innovation to support the Alliance's core tasks.

The NATO Programmes of Work show that we are already working hard to maintain NATO's technological edge, as the London Declaration set out. The highlights in this booklet are a testament to the wide-ranging and expert-level military science and technical work that is done for the benefit of NATO and its partner nations. But we are not complacent, and we are constantly looking at ways to improve our programme of work and to increase its relevance to our Armed Forces.

The statistics on our Programmes of Work demonstrate the scale of our efforts. We now have over 300 projects currently underway, ranging from major research programmes to horizon scanning activities and lecture series. Over 6,000 scientists from Nations now actively work in the STO, making this the biggest international defence S&T network in the world. These scientists are drawn from government, academia and industry, from Allies and partners; and we have close links with the institutions of the European Union. In addition to the scientists from the Nations, NATO supports an Office of the Chief Scientists in the NATO HQ in Brussels, to give scientific advice direct to NATO political and military leadership, a Collaboration Support Office in Paris, to administer the Collaborative Programme of Work, and the Centre for Maritime Research and Experimentation at La Spezia, a world-class laboratory in its area of expertise.

When I became NATO Chief Scientist and Chair of the NATO Science & Technology Board in July 2019, I made a commitment to maintain the excellence of the work of the STO, but also to take these efforts to the next level, by incorporating the best of all the Nation's international research collaboration practice, be it in terms of rapidity of response, or clear paths to exploitation, or in other aspects. This booklet demonstrates the very high quality of work that is already being done, and it also points the way in which we are working to enhance our work and its importance for the Alliance.

This year, we have focused the Highlights report onto the work that the STO has recently completed in the field of emerging and disruptive technologies, including areas such as cyber, artificial intelligence, quantum and novel materials. The STO is therefore already actively working on the technologies that our leaders set out in the London Declaration. In the coming years we will continue to serve the Nations and NATO with greater understanding of the opportunities and challenges that these technologies provide, and how our Armed Forces can embrace and respond these new developments.

It is an honour to be the new Chairman of the NATO Science & Technology Board, which oversees the work of the STO, the dedicated men and women who form the largest multinational defence S&T network in the world. And it is equally a privilege to serve as NATO Chief Scientist, providing NATO leadership with scientific advice on the key technologies of the future. This Highlights 2019 document showcases examples of the very best defence science available to the Alliance and its partners.

NATO Chief Scientist (CS)
STB Chairman

TABLE OF CONTENTS

INNOVATION

INNOVATION FOR THE ALLIANCE

Science and technology (S&T) is a key driver for innovation in NATO and its partner nations. In 2019, the Alliance embarked on an ambitious innovation agenda that looks at three targets:

- **Capability development and delivery**, where military capability needs to be fielded more rapidly, through gradual maturation as well as exploiting the disruptive effects of technologies;
- Policy-making and decision-making, where new technologies may enable a larger range of options for future actions, and where operational decisions may be required in highly compressed timescales; and
- Management, where the Alliance may need to adapt the processes and cultures that underpin its political, military, and administrative functions.

EMERGING AND DISRUPTIVE TECHNOLOGIES

For the purposes of the Alliance, some differentiation of the terms "innovation," "technology," and "disruption" is essential. Adopting a broadly inclusive perspective, innovation can be seen as "novelty for a purpose," while disruption is "a surprising change that creates a competitive (dis)advantage." Seen through this lens, novel technology comes to us as original innovation, but the disruptive impact it might bring fully depends on a potential user's intent and creativity, well beyond the initial ideas of its original designers. Disruptive effects do not automatically originate from high-tech; they may well spring from creative application of low-tech or a convergence of technology developments. Promising S&T developments—so-called emerging technologies—often combine with well-established technologies to create unforeseen impact. Therefore, a balanced S&T portfolio is necessary, addressing disruptive and militarily essential science and technology, whether emerging or otherwise.

With this broad understanding, the Alliance seeks to explore and exploit the following Emerging and Disruptive Technologies (EDTs): space, data, artificial intelligence, autonomy, hypersonics, quantum technologies, and biotechnologies.

STO'S RESPONSE TO EDTS

The STO is responding to the challenge of EDTs through a variety of established mechanisms;

- Through its Technology Watch, von Karman Horizons Scans, and Technology Trend Reports, the STO leads the maturation of the Alliance's understanding of the implications of EDTs, such as hypersonics, quantum, and biotechnologies.
- Ongoing work on STO Themes generates a considerable body of knowledge that contributes to priority developments in autonomy, and can readily inform the development of an artificial intelligence (AI) strategy.
- The STO's Programme of Work provides the underlying knowledge base for targeted, evidence-based advice to inform policies for space and data.

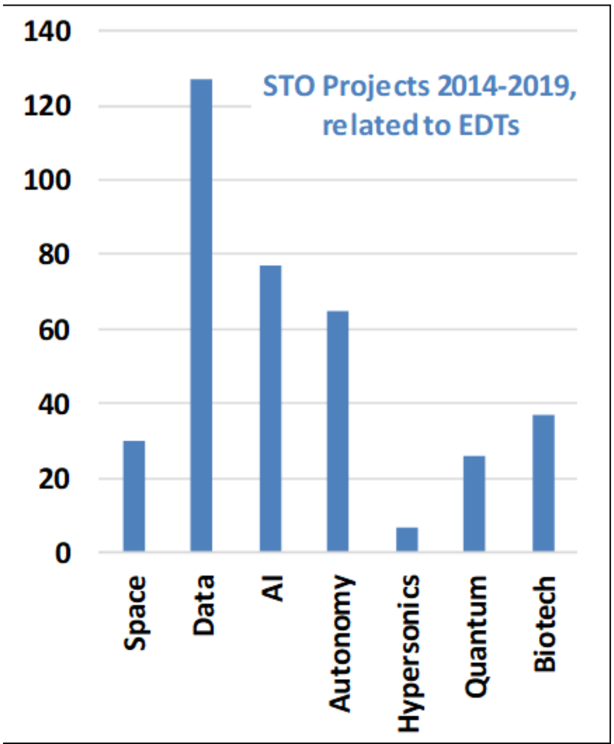


Figure 1: STO Projects 2014-2019, related to EDT.

> i An analysis across all programmes and across all types of projects highlights that **well over 40% of the 855** projects executed by the STO since 2014 are directly related to these EDTs [Fig. 1]. This body of work provides the foundation for the **Alliance's enduring knowledge advantage**.

A closer inspection of the STO programmes[1] and their individual contributions to the Alliance knowledge base reveals the diversity of STO work, as well as the differences in technological maturity and readiness of the EDTs [Fig. 2]. The broad topical cluster of data, artificial intelligence, and autonomy has been at the heart of STO programmes for considerable time already. As a shared effort across all programmes, projects cover the full spectrum of basic science (data to artificial intelligence) to application (artificial intelligence to autonomy). Work in the areas of space and hypersonics is more focused on advancing technologies for vehicles and systems, while projects in quantum technologies and biotechnologies expand scientific knowledge to develop applications.

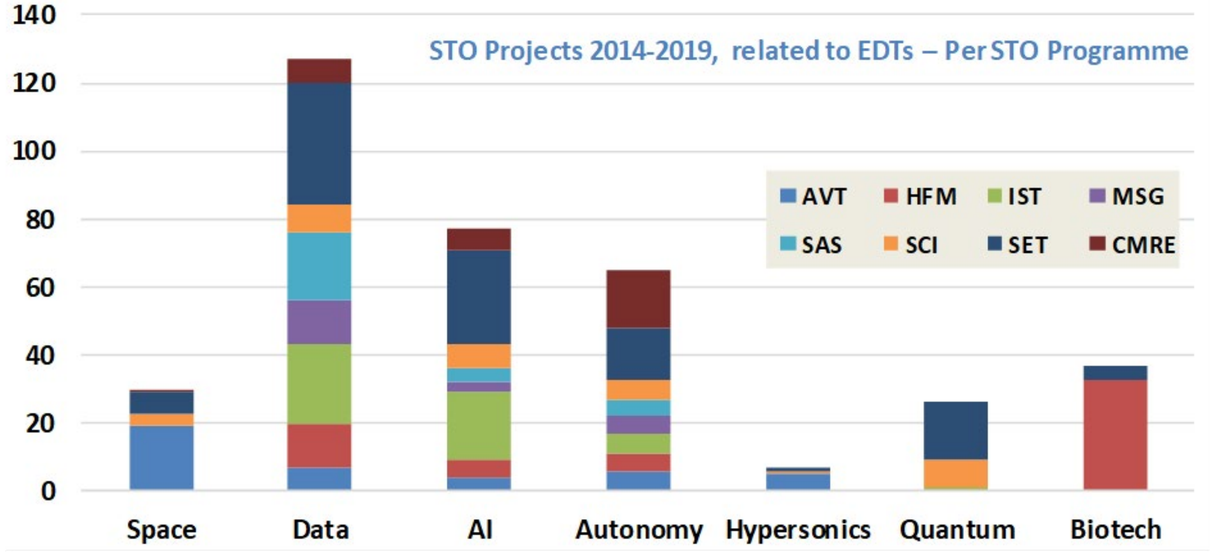


Figure 2: STO Projects related to EDTs – Per STO Progamme, 2014–2019

The following sections present examples of recent STO projects that delivered valuable contributions to the Alliance's understanding of EDTs, in particular by assessing their maturity and potential military impact, and advising decision-makers on promising opportunities for developing and delivering advanced capabilities.

The examples presented clearly extend beyond the current set of EDTs to demonstrate the full topical breadth of the STO programmes. Committed to delivering value to the Alliance, the STO will maintain a balanced and militarily relevant S&T portfolio that responds to current requirements and seeks to anticipate needs.

OUTLOOK

In 2020, the STO will not rest on its laurels. Under the guidance of the NATO Science & Technology Board, the STO will shape its programmes to focus on the identified EDTs. At the same time, the STO will look for weak signals in currently ongoing S&T projects that could indicate new, potentially disruptive applications of either cutting-edge or well-established technologies. **The Science & Technology Trends 2020-2040** are intended to deliver a systematic assessment of the EDTs (including maturity, current developments, potential applications and military impact) to inform planners and decision-makers, already in the first quarter of 2020.

[1] AVT – Applied Vehicle Technology Panel; HFM – Human Factors and Medicine Panel;
IST – Information Systems Technology Panel; MSG – NATO Modelling & Simulation Group;
SAS – System Analysis and Studies Panel; SCI – Systems Concepts and Integration Panel;
SET – Sensors and Electronics Technology Panel; CMRE – Centre for Maritime Research and Experimentation.

NATO STO PROGRAMME OF WORK

NATO STO Programme of Work

ACCELERATING AND ACHIEVING CAPABILITY DEVELOPMENT AND DELIVERY (A2CD2)

3D SCANNING FOR CLOTHING FIT AND LOGISTICS (HFM-266)

Body dimensions vary considerably between NATO countries and within national armed forces. Both clothing and equipment need to be sized properly to accommodate this variation. Better fit leads to a better fighting force, and good fit is related to the size and 3D shape of the body. HFM-266 investigates 3D scan and fit technologies to better fit garments to the soldier to improve protection, mobility, and survivability.

Prof. Dr. Hein DAANEN, NLD, Sizing Science; Allan KEEFE MSc, CAN, Defence Research and Development Canada (DRDC)

BACKGROUND AND MILITARY RELEVANCE

Human variability is tremendous between and within NATO countries. Providing accommodating clothing and equipment is a major design challenge. There is also a need for improved awareness regarding the impact of fit on performance. 3D scanning provides an objective methodology for assessing body shape and size to improve the clothing fit/pattern and to identify the most appropriately sized garments.

OBJECTIVES

The main objectives of HFM-266 were to review current and emerging 3D scanning and fit technologies, investigate how to translate 3D scan data into appropriately sized garments, and suggest improved sizing and fitting systems.

S&T ACHIEVEMENTS

A survey among NATO members involved in procurement and supply of clothing and equipment identified a need for a manual on how to size and fit clothing. As a result, HFM-266 produced a manual that is currently processed as STANREC 4833 with the Combat Clothing, Individual Equipment & Protection (CCIEP) working group of NAAG/LCG DSS. In addition, a report contains an overview of 3D scanning systems, procedures, and examples of successful implementation in the clothing supply and research process.

SYNERGIES AND COMPLEMENTARITIES

Synergies exist with NAAG/LCG DSS and its CCIEP working group CCIEP , in which there is ongoing collaboration between the two groups. Close contacts were established with HFM-260 on Enhancing Warfighter Effectiveness with Wearable Bio Sensors and Physiological Models, since smart systems worn on the body can only function properly when appropriate fit is guaranteed.

EXPLOITATION AND IMPACT

The STANREC 4833 document provides a tool to inform better sizing and fit of clothing and equipment. Information on scanning systems and procedures has been exchanged, since several

> *We equip our soldiers to fight, we shouldn't expect them to fight their equipment.*

countries (AUS, NLD, CAN, LUX) are considering implementing or upgrading their 3D scanning tools in the anthropometric measuring process of soldiers as part of the clothing supply chain. The implication of new technologies on clothing supply and logistics is expected to lead to cost benefits.

CONCLUSIONS

The work of this Research Task Group (RTG) leads to new insights by combining the expertise of different fields (3D scanning, clothing fit, and logistics), to cost reduction in the clothing supply chain and better interoperability within NATO forces.

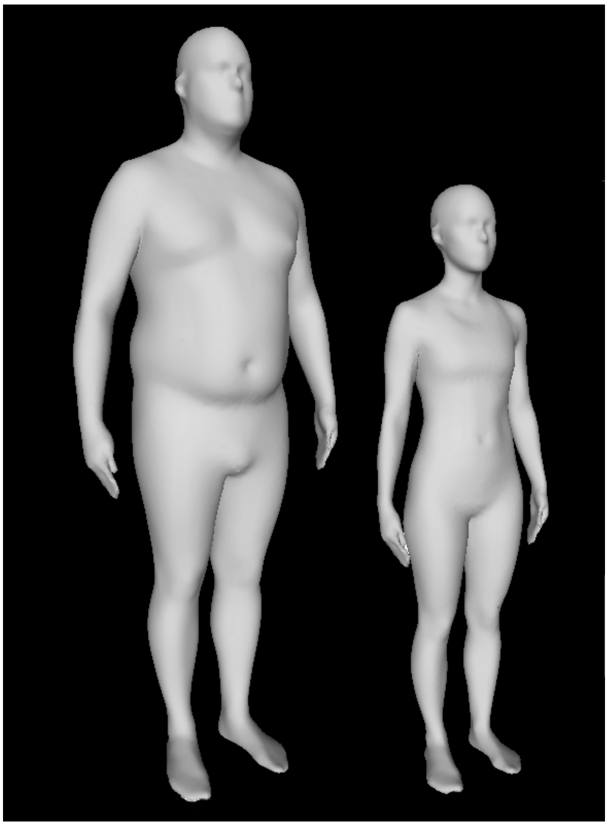


Figure 3: Depersonalized 3D scans showing the large variability in body dimensions.

JANUS: ACCELERATING THE DEVELOPMENT OF INTEROPERABLE DIGITAL UNDERWATER COMMUNICATION CAPABILITIES (CMRE)

NATO Standardization Agreement (STANAG) 4748—commonly known as JANUS—is the first ever standard for digital underwater communications. Many research groups, industrial providers, and navies have been working on JANUS for the past few years, both for research purposes and in operational exercises.

Dr Joao ALVES; Dr Fausto FERREIRA, STO-CMRE

BACKGROUND

In the flourishing yet developing market of underwater acoustic communications, several manufacturers provide their products operating on vendor-specific protocols. Most of these are not interoperable, with the result that end-users are confronted with an increased acquisition risk since they need to commit to one single provider in order to have a working underwater communications system. With the pressing need for interoperability in mind, the NATO STO Centre for Maritime Research and Experimentation (CMRE)—in collaboration with academia, industry, and national research laboratories—dedicated several years of research to establishing a standard for digital underwater acoustic communications (STANAG 4748 or JANUS).

Figure 4: Participants in the JANUS Interoperability Fest 2019

OBJECTIVES

To promote interoperability and engagement with Industry, CMRE organized the Second JANUS Interoperability Fest in 2019, a pier-side experimental activity in La Spezia, Italy. The event was sponsored by NATO Allied Command Transformation (ACT) and supported by the Italian Navy "Centro di Supporto e Sperimentazione Navale" (CSSN). The objective of this event was to collectively exercise JANUS implementations from commercial vendors with the opportunity to correct any possible misunderstandings with the technical specifications. It was intended to be a collaborative effort to promote interoperability and accelerate capability development.

S&T ACHIEVEMENTS

The event brought together over 25 participants from seven companies: Applicon (ITA), ATLAS ELEKTRONIK (DEU), EvoLogics (DEU), PopotoModem (USA), Teledyne Benthos (USA), W-Sense (ITA), and Wärtsilä ELAC (DEU). Additionally, several observers participated from international navies and government institutions.

Over the various days of experimentation, all participants were able to use JANUS successfully to exchange data among the different industrial platforms targeting novel applications, such as emergency messages in support of distressed submarines, an underwater Automatic Identification System (AIS) to increase situational awareness, and a Chat application (WetsApp) for quick exchange of information between surface and underwater platforms. Experimental activities involving static and mobile assets (such as the CMRE Unmanned Surface Vehicle) were addressed. This was a major step towards true interoperability with the possibility of industry providing these novel capabilities to NATO partner nations and their navies.

SYNERGIES AND COMPLEMENTARITIES

Immediately following the JANUS Interoperability Fest, the CMRE organized the 2019 JANUS International Workshop sponsored by ACT to foster the development of JANUS and engagement with the wider community.

EXPLOITATION AND IMPACT

Topics addressed during the 2019 JANUS International Workshop included the current status of the standard, JANUS-based service during at sea experimentation, experience and lessons from the 2nd JANUS Interoperability Fest, and proposals for new applications and future developments. The workshop was a perfect venue to foster interactions among governments, industry, and academia about user experiences, future developments, and revisions of the standard.

Figure 5: CMRE Unmanned Surface Vehicle

CONCLUSIONS

The JANUS Interoperability Fest is a joint experimentation activity to validate the initial steps of underwater communications interoperability among different underwater modem vendors. It contributes to achieving and accelerating the development and delivery of critical underwater communication capabilities within the Alliance.

LIVE VIRTUAL CONSTRUCTIVE–TRAINING (LVC-T) IN THE MARITIME DOMAIN (MSG-169)

Live Virtual Constructive – Training (LVC-T) is the future training tool to prepare maritime forces for their missions. It is a cost-efficient, scalable, repeatable solution that can provide realistic and challenging training within a safe and controllable environment to achieve and maintain a high level of war-fighting proficiency and improve interoperability through a NATO-wide synthetic training architecture.

Commander Jörg FELDHUSEN, DEU, Centre of Excellence for Operations in Confined and Shallow Waters, MSG-169 Chairman

BACKGROUND AND MILITARY RELEVANCE

Originating from the 2015 Gap Analysis Report on Modelling & Simulation, the introduction of LVC-T into NATO represents a quantum leap in maritime collective training, evaluation, and experimentation. At the same time, it paves the way for distributed synthetic training in a joint environment.

> *"M&S is already a mature technology widely used by the Allies to enable military training. However, it is considered that the use of M&S to support education and training in NATO has not been developed to its greater extent." (NATO Action Plan on Modelling and Simulation in Support of Military Training – Rev. 2)*

OBJECTIVES

The LVC-T concept was developed by the Centre of Excellence for Operations in Confined and Shallow Waters, together with several NATO nations under the auspices of the NATO Training Group. The RTG MSG-169 was tasked to develop a more detailed Implementation Paper, describing the required technical and organizational infrastructure.

S&T ACHIEVEMENTS

The two delivered documents (LVC-T Concept in conjunction with the Implementation Paper) provide sufficient information to start the implementation of LVC-T in the Maritime Domain. The technology is available and already in use by some nations on the national and multinational levels (e.g., the US Navy conducting their Fleet Synthetic Training [FST]).

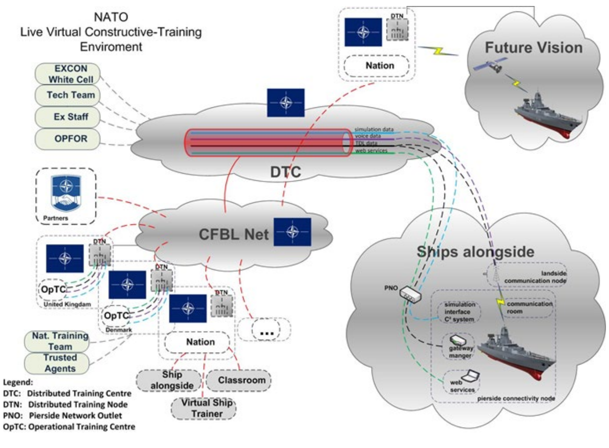


Figure 6: NATO Live Virtual Constructive – Training Environment

SYNERGIES AND COMPLEMENTARITIES

MSG-169 worked in close collaboration with MSG-165 "Incremental Implementation of Mission Training through Distributed Simulation (MTDS) for Joint and Combined Air Operations" to ensure the interoperability of their distributed synthetic training environments.

EXPLOITATION AND IMPACT

Under the lead of the NATO Modelling & Simulation Group and the NATO Chief Scientist, the results of MSG-169, together with the achievements of MSG-165 and MSG-164 "Modelling & Simulation as a Service," will be combined under the NATO Joint Mission Training through Distributed Simulation Initiative to accelerate delivery of this capability to NATO.

CONCLUSIONS

The LVC-T Concept and Implementation Paper provide a solid baseline for distributed synthetic training in the Maritime Domain. The follow-on RTG MSG-180 "Implementation of LVC-T in the Maritime Domain" will assist the Allied Maritime Command in implementing LVC-T and utilizing the inherent advantages of this approach to maintain a high degree of operational readiness.chain and better interoperability within NATO forces.

MULTI-DISCIPLINARY DESIGN AND PERFORMANCE ASSESSMENT OF EFFECTIVE, AGILE NATO AIR VEHICLES (AVT-251)

AVT-251 re-designed an existing generic unmanned combat aerial vehicle (UCAV) into a vehicle able to achieve specific military mission requirements for an advanced, agile UCAV. The re-design was conducted in a multi-disciplinary environment (without additional wind tunnel testing) and represents a good example of how modern design and analysis tools streamline the military aircraft design process to result in a timely, feasible design.

Prof Russel M. CUMMINGS, USA, USAF; Dr Andreas SCHUETTE, DEU, DLR; Mr Carsten LIERSCH, DEU, DLR

BACKGROUND

Over the last ten years, a Technical Team consisting of a remarkable group of specialists with high expertise in the area of vortical flowfields collaborated under the NATO framework and established an outstanding knowledge base. This team's main goal was to re-design a given generic aerial platform already used by previous teams to demonstrate a developed, fully virtual multi-disciplinary design approach.

MILITARY RELEVANCE

In a highly contested operational environment, manned or unmanned combat air vehicles (M/UCAVs) may be required to fly at higher angles of attack with more agility as compared with current designs in order to survive and accomplish their missions. Adding this additional capability using simulation tools rather than extensive paper studies with additional wind tunnel testing would modernize the design process.

OBJECTIVES

The generic aerial configuration of the SACCON unmanned vehicle was re-designed based on the requirements of a desired mission and/or a defined flight envelope. This evolved into a configuration named MULDICON. The design incorporated several additional aspects and disciplines that were dependent on the availability of the contributing nations and links to other Task Groups. Finally, the design strategy and use of advanced simulation design tools was documented and evaluated with respect to the applicability and reliability of the methods used.

> *"Digital engineering is a much better way to assess [options] than a paper input with a lot of government expertise trying to fill in the gaps. Let's just simulate the system and pick." – Dr. William Roper, Assistant Secretary of the Air Force for Acquisition, Technology and Logistics, 2019)*

S&T ACHIEVEMENTS

AVT-251 showed that the MULDICON unmanned combat aerial vehicle demonstrator was able to achieve specific mission requirements that were typical for an advanced, agile UCAV configuration, without the need for additional wind tunnel testing. The design trade studies were conducted within the framework of multiple groups, including design, aerodynamics, controls, structures, and engine integration.

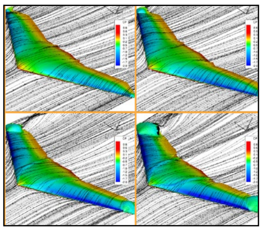


Figure 7: US Air Force Academy Kestrel flow development with different angles of attack.

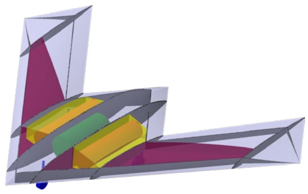


Figure 8: SACCON Unmanned Combat Air Vehicle concept.

SYNERGIES AND COMPLEMENTARITIES

The Technical Team supported two NATO Long-Term Aspects:

- Assured Precision Strike, by providing the required platform design in the air domain; and
- Vehicle Mobility, Safety and Survivability, since survivability will be considered to be a key military requirement for future air vehicle platforms.

EXPLOITATION AND IMPACT

The advances in methods and tools achieved by AVT-251 and its predecessors were fed back to national tools as solver for complex flow simulations, like the TAU and Kestrel codes, in order to enhance national procurement programs resulting in continuous improvements of existing systems (Eurofighter Strakes and B-52 Re-Engining) and developments of future systems (5th Generation Aerial Target).

CONCLUSIONS

TThe results of AVT-251 represent a good example of how modern design and analysis tools can streamline the design process and determine a feasible configuration within a reasonably short period of time. The MULDICON configuration has similarities to a number of other modern UCAVs, and represents a feasible design that would have controllable flight characteristics at angles of attack that will make the configuration agile and capable of fulfilling more challenging missions.

THE SPACE DOMAIN AND NATO OPERATIONS: A CRITICAL S&T REVIEW (SCI-318)

To prepare the Alliance for future demands on the space domain and operations within it, there is a recognized critical need for a common, forward-leaning posture among NATO's operational, planning, and S&T communities. The SCI-318 Research Specialists Meeting (RSM) sparked the NATO space community of interest (COI) by delivering a shared awareness and assessment ofthe STO's space-focused programme of work. It also made recommendations for future efforts under the stewardship of the STO that are coherent with NATO's current and future needs for affordable, resilient space capabilities.

LTC Giovanni SEMBENINI, ITA, Italian Secretariat General of Defense and National Armaments Directorate; Dr. Don LEWIS, USA, Aerospace Corporation

BACKGROUND AND MILITARY RELEVANCE

A shared awareness of needs and potential challenges enhances the return on investment of technical activities conducted under the NATO S&T enterprise. As a result, SCI-318 focused on improving the relevance of collaborative S&T activities related to the space domain for the NATO operator, decision maker, and military planner.

> *Space Domain Awareness is not the same as Space Situation Awareness.*

OBJECTIVES

Researchers, operators, planners, and space thinkers worked to achieve the following objectives:

- Develop a shared awareness of NATO's future space capability needs.
- Identify critical scientific and technical challenges that would benefit from focused NATO S&T attention.
- Identify and develop crucial relationships across NATO's technical, operational, and policy-making communities.
- Promote a COI focused on NATO's operational and technical requirements to maximize successful space domain endeavours.

S&T ACHIEVEMENTS

Considering that NATO has neither owned nor operated space assets in a long time, the specialists clearly outlined how this condition is not a liability. The diverse audience characterized ways of using national military and commercial assets to prevail in the space domain.

SYNERGIES AND COMPLEMENTARITIES

This RSM brought together participants from 12 NATO nations, representatives of NATO bodies such as Allied Command Transformation (ACT), the NATO Communications and Information Agency (NCIA), and the Joint Air Power Competency Center (JAPCC), as well as the European Union's Satellite Centre (EU SatCen).

EXPLOITATION AND IMPACT

The output of this RSM aids various military space operators (communications, intel, etc.) in making choices that will increase the effectiveness of available space assets in peacetime support operations and beyond.

CONCLUSIONS

Warfighters in the space domain must strive to sustain resiliency in the face of adversarial threats. Having fragile space-based capabilities that are lost at the outset of hostilities is of little value. SCI-318 provided a basis for promoting a shared awareness of the space domain, as well as identifying appropriate technical investments for NATO to consider sanctioning in its collaborative PoW under the stewardship of the STO.

Figure 9: Promoting a shared awareness of the space domain.

URBAN COMBAT ADVANCED TRAINING TECHNOLOGY – LIVE SIMULATION STANDARDS (UCATT-LSS) (MSG-140)

As missions are increasingly being conducted within a multinational, coalition context., the need for multinational live training involving tactical engagement simulation instrumentation systems is becoming more important for mission preparation. Within a "train as you fight" philosophy, using an instrumentation system with appropriate fidelity and interoperability is vital.

The first Urban Combat Advanced Training Technology (UCATT) standard accredited by the Simulation Interoperability Standards Organization (SISO) was released in 2016. This marked a milestone in Live Simulation interoperability. In 2019, two new UCATT Live Simulation Standard (UCATT-LSS) interface standard drafts were completed, and the first UCATT Laser Engagement Interface Standard (U-LEIS) was ratified by NATO as STANREC 4816.

Mr. Armin THINNES, DEU, Federal Office of Defence and Procurement; Mr. Ingo WITTWER, DEU, Rheinmetall Electronics GmbH; Capt. Sander CRUIMING, NLD, Royal Netherlands Ministry of Defence

BACKGROUND AND MILITARY RELEVANCE

At the beginning of 2000, NATO studies concluded that their forces would increasingly have to conduct operations in urban areas. This led to a series of UCATT RTGs that have focused on interoperability for live training. These RTGs have developed a generic functional architecture for live simulation training systems, identified a set of interfaces, and released the first draft SISO standard in 2015.

With urban areas being the battlefields in the 21st century, multinational instrumented live training is becoming more important for mission preparation. To provide NATO members with the capability of conducting training exercises within a "train as you fight" philosophy, an instrumentation system with appropriate fidelity and interoperability is vital.

OBJECTIVES

MSG-140, as the fourth UCATT mandate, was chartered to ensure U-LEIS was ratified by NATO, continuously validate UCATT's functional architecture, continue the ongoing standardization work, and invest in supporting SISO activities.

Figure 10: German infantry soldier wearing tactical engagement simulation equipment. Screen capture of a combat training centre after-action-review

S&T ACHIEVEMENTS

U-LEIS was ratified by NATO. MSG-140 created two additional draft interface standards—UCATT Networking Instrumentation and Tactical Engagement Simulation System Equipment (U-NITE) and UCATT Federation Object Model (U-FOM) and supported the standards already in place by establishing a standard certification test plan for U-LEIS.

SYNERGIES AND COMPLEMENTARITIES

UCATT monitors other NATO and SISO standardization activities. The goal is to ensure close cooperation with relevant groups by exchanging information or inviting subject matter experts. With members from the military, government acquisition organizations, and industry, all of whom are involved in live training and simulation, UCATT has become the focal point for the live simulation community within NATO and its partners.

EXPLOITATION AND IMPACT

Standardized interfaces will ensure that military users and acquisition organizations are better positioned for new projects, focus industry investments, and bring interoperable training to a new level. The adoption of U-LEIS has already begin in various NATO and Partnership for Peace countries. UCATT activities will continue with the recently approved Research task Group MSG-174 UCATT-LSS2.

CONCLUSIONS

Interoperability across live training systems has national procurement benefits, provides training flexibility, and makes international training easier and cheaper. Major benefits from the UCATT work of MSG-140 are available today.

NATO STO Programme of Work

ADVICE

A CMRE PAN-ARCTIC ICE-OCEAN PREDICTION MODEL TO SUPPORT NATO NAVAL OPERATIONS IN THE ARCTIC OCEAN (CMRE)

The CMRE developed a Pan-Arctic ice-ocean prediction model in 2019 with the aim of supporting NATO maritime operations in the Arctic Ocean.

Dr Paolo ODDO, Dr Andrea STORTO; Dr Silvia FALCHETTI; Dr Ines BORRIONE; Mrs Giuliana PENNUCCI; Mr Aniello RUSSO; Dr Pierre-Marie POULAIN, STO-CMRE

BACKGROUND

As a result of global warming, the Arctic Ocean is currently experiencing a rapid retreat of sea ice. If predictions are accurate, climate change is expected to lead to a nearly ice-free Arctic Ocean during the summer and increased access to Arctic waters in a few decades. Retreating ice will also facilitate extraction of the abundant natural resources (minerals, oil and gas) in the Arctic seabed, which not only implies new economic opportunities, but also opens new defence challenges. Specifically, the current combination of great power competition, the long-range strike capability of military technology, and global warming conspire to make the Arctic Ocean a fundamental component of the future defence of the North Atlantic zone. For this reason, NATO maritime forces may be required to conduct operations more frequently north of the Arctic Circle in the near future.

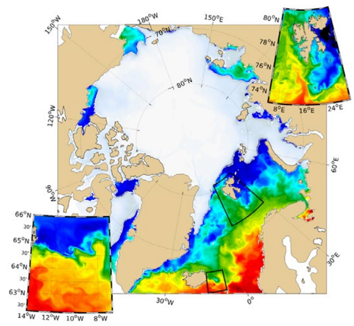


Figure 11: Predictions of the sea surface temperature in the Pan-Arctic and nested domains.

OBJECTIVES

Funded by Allied Command Transformation, the objective of this work was to develop a Pan-Arctic ice-ocean prediction model with the aim of supporting NATO maritime operations in the Arctic Ocean at an appropriate temporal and spatial resolution.

S&T ACHIEVEMENTS

Unlike the weather, assessment of the marine environment is not supported by a worldwide, permanent observational network. Instead, the timely provision of useful ocean environmental information relies on just a few observational assets and numerical ocean prediction models. The latter consists of sophisticated software that runs on high-performance computers, integrating fundamental equations of fluid motion in time to obtain the future conditions of the marine environment. Although current ocean prediction models capture much of the complexity of the real ocean, their results tend to deviate from reality after some integration period. Data assimilation methods attempt to constrain models to reality by incorporating existing observations in the model integration process.

Specifically, Nucleus for the European Modelling of the Ocean (NEMO), coupled with the Louvain-la-Neuve sea-ice model-LIM, was implemented in a Pan-Artic domain with a spatial horizontal resolution ranging from 7 to 20 km. The model has 91 unevenly spaced levels in the vertical (depth) dimension, with more levels—and therefore greater resolution—near the surface. Two nested "child" models, with a greater horizontal resolution of 2 km, increase the spatial-temporal resolution of the forecasts in the regions of the Iceland Faroe Front (IFF) and Svalbard (see Figure 11). Both regions constitute potential maritime operational areas of interest. The parent model uses an assimilation scheme to incorporate observations from different ocean platforms, inter alia ships, satellites, gliders, drifters, and drifting profilers. Tidal effects are implemented in the higher-resolution child models.

SYNERGIES AND COMPLEMENTARITIES

CMRE proactively collaborates with NATO commands and national defence organizations, academies, and universities to understand the implications of Arctic environmental changes on naval operations, deliver meaningful guidance in support of NATO, and improve characterization of the Arctic battlespace across all space and time scales.

EXPLOITATION AND IMPACT

The CMRE Pan-Arctic ice-ocean prediction model forecasts the time evolution of ice coverage and water column temperature, salinity, and current in the Pan-Arctic domain. This type of environmental information is used as an input to different maritime decision-support and risk-assessment tools to support science-informed operational and tactical decision-making.

CONCLUSIONS

In maritime operations, knowing the ocean environment better than the adversary provides a significant tactical advantage, allowing commanders to select appropriate tactics and to employ an optimum combination of sensors and combat systems. CMRE's pan-Arctic ice-ocean prediction model is another step towards producing exploitable knowledge of the Arctic Ocean.

AIRCREW NECK PAIN PREVENTION AND MANAGEMENT (HFM-252)

Self-reporting surveys from Armed Forces around the world continue to document high rates of aircrew neck pain that can negatively impact aircrew health, safety, and performance. HFM-252 made scientific advances to aircrew neck pain research and provided twenty-nine evidence-based recommendations and organizational considerations towards mitigating aircrew neck pain.

Dr. Philip S. E. FARRELL, CAN, Defence Research and Development Canada (DRDC)

BACKGROUND

Heavy unbalanced helmets, extreme postures, vibration and high G, long duration missions, and poor physical fitness are some of the possible causal factors that have led to aircrew neck pain rates that are greater than 75% in most NATO and coalition partner nations. This places aviator health, safety, and performance at risk.

OBJECTIVES

HFM-252's objective was to seek and recommend evidence-based procedural, ergonomic, engineering, preventive, treatment, and administrative solutions to address the problem of aircrew neck pain.

Figure 12: HFM-252 Aircrew Neck Pain Framework.

S&T ACHIEVEMENTS

Scientific advances were made to aircrew neck pain research by developing the Aircrew Neck Pain Framework (Figure 12), in which five possible casual factors were identified. Evidence for mitigating neck pain was found for potential solutions that would address these factors, such as light balanced helmet systems, biomechanically advantageous postures, vibration mitigation, optimal mission schedules, and aircrew conditioning. Twenty-nine recommendations were produced for implementation into operations.

SYNERGIES AND COMPLEMENTARITIES

This multi-faceted problem demanded a multi-disciplinary approach that included military and civilian scientists, clinicians, operators, and industry from twelve nations. This collaboration yielded multi-nation projects, experimentation, and resources, including an operational definition for significant flight-related neck pain and the HFM-252 Aircrew Neck Pain Questionnaire that has become a standard by which to assess neck pain.

Figure 13: HFM-252 Aircrew Neck Pain.

EXPLOITATION AND IMPACT

NATO nations have tailored recommended solutions from HFM-252 and implemented them into operations. Examples include Helmet Fit Training (RCAF), and Aircrew Conditioning Programme (RAF and RAAF), and Seat Ergonomics (US Navy).

CONCLUSIONS

There is no single silver bullet or quick fix. However, it is anticipated that, with the implementation of these evidence-based solutions, NATO nations and coalition partner aircrew will have healthier necks, longer and safer careers, and less distraction when performing their missions.

ASSESSMENT AND COMMUNICATION OF UNCERTAINTY IN INTELLIGENCE TO SUPPORT DECISION-MAKING (SAS-114)

SAS-114 collected and evaluated a wide range of uncertainty communication standards currently used in defence and security, as well as in other domains. By systematically drawing on relevant scientific evidence, intelligence organizations could improve their accuracy, rigour, and communication fidelity, which in turn should better support sound decision-making and interoperability within NATO.

Dr David MANDEL, CAN, Defence Research and Development Canada (DRDC)

BACKGROUND AND MILITARY RELEVANCE

In a wide variety of defence contexts, risks and uncertainties must be effectively assessed and just as effectively communicated to support sound decision-making and action. Two broad problem areas include the promulgation of multiple, inconsistent uncertainty assessment and communication standards within and across nations, and the use of standards that are either fundamentally flawed in certain respects or that are poorly suited to the specific context in which they are applied. Assessment and communication of risk and uncertainty is seldom an end in and of itself. In most instances, the information that is communicated is meant to support effective decision-making. Yet little is known about how decision-makers interpret and act on such information. Although standards exist, there have been few efforts to scientifically evaluate those standards for assessing and communicating risk and uncertainty.

> *SAS-114 has made evidence-based recommendations for future practice in the areas of assessment and communication of risk and uncertainty.*

OBJECTIVE(S)

The goals for SAS-114 were to examine current or new methods for: (a) communicating uncertainty in intelligence products to decision-makers, (b) supporting intelligence assessment under uncertainty (i.e., structured analytic techniques), and (c) monitoring forecasting accuracy in intelligence to inform best practices for superior intelligence production.

S&T ACHIEVEMENTS

SAS-114 reviewed intelligence and other organizational standards for communicating uncertainty promulgated in NATO and across member nations. It further conducted several experiments with expert and non-expert samples to test the effectiveness of methods for improving intelligence assessment quality. The team produced numerous peer-reviewed papers from their work and specific recommendations for NATO.

Figure 14: A U.S. Army paratrooper distributes intelligence in a command post exercise during Exercise Rock Frost 20 in Grafenwoehr, Germany, Dec. 07, 2019. (U.S. Army photo by Sgt. John Yountz)

SYNERGIES AND COMPLEMENTARITIES

In total, eight nations and one NATO centre, as well as numerous academic affiliates, participated in this research activity. This diverse group contributed to the high quality of the work.

EXPLOITATION AND IMPACT

SAS-114 made evidence-based recommendations for future practice in the areas of assessment and communication of risk and uncertainty. Their final report will be exploited by Alliance members and partners with interests in improving the quality of uncertainty-based assessments and communication for the purpose of supporting critical defence and security decision processes.

CONCLUSIONS

A significant challenge for NATO intelligence communities is organizational and cultural reform, rather than technological reform. Accountability pressure from senior leadership will be essential to prompt changes that go beyond the usual approaches, which have relied far too heavily on self-assessed good ideas and far too little on evidence-based research and relevant S&T advice. Numeracy and statistical literacy will also have to be improved throughout the ranks, including at senior leadership levels. The work of SAS-114 will help address these issues in NATO.

DEMONSTRATION OF MARITIME SITUATIONAL AWARENESS PATTERN-OF-LIFE CAPABILITIES AT THE INTERNATIONAL MARITIME EXERCISE 2019 (CMRE)

Following extensive testing with real-world ship traffic datasets, CMRE demonstrated two Maritime Situational Awareness (MSA) capabilities that can reveal ship traffic patterns from large amounts of Automatic Identification System (AIS) data at the International Maritime Exercise (IMX) 2019. that.

Mr Leonardo MILLEFIORI; Dr Paolo BRACA; LCdr Tom MILLER; Lt Kathryn RANSOM; STO-CMRE

BACKGROUND

The abundance and availability of maritime traffic data overwhelm end-users and challenge established analysis workflows. To make sense of naval traffic data, operators often rely on summary statistics and representative patterns-of-life (POL) to achieve a better understanding of the behaviour of maritime traffic and extract key indicators related to day-to-day vessel and port operations.

OBJECTIVE

The aim of CMRE's participation in IMX 2019 was to support the Naval Cooperation and Guidance to Shipping (NCAGS) unit, which included officers from the USN Fifth Fleet, Norway, Lithuania, Belgium, Denmark, and Germany. CMRE supported the NCAGS unit with ship traffic patterns-of-life (POL) automatically computed from historical AIS data. Allied Command Transformation provided the funding for this activity.

S&T ACHIEVEMENTS

At IMX 2019, CMRE demonstrated two MSA capabilities to automatically compute POL in the form of traffic density maps and synthetic indicators (analytics) of traffic volumes in ports and across straits from large amounts of AIS data. These capabilities successfully supported the NCAGS unit at IMX 2019 and provided access to historical ship traffic information by traffic category, therefore contributing to a better global understanding of the maritime situational and operational pictures. The maritime POL capabilities enabled operators to highlight the presence of main shipping lanes, congested areas, or recurrent patterns for specific categories of traffic, and to understand ship traffic volume in the ports and across the main straits in the area of the exercise.

SYNERGIES AND COMPLEMENTARITIES

Many NATO Nations are pursuing strategies to bring forward the way operators process intelligence and data by using machine learning and automation in their day-to-day work. At IMX 2019, CMRE successfully tested the integration of traffic density maps with SeaVision, an unclassified web-based MSA tool operated by the US Department of Transportation that enables users to view and share maritime information.

EXPLOITATION AND IMPACT

Achieving a comprehensive maritime operational picture is crucial for the security of operations at sea. The development of computational tools that support MSA operators in handling large amounts of information has a huge potential, especially considering the growing availability of big maritime data.

CONCLUSIONS

Through recent developments, CMRE developed MSA techniques to process ship traffic data, which analysts and end-users can use to convert the vast amounts of information that would be otherwise intractable to human operators into actionable knowledge.

Figure 15: Traffic density map visualization in SeaVision during IMX 2019.

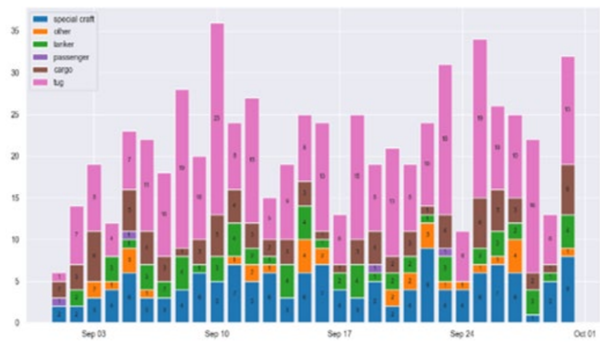


Figure 16: Daily visits in a port of interest, broken down by traffic category.

INFORMATION OPERATIONS FOR INFLUENCE (SAS-117)

A new phase in the evolution of warfare has emerged – one in which the information environment (IE) is the contentious battleground and communication is the preferred method over traditional and conventional kinetic approaches to achieve desired behavioral outcomes. SAS-117 developed a handbook that examines emerging threats and adversarial exploitation of the IE and makes concrete recommendations for NATO to achieve the advantage in this domain.

Mr Matthew LAUDER, CAN, Defence Research and Development Canada (DRDC)

Figure 17: The Strategic Communications cell receives orders at the morning update brief during Exercise Citadel Bonus 2019, in Bydgoszcz, Poland on December 7th, 2019. Source: Canadian Forces Combat Camera.

Figure 18: Lieutenant Brad Roy (left) from the Canadian Armed Forces Military Strategic Communications Team works alongside the Rapid Reaction Corps, France in the Joint Operation Centre during Exercise Citadel Bonus 2019, in Bydgoszcz, Poland on December 7th, 2019. Source: Canadian Forces Combat Camera.

BACKGROUND AND MILITARY RELEVANCE

Two key trends characterize the contemporary operating environment. The first is increased involvement by non-state actors in violent conflicts, whether as the primary instigator of violence or as a proxy for a state-based adversary. The second is shaping and managing the narrative and conduct of information warfare as a leading line of effort within a larger non-linear/hybrid warfare construct. Although NATO has, on the whole, achieved technical overmatch in many areas, such as intelligence, surveillance, and reconnaissance, it has nevertheless faced challenges in achieving asymmetric advantage in the IE. The result has been the domination of the IE by our adversaries.

> *A new phase in the evolution of warfare has emerged – one in which the information environment is the contentious battleground and communication is the preferred method over traditional and conventional kinetic approaches to achieve desired behavioral outcomes.*

OBJECTIVES

SAS-117 examined emergent threats in the information environment, issues related to adversary exploitation of the IE, and the employment of non-linear/hybrid warfare. It also explored capability gaps required to counter adversary asymmetric advantage in this domain to help NATO and its partners dominate the IE.

S&T ACHIEVEMENTS

SAS-117 developed a handbook that presents case studies focusing on emerging threats in the IE and the panel's other objectives the case studies also present conceptual models and best practices/methods and recommendations to counter adversary asymmetric advantage in this domain. The team made concrete recommendations for NATO to move forward in this area.

SYNERGIES AND COMPLEMENTARITIES

In total, five nations and two NATO Centres of Excellence contributed to the team's efforts, which provided diverse perspectives and a robust view of this area of research.

EXPLOITATION AND IMPACT

The outputs of SAS-117 are expected to have broad exploitation by NATO to inform future doctrine, joint Information Operations (Info Ops) and Military Strategic Communications (StratCom) capability development, and NATO Info Ops course development and delivery.

CONCLUSIONS

SAS-117 identified three key takeaways. First, SAS-117 identified three key takeaways. First, NATO militaries need to reorganize and prepare for the continued use of non-linear/hybrid warfare by adversaries. Second, robust and fully integrated information related capabilities (IRCs) are required to effectively conduct operations, especially in the pre-conflict phase. Third, a cultural shift is occurring in what and how people perceive in terms of credibility and trustworthiness, which has significant implications for conducting operations, specifically as it relates to shaping and managing the IE.

MODELS AND TOOLS FOR LOGISTICS ANALYSIS (SAS-132)

The cost of logistics and support (L&S) is typically a large proportion of a nation's defence budget. A small investment in analysis methods and tools can have significant impacts. The SAS-132 research team developed an analysis framework and used it to analyze over 70 logistics tools and models. They created a solid foundation for future cooperation between NATO and partner nations on logistics analysis and provided opportunities for nations to share and receive existing tools and models.

Mr Goran BERG, SWE, Swedish Defence Research Agency, FOI

BACKGROUND AND MILITARY RELEVANCE

All nations develop methods and models for logistics analysis that look at cost reduction, effectiveness, and optimization. Since the cost of L&S is typically a large proportion of a nation's defence budget, small investments in analysis methods and tools can have large impacts. By learning from the experiences of other countries, nations can save on development costs, effort, and time, and they can compare and contrast approaches for method cross- validation. Nations can also focus development efforts on capability gaps and areas of mutual interest to the NATO defence logistics analysis community.

OBJECTIVE(S)

The aim of SAS-132 was to develop a matrix of analysis coverage to assess gaps, overlaps, and collaborative opportunities by surveying models and tools for defence logistics analysis within the countries participating in this activity. The panel also sought to exchange knowledge and experience regarding these models and tools, and identify opportunities for sharing and future collaborations.

S&T ACHIEVEMENTS

SAS-132 developed a data collection template to inventory and characterize models and tools and to survey results from the participating nations and organizations. They used this to develop a catalogue (matrix) of models and tools used by NATO and partner nations to analyze military logistics. SAS-132 was able to identify gaps in analytical capabilities, overlaps, and areas for potential collaboration.

> *Logistics and support is typically a large proportion of a nations' defence budget -a small investment in the analysis methods and tools can have significant impacts.*

SYNERGIES AND COMPLEMENTARITIES

The activity received over 100 model inputs from seven nations and the NATO Communications and Information Agency, of which 70 were inventoried. This provided a broad range of models and tools of interest and a strong foundation for their work.

EXPLOITATION AND IMPACT

SAS-132 developed a process to help learn from the experience of other nations in analyzing logistics problems. This results in valuable savings And allows nations are now able to focus on capability gaps and areas of mutual interest in defence logistics analysis.

CONCLUSIONS

The analysis revealed that individual nations have different approaches to logistics analysis. Some nations mainly use broad, institutionally recognized models, while others mainly use fit-for-purpose models designed to handle specific problems. Some nations only rely on NATO-recognized software. Despite these differences, the set of instruments identified by SAS-132 creates a solid foundation for cooperation between nations on logistics analysis and opportunities to share existing models.

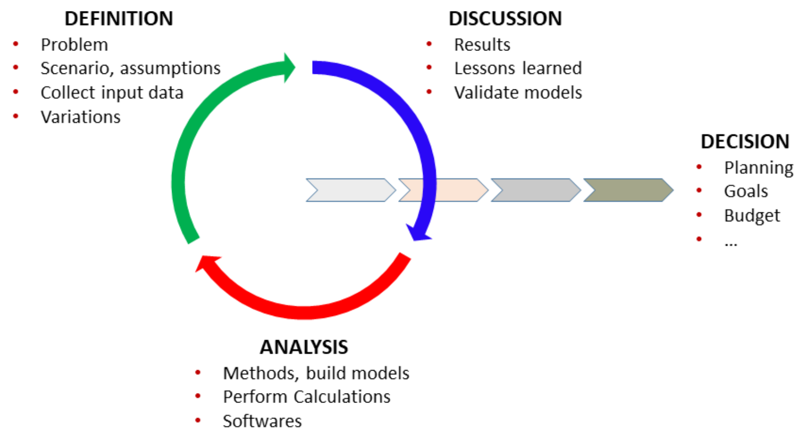


Figure 19: The Dynamics of Logistics Analysis

MULTI-SOURCE REASONING WITH VALUATION NETWORKS FOR MARITIME ANOMALY DETECTION – THE ANDROMEDA CASE (CMRE)

Funded by Allied Command Transformation (ACT), the CMRE developed cognitive assistance tools that fuse information from multiple, heterogeneous sources to support the monitoring and analysis of anomalous vessel behaviour. These tools enhance Maritime Situational Awareness (MSA) and inform decision-making.

Mr. Paweł KOWALSKI; Dr Anne-Laure JOUSSELME, STO-CMRE

BACKGROUND

Combining collaborative information sources like Automatic Identification Systems (AIS) and non-collaborative ones like satellite imagery can help with detecting anomalies in vessel movement behaviour. This includes situations when vessels stop transmitting AIS data, informally referred to as "a vessel going dark." While the detection of a vessel under such circumstances may raise doubts about its intent, an increased understanding and confirmation of suspicious behaviour should be obtained before committing to a possibly costly intervention. For example, context and poor quality of sensors or information sources might explain the vessel's behaviour. The joint analysis of the observed behaviour, source quality, and context of the situation is a complex cognitive task for the decision maker, one that can be made easier with the assistance of appropriate tools.

OBJECTIVE

The aim of this research is to develop methods to support human reasoning under uncertainty, providing the tools to fuse a variety of sources, handle source quality, and reason with context.

S&T ACHIEVEMENTS

CMRE has developed a multi-source reasoning capability to investigate the behaviour of suspicious vessels and detect anomalies. It has been used to explain real case events reported in the media by processing real data. For example, the investigation of the MV Andromeda, intercepted with 410 tonnes of explosives supposedly sailing to Libya in December 2017, highlighted that bad weather conditions together with poor AIS coverage explained the suspicious behaviour of the vessel.

SYNERGIES AND COMPLEMENTARITIES

The approach was presented at the inaugural Data and Information Fusion conference. Expected participation in the special session on Explainable Artificial Intelligence at the 23rd international conference on Information Fusion (FUSION 2020) will allow an exchange with experts on the topic.

EXPLOITATION AND IMPACT

A deeper understanding of detected anomalies is a necessary step towards enhanced MSA, providing greater evidence for the decision maker to properly plan for an intervention. The overall benefit is improved maritime security.

CONCLUSIONS

Maritime Security requires detecting a suspicious vessel's behaviour through proper exploitation of the variety of sources, which mixes physical sensors with human observations. CMRE has recently developed an automated reasoning capability to support the investigation of abnormal vessel behaviour that considers the quality and context of such sources.

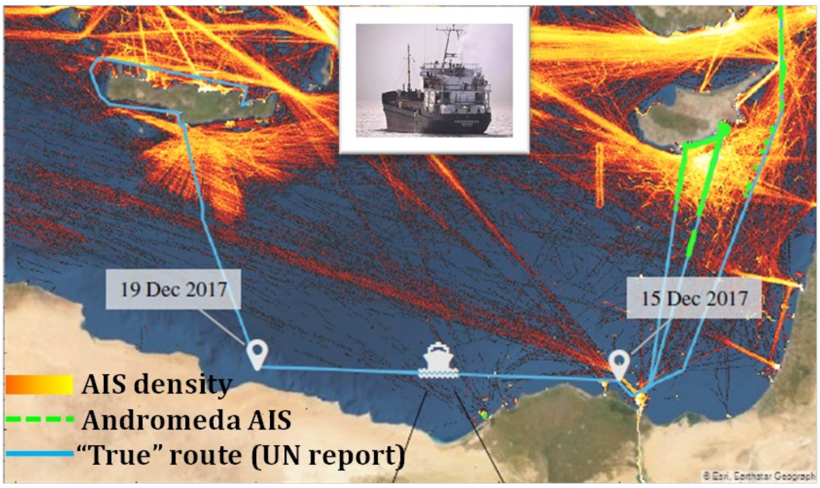


Figure 20: High-profile case of MV Andromeda intercepted with 410 tonnes of explosives supposedly sailing to Libya. Uncertain, heterogeneous reports and contextual information were combined to determine the vessel's intent.

PROVIDING ADVICE TO PLANNERS AND OPERATORS FOR ASW MISSIONS (CMRE)

The CMRE developed a tool to support anti-submarine warfare (ASW) operations at the NATO maritime task group/force level using a consistent sonar model and environmental input to determine the sonar performance of all assets.

Mr Christopher STRODE; Dr Manlio ODDONE, STO-CMRE

BACKGROUND

Anti-submarine warfare missions are complex operations involving a heterogeneous mix of platforms that typically employ both active and passive sonar to maximize the probability of detecting a submarine. ASW operations often require coverage of large areas of water, employing sensors on the surface, below the surface, and in the air.

OBJECTIVE

With funding from Allied Command Transformation (ACT), CMRE developed the Rapid Acoustic Prediction Service (RAPS). This fast and easy to use tool takes the acoustic model from more scientific tools and packages it with a clean interface to provide the most salient information to operators.

S&T ACHIEVEMENTS

Currently, each national maritime ASW asset in a NATO maritime task group/force predicts the performance of their own sonars, often employing different acoustic models and environmental inputs. RAPS provides a more accurate assessment of the relative performance of the different assets available to the ASW commander, and provides advice on the optimum disposition of the available sensors. Such optimization requires acoustic modelling that is able to consider the changing underwater environment throughout a large area of water for the different available acoustic sensors. The tool is also able to operate as a server, enabling any PC on a network to access the acoustic calculations through a simple web browser interface. This allows a single high-performance computer to provide predictions for multiple users.

SYNERGIES AND COMPLEMENTARITIES

RAPS has the capability to use quasi-real-time environmental data from persistent sensors, such as ocean glider fleets. Exercising this capability would improve the accurate prediction of sonar system performance and decision making.

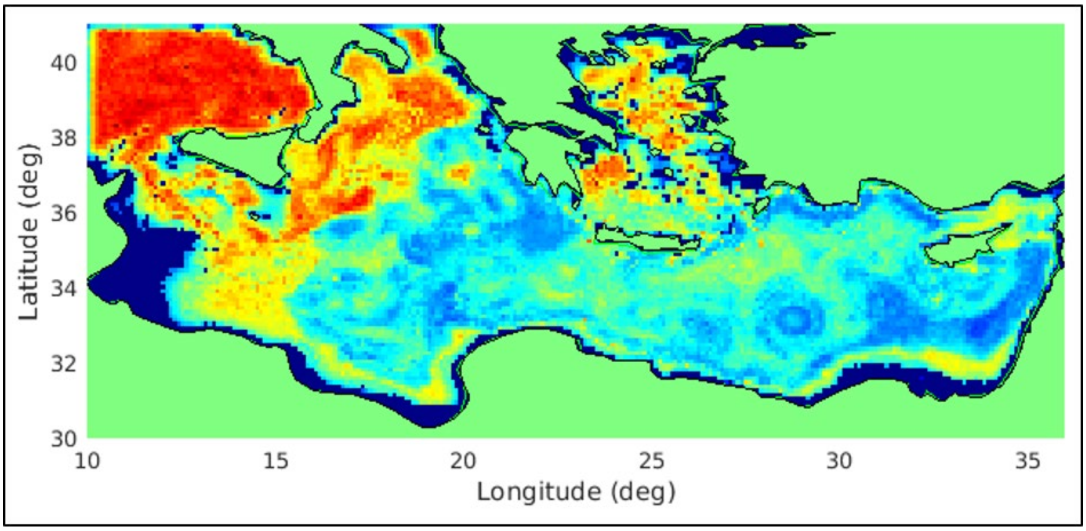


Figure 21: RAPS predicted sonar detection ranges for the Eastern Mediterranean.

EXPLOITATION AND IMPACT

CMRE released the complete RAPS software package in 2019. Several allies are already using it for evaluation purposes..

CONCLUSIONS

RAPS can be configured for all the available sonar types in a NATO maritime task group/force, providing a picture of the sonar coverage of all available assets. This visual output, being geo-referenced on a map, serves to highlight areas in which coverage may be limited, allowing the planner to apply suitable mitigation measures by altering the position or depth of sensors or deploying extra assets (e.g., vectoring a helicopter equipped with a dipping sonar).

THE TRANSITION OF MILITARY VETERANS FROM ACTIVE SERVICE TO CIVILIAN LIFE (HFM-263)

Col Carl CASTRO, Ph.D., USA, Associate Professor University of Southern California Director, Military and Veteran Programs

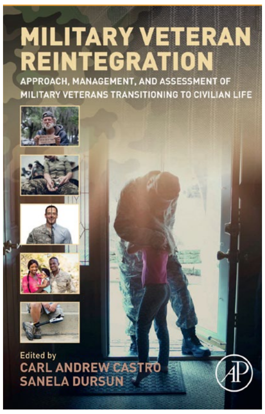


Figure 22: Book cover for Military Veteran Reintegration: Approach, Management, and Assessment of Military Veterans Transitioning to Civilian Life

BACKGROUND

Transition to civilian life is an inevitable part of military service that involves many adjustments, especially for members who have served in combat operations. The quality of the transition and the service leaver's ability to manage these adjustments have implications for post-service well-being and functioning. Nonetheless, little has been done to conceptualize how transition occurs, to identify factors that promote or impede transition, or, importantly, to identify outcomes associated with successful transition.

OBJECTIVE

In this RTG, participating NATO nations sought to (1) identify current programmes, polices, and processes to support service personnel (and families) transitioning from the military, (2) develop guiding principles for effective and efficient military-to-civilian transition, and (3) document existing research and lessons learned in military-to-civilian transition. Based on research and theoretical models, the RTG developed principles for policies and programmes aimed at transitioning NATO military personnel.

S&T ACHIEVEMENTS

Drawing on the scientific literature, the RTG designed and administered a survey to collect and synthesize policies and practices on participating countries to uncover best practices for implementing new programmes and improve existing ones. Furthermore, this RTG proposed nine key principles for developing successful military-to-civilian transition policies and programmes: the importance of having (1) a transition framework that captures the key phases of transition, (2) a definition of veteran, (3) a focus on work disability prevention, (4) a measurement for outcomes, (5) timely and appropriate engagement prior to release, (6) needs-based interventions, (7) societal recognition, (8) the involvement of families, and (9) employment assistance. RTG members produced an academic book[1] to distil and disseminate the panel's findings.

SYNERGIES AND COMPLEMENTARITIES

The RTG consisted of currently serving personnel, veterans, civilian practitioners, policy-makers, and academics with over 200 years of collective experience working on military and veteran issues. The work underpinning the academic output of the RTG has furthered international cooperation and understanding of the theoretical and practical challenges of transition.

EXPLOITATION AND IMPACT

This research provides valuable tools for policy and decision-makers, showing NATO members how to get the best value from the billions of dollars invested in their military and veteran benefits, programmes, and services. The RTG's work has also been used to further discussions and understanding of transition in non-NATO countries, such as the Ukraine and South Korea.

CONCLUSIONS

This expert panel was the first to take a multinational approach to understanding the military-to-civilian transition. It is expected that the guiding principles, conceptual framework, and best practices provided by this RTG will help each nation better formulate how it approaches the military-to-civilian transition.

[2] Castro, C.A. and Dursun, S. (Eds.) (2019) *Military Veteran Reintegration: Approach, Management, and Assessment of Military Veterans Transitioning to Civilian Life* London and San Diego: Academic Press ISBN: 978-0-12-815312-3.

TOP TEN CYBER EFFECTS FOR CAMPAIGN AND MISSION SIMULATIONS (MSG-170)

MSG-170 was tasked with identifying which cyber elements are eligible for inclusion in alliance Training and Exercises (T&E). The methodology that was developed, known as “Achievability, Timeliness, Credibility and Disruptiveness (ATCD),” consists of an effect-ranking schema and prioritization workflow that supports identification of cyber effects that are best suited for T&E scenarios, environments, and goals.

Dr. Bert BOLTJES, NLD, Netherlands Organisation for Applied Scientific Research (TNO), MSG-170 Chairman

BACKGROUND AND MILITARY RELEVANCE

NATO seeks to integrate cyber elements into alliance T&E. At present, few exercises include cyber training goals or simulated cyber effects. Such limitations are problematic, since cyber has emerged as a tool, target, and venue of conflicts. All military personnel must be trained to maintain mission assurance in the event of a cyberattack on their systems.

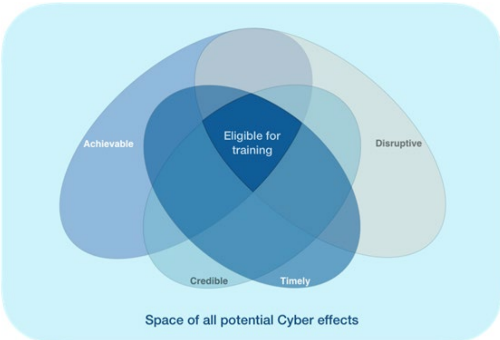


Figure 23: A representation of all possible cyber effects in relation to those eligible for training purposes.

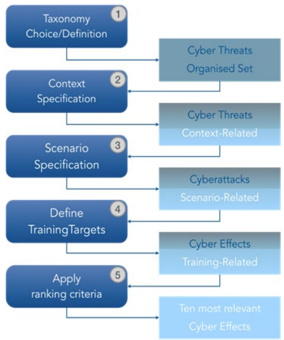


Figure 24: Workflow to select cyber effects eligible for training.

OBJECTIVE

The goal of MSG-170 was to assist planners and developers select the cyber effects that are eligible for introduction into campaign and mission simulations.

> *All military personnel must be trained to maintain mission assurance in the event of a cyberattack on their systems*

S&T ACHIEVEMENTS

TThe ATCD methodology developed by MSG-170 assists training staff identify the cyber effects that are best suited for their T&E. The methodology focuses on the effects of cyberattacks, as opposed to potential attack vectors or adversarial intelligence operations. Effects are ranked by their attributes (see Figure 22):

- Achievable: implementation in a simulation must be straightforward to produce, undemanding for controllers to use, and suitable for automated use.
- Timely: presence of effects must be felt within a reasonable time-period. ”Slow burn” effects should be avoided.
- Credible: effects must be a reasonable result of manipulating an Information and Communications Technology (ICT) system (e.g., reduced network capacity, inaccurate position data, and ineffective sensors/shooters).
- Disruptive: effects must impose a definite change on the simulation. Effects that are too subtle to observe will have no training benefit. However, effects always leading to mission success or failure have no benefit.

A workflow (see Figure 23) was developed to identify the “Top Ten” cyber effects. To prioritize the effects that are relevant in various scenarios, the rankings HIGH, MEDIUM, LOW, or Not Applicable, as well as a numerical score (3, 2, 1, and 0) are assigned to the ATCD attributes of the effects. The workflow, ranking schema, and sorted total numerical scoring constitute the ATCD methodology.

SYNERGIES AND COMPLEMENTARITIES

MSG-170 worked closely with the Simulation Interoperability Standards Organization (SISO) Cyber Modelling and Simulation (M&S) study group. It supported a cyber M&S environment developed by the NATO M&S Centre of Excellence.

EXPLOITATION AND IMPACT

A report was produced to be shared within NATO and presentations were delivered at various conferences. The ATCD methodology can support planners that are pre-selecting the top ten cyber effects best suited for their training scenarios from a large set of effects..

CONCLUSIONS

Prior to this work, no methodology existed to select cyber effects for inclusion in T&E. The methodology can be of great value for introducing cyber effects into simulations in an effective and trackable manner.

NATO STO Programme of Work

DISRUPTIVE TECHNOLOGIES

AUTONOMY FOR NAVAL MINE COUNTERMEASURES SYSTEMS (CMRE)

The autonomy topics in the CMRE's mine countermeasures (MCM) programme of work funded by Allied Command Transformation (ACT) include research into machine-driven decision making, adaptive behaviours for data quality augmentation, architectures for autonomy at the single- and multi-vehicle level, as well as meta-topics like standardization of unmanned architectures, and data modelling for unmanned mine hunting.

Dr Samantha DUGELAY; Mr Thomas FURFARO; Mr Christopher STRODE; Dr Veronika YORDANOVA, STO-CMRE

BACKGROUND

NATO nations are in the process of acquiring autonomous platforms for naval minehunting applications. Such autonomous capabilities offer several advantages over conventional minehunting systems, including extended stand-off range potential and removing the man from the minefield. CMRE has been developing and taking demonstrator autonomous systems to sea for over 17 years.

OBJECTIVE(S)

During 2019, the principal objectives were to test at sea a new experimental vehicle designed for underwater MCM contact reacquisition and identification tasks, and to embed new coverage path planning solution on board the CMRE's autonomous mine detection capability platform.

S&T ACHIEVEMENTS

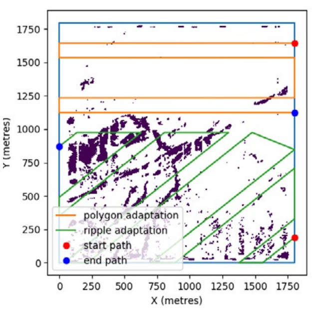


Figure 25: Simulation of adaptive survey track lines

During 2019, ACT funded the CMRE to participate in the NATO DYNAMIC MARINER 2019 live maritime exercise on board the NATO ship NRV Alliance off the coast of Spain. Three different vehicles were used to demonstrate autonomous naval minehunting operations: one vehicle (MUSCLE) to perform the detection and classification phase using its synthetic aperture sonar (SAS); another vehicle (Black CAT) to identify potential contacts using optical video and multi beam sonar; and CMRE's new BIONDo SPARUS II platform. This last underwater vehicle has been under development at the CMRE since 2018 and has the capability to remain stationary—to hover—in the water column. The vehicle is equipped with a very advanced ARIS Explorer 3000 acoustic camera, and the combination of a hovering platform with a high-resolution, short range sonar results in a platform that is suited for MCM contact reacquisition and identification tasks. DYNAMIC MARINER 2019 was the first time that this new BIONDo vehicle was tested at sea in its final configuration, and many valuable lessons were learned.

The principal focus of the CMRE's 2019 work on the detection and classification of mine targets was the creation of a new coverage path planning solution for embedding on board the CMRE's autonomous mine detection capability platform—the MUSCLE vehicle. This approach allows for mission areas of complex geometry, while the vehicle can autonomously and adaptively adjust its track orientation and track spacing depending on changes to the environmental characteristics of the area being searched, as observed through the vehicles's organic sensors. The algorithm leverages data products created on-board the MUSCLE from the Planning and Evaluation for MCM project (PE-MCM). The new adaptive survey was integrated into the MUSCLE, and was tested in three engineering-type trials through the year. The outcome is that the vehicle can optimize autonomously the effectiveness and efficiency of its operations to search an area.

SYNERGIES AND COMPLEMENTARITIES

The CMRE has been leading a standardization initiative by co-chairing the STO SCI-288 Research Task Group (RTG) "Autonomy in Communications-Limited Environments". The aim of this RTG is the development and integration of a prototype messaging layer to promote interoperation between squads of maritime unmanned systems. A workshop, held at CMRE in 2019, demonstrated a simulation scenario where partners from three other institutions successfully connected autonomous systems in a network driven by SCI-288-styled messages.

EXPLOITATION AND IMPACT

The Belgian MoD recently awarded a 2 Billion EUR contract to procure new naval minehunting capabilities based on autonomous systems, and is an excellent example of where Nations have looked to CMRE to see if the technology is relevant and have gone ahead with a spiral development concept starting with most of the CMRE research outputs as a baseline.

CONCLUSIONS

Experimentation at sea is a significant part of the research work resulting in integration and validation of theoretical work, as well as technical demonstrations at sea of capabilities to NATO Nations.

DEMONSTRATION AND RESEARCH OF RADIO FREQUENCY DIRECTED ENERGY WEAPONS EFFECTS ON ELECTRONICALLY CONTROLLED VEHICLES, VESSELS AND UAVS (SCI-294)

Abstract Radio Frequency (RF) Directed Energy Weapons (DEW) provide military post commanders with a non-lethal means to ascertain the intent of a potential aggressor during the escalation of force, as well as precious extra time to do so. RF DEW has the potential to be deployed at NATO facilities as part of an overall force protection package.

Dr. Gerry LOUVERDIS; GBR, Defence Science and Technology Laboratory (DSTL); Mr. John SHANNON, USA, Naval Surface Warfare Center (NSWC) Dahlgren; Mr. Odd-Harry ARNESEN, NOR, Norwegian Defense Research Establishment (FFI).

> *"I'm a firm believer that it's time we take directed energy...and move it into the battlefield." Lieutenant General Bradley A. Heithold, Commander, United States Air Force Special Operations Command – (2016 Directed Energy Summit, Washington D.C., USA)*

BACKGROUND AND MILITARY RELEVANCE

Within NATO, the term Electronic Warfare (EW) is defined to be warfare in the electromagnetic (EM) environment. Offensive EW, usually called Electronic Attack (EA), includes jamming and spoofing of electronic systems by a focused radar beam. RF DEW can be thought of as EA at substantially higher power levels. Whereas EA is usually coupled into a receiving antenna or aperture, RF DEW produces effects by coupling EM energy directly onto circuit boards and into semiconductor components. This process induces electrical currents capable of a variety of electronic effects, such as erroneous signals, system lock-up, system shut-down, loss of communication between systems, and even component damage.

OBJECTIVES

The objective of this RTG was to demonstrate RF DEW's ability to stop vehicles, vessels, and UAVs, and to show its effects on electronically controlled components.

S&T ACHIEVEMENTS

The demonstration showcased British and French RF DEW sources from Teledyne e2v and ITHPP (an ALCEN subsidiary), respectively. The L-band emitters provided potential post commanders with increased awareness of RF DEW's effectiveness and ability to prosecute high-priority target sets.

SYNERGIES AND COMPLEMENTARITIES

The demonstration of RF DEW was conducted on the island of Crete, Greece at the NATO Missile and Firing Installation (NAMFI) and the NATO Maritime Interdiction Operational Training Centre (NMIOTC) for an audience of representatives from 13 nations. This marked the first time either installation operated RF DEW on their premises.

EXPLOITATION AND IMPACT

Compared to conventional kinetic weaponry, RF DEW systems offer significant advantages:

- A non-lethal means to determine the intent of potentially hostile vehicle/vessels;
- Ability to defeat electronics with low-collateral damage and a very low risk of significant injury to personnel from RF exposure in short durations;
- Area coverage with a wide beam antenna to engage multiple simultaneous targets in swarm scenarios; and
- Greater "magazine" capacity and lower cost per engagement.

CONCLUSIONS

The SCI-294 RTG demonstrated commercially available, non-lethal force protection capabilities at tactically relevant distances by demonstrating the ability of RF DEW to disarm the electronic controls of vehicles, vessels, and UAVs, individually and in swarms.

Figure 26: Military Access Control Point.

TECHNICAL CONSIDERATIONS FOR ENABLING A NATO-COMMON SPACE DOMAIN OPERATING PICTURE (SCI-279)

NATO presumes that allied forces will be more efficient, protected, and successful in their future missions if a common operating picture (COP) can be achieved across all warfighting domains: air, land, sea, cyber, and space. Without a common Alliance perspective of the space domain, serious operational weaknesses may result when space services and capabilities are degraded or denied to NATO forces due to natural or man-made causes.

Dr Moriba JAH, USA, University of Texas; Dr Tiziana CASINELLI, ITA, European Telecommunications Satellite Organization (EUTELSAT)

BACKGROUND AND MILITARY RELEVANCE

Protecting space systems (satellites and controlling ground infrastructure) that provide capabilities and services to NATO is a singularly sovereign responsibility. In fact, both the operation of these systems and the collection and dissemination of space domain information is also inherently sovereign in nature. Since space has become more important as an operating domain, this increasingly poses a dilemma for achieving the NATO objective of maximizing the interoperability and integration of force capabilities.

OBJECTIVES

The objectives of this RTG were to Identify and characterize the necessary and enabling concepts and architectural elements that are anticipated for facilitating the discovery, access, and integration of space domain data into a COP.

S&T ACHIEVEMENTS

Methods for data collection, curation, and exploitation studied by the SCI-279 RTG have led to the first automated, crowd-sourced space traffic monitoring system, known as ASTRIAGraph. It has also resulted in an open-source orbit determination tool that is available to on-going and future STO space activities.

SYNERGIES AND COMPLEMENTARITIES

This STO activity was the first of its kind to bring together military and commercial space operators and leading edge academic researchers, from 11 NATO nations, to assess and provide recommendations regarding the technical considerations needed by the Alliance to achieve a COP for Space Domain Awareness (SDA).

Figure 27: Monitoring space domain data.

EXPLOITATION AND IMPACT

The RTG's list of recommendations include:

- Developing an initial set of standards for characterizing and applying space domain related data;
- Articulating requirements for space data fusion capabilities and investments that should be pursued for SDA; and
- Seeking opportunities for experiments and field trials involving shared collection, processing, and dissemination of space domain data.;

At the time of this publication, nine NATO nations are actively contributing space domain data from 16 separate sources for a follow-on study. The title of the follow-on study is Collaborative Space Domain Awareness Data Collection and Fusion Experiment (SCI-311).

> *The three main pillars of Space Domain Awareness are Space Surveillance and Tracking, Space Environment and Impacts, and lastly Radio Frequency Interference.*

CONCLUSIONS

Current space domain awareness is required in all phases of military planning through to mission execution and assessment. Providing the most comprehensive space domain awareness picture available to NATO commanders and operators was the objective in this case.

PASSIVE RADAR TECHNOLOGY (SET-243)

Research on passive radar is being conducted in many countries around the world. Passive radar is very attractive for military purposes, because it enables covert operations. The detection ranges for passive radar are comparable with medium range radar detection ranges, and the update rate is similar to that for tracking radars.

Prof. Krzysztof KULPA, POL, Warsaw University of Technology.

BACKGROUND AND MILITARY RELEVANCE

Passive radar systems have been defined as an anti-stealth technology. These systems exploit existing radio emissions, such as FM, TV, and cellular phone signals, detecting echoes that warn the enemy. Currently, ground-based passive radars are entering the maturity stage and in the near future will be deployed in the field to protect our borders. Since these systems can be light, compact, and have low power consumption, they can be deployed in many scenarios and installed on the ground and in vehicles, aircraft. and ships.

OBJECTIVES

The aim of this activity was to provide information about passive radars to a broad military and civilian audience. This includes passive radar fundamentals, properties of passive radars, potential illumination sources, coverage for different altitudes, detection ranges, Doppler and localization accuracy, ability to be deployed in different scenarios, applications for tracking, imaging, and non-cooperative target recognition (NCTR).

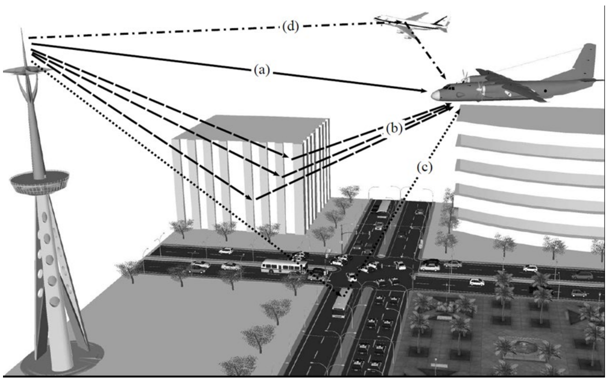


Figure 28: Concept of Passive Radar on an airborne platform.

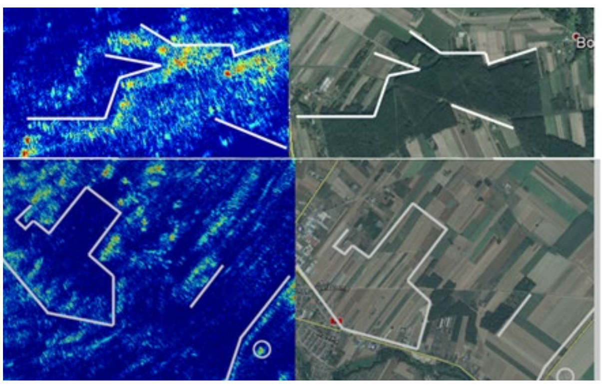


Figure 29: Example of Passive synthetic aperture radar (SAR) images obtained during a passive radar experiment and an optical image of the same observed area, with characteristic elements highlighted (white line).

> *Passive Radar Technology is aimed at detecting and tracking airborne targets using emitters of opportunity for target illumination..*

S&T ACHIEVEMENTS

Most stealth aircraft have been optimized for higher frequency bands (where most fire control radars operate)and monostatic types of radars to minimize specular reflection at their front sector. Passive radars seem to be a viable approach to counter these designs, since they involve lower frequency bands and multistatic-type scattering. Furthermore, passive radars cannot be detected, allowing for covert operation.

SYNERGIES AND COMPLEMENTARITIES

This activity identified existing interoperability efforts across the nations represented by the Panel members. Middleware capabilities from several participating Nations were identified as potential areas that Panel members could adopt to enable interoperability.

EXPLOITATION AND IMPACT

The use of active, low frequency band radars, along with passive radars covering the lower tier, would provide an ideal combination against stealth threats. Continuous illumination with passive radar makes NCTR possible.

CONCLUSIONS

Information about new passive radar technology was provided to a broad military and civilian audience, including the ability to fill active radar surveillance gaps. The main advantages of passive radar include covert work, stealth target detection, coverage at low altitudes, and foliage penetration. This makes passive radar an ideal complement to active radar in military surveillance. Passive radar not only offers the ability to exploit illuminators of opportunity for precise detection and tracking with a high update rate, but it can also be used for target imaging and recognition in NCTR scenarios.

NATO STO Programme of Work

EMERGING TECHNOLOGIES

ACOUSTIC TRANSIENT THREAT DETECTION SENSORS & SIGNAL PROCESSING FOR BATTLEFIELD SITUATIONAL AWARENESS (SET-233)

SET-233 RTG advanced the understanding of acoustic sensors, algorithms, and distributed processing to overcome signature and timing distortions caused by the propagation channel. It also characterized the influences of urban structures, and created a signature database that will accelerate transient threat classifier research.

Mr. Michael SCANLON and Dr. William ALBERTS, USA, Combat Capabilities Development Command - Army Research Laboratory, Co-Chairs SET-233

BACKGROUND AND MILITARY RELEVANCE

Acoustic sensor systems have already been fielded to detect transients from gunshots, mortars, rockets, and artillery, as well as other broadband sources such as air and ground vehicles. There is a need for robust acoustic threat awareness and automated threat reporting from sensors distributed throughout the battlefield. Acoustic systems tend to perform better in open areas than in urban environments. With increasing military operations in cities, the need exists to underpin and improve acoustic system performance.

OBJECTIVES

The objective of the SET-233 RTG was to develop a foundational understanding of factors that influence the acoustic detection and localization accuracy for threats that emit transient or impulsive acoustic signatures. It also intended to develop sensors, algorithms and techniques to enhance a soldier's persistent situational understanding in complex and dynamic environments. SET-233 also aimed to characterize system performance in realistic environments and capture signatures for future research and development (R&D).

S&T ACHIEVEMENTS

SET-233 showed

- improved acoustic detection range and accuracy by overcoming signature and timing distortion caused by atmospheric propagation;
- channel characterization with a 3D in-situ array that derived the Green's function to improve bearings;
- distributed acoustic arrays that led to sniper localization in the presence of reverberation and multipath;
- a wearable, distributed antenna of six nodes built on Android smartphones detected all shots and produced accurate solutions;
- that shooter localization accuracy strongly depends on array geometry and range, but not necessarily the gun calibre; and

Figure 30: Concept of Passive Radar placed on airborne platform.

- acoustic particle velocity sensors can significantly reduce the size of traditional microphone arrays.

SYNERGIES AND COMPLEMENTARITIES

Joint field experimentation leveraged all of the participants' sensor hardware and algorithmic approaches.

EXPLOITATION AND IMPACT

The complexities of dense/urban environments can limit range and localization accuracies, but limitations can be overcome with advanced algorithms and innovative approaches. Three-dimensional localization of snipers was demonstrated in reflective and reverberant environments. The systems and methods developed are applicable to stationary and mobile sensing for soldier-worn, unattended ground systems, and air/ground vehicle systems. Individual acoustic arrays can cue other collocated sensors, and distributed systems can monitor the larger battlespace and disseminate information products that locate and classify the threats.

CONCLUSIONS

The acoustic sensor system provided continuous, omnidirectional, non-line-of-sight threat detection and localization capabilities at low size, weight, power, and cost. Research improved the understanding of propagation channel effects and acoustic system performance in open field and urban environments.

> *Acoustic sensing of threats in urban environments can augment heterogeneous sensing and fusion for Multi-Domain Operations dominance.*

BIG DATA CHALLENGES: SITUATION AWARENESS AND DECISION SUPPORT (IST-178)

He IST-178 workshop reflected both a military and scientific perspective on the opportunities and risks of Big Data for Situation Awareness and Decision Making. This was addressed from the point of view of the following disciplines: Artificial Intelligence (AI) and Machine Learning, Human Factors, Information Warfare and Social Media, and Visual Analytics and Visualization. A selected number of peer-reviewed papers and two invited keynote papers gave the status and descriptions of current research happening within, and relevant to, the NATO Science and Technology Organization. One conclusion of the workshop was that analysis of big data can potentially assist decision makers, but care must be exercised in its use. For example, there is evidence that the proliferation of fake information over the internet for nefarious purposes may be detected with tools that may be able to identify actors attempting to influence specific groups.

Dr. Margaret VARGA, UK, University of Oxford; Dr. Karel VAN DEN BOSCH, NLD, Netherlands Organisation for Applied Scientific Research

Figure 31: Deep Fake Videos Examples (retrieved from Keynote Speaker presentation). (https://www.youtube.com/watch?v=knRGxj37AjM; https://youtu.be/cQ54GDm1eL0)

BACKGROUND AND MILITARY RELEVANCE

Visual analytics, visualization, and other forms of analysis tools and techniques, together with human factors, may provide effective solutions to support users in exploring, analyzing, and understanding large, complex, dynamic Big Data sets. This will ultimately support users in the intelligence, defence, and cyber domains with situational awareness and decision-making. Bringing together researchers from different NATO STO Panels and Groups will enable further exploration collaboration to complement and enhance their respective efforts. It will also facilitate the sharing of data, tasks, and tools.

> *Visual analytics/visualization, together with modelling and simulation and other forms of analysis techniques and tools, supported by human factors, are key enabling elements tha provide a possible link to bring together these disparate groups*

OBJECTIVES

The workshop aimed to advance knowledge as applied in a military domain by answering several questions. How can the availability of Big Data assist the military in understanding the situations they face today and in the future? How will this support them in making better decisions? What are the challenges for developing Big Data and the opportunities for its exploitation?

S&T ACHIEVEMENTS

Fifteen papers were selected by peer-review, together with two invited keynote papers designed to give background with a general assessment of the current state-of-the-art research in hand. The technical papers were divided into four themes: 1) AI and Machine Learning, 2) Human Factors, 3) Information Warfare and Social Media, and 4) Visual Analytics and Visualization. The topics were introduced by high quality presentations from authors that, in some instances, involved demonstrations of the tools. All papers and presentations have been published.

SYNERGIES AND COMPLEMENTARITIES

IST-178 brought together scientists and experts from the different STO Panels and Groups. It provided an effective means for participants to present, discuss and share their work, problems, and challenges in relation to exploring, exploiting, and utilizing massive, complex, and dynamic Big Data sets in their respective tasks and mission domains.

EXPLOITATION AND IMPACT

The workshop resulted in a raised awareness of both common and unique problems, technologies,

Figure 32: Live Automated Video Analysis Detection Capabilities (retrieved from a presentation by DRDC).

capabilities, and efforts It also developed collaborations across the STO Panels Groups that participated. Outcomes potentially include cross-panel collaborations, further sharing of data, tools and tasks, and the generation of new research ideas and new STO activities.

CONCLUSIONS

The workshop achieved the objectives of informing the participating subject matter experts of the issues affecting NATO and providing an interface among scientists working with and for the STO. Knowledge about the meaning of big data for situational awareness and decision making was advanced with a number of aspects that require further research. The availability of raw data is expanding at a rapid rate, dictating that AI assistance is required for decision-makers to analyze and comprehend the information. Humans-in-the-loop remain essential and smart filters and visual analytics play a significant role in assisting these users. A raft of tools were presented and demonstrated with the recommendation that more research is necessary for the tools to evolve. Trust in the information displayed is considered paramount, but it is also recognized as difficult to achieve. Identifying corrupted data remains critical, particularly for training, testing, and evaluation of AI systems. The coupling of social media with the internet of things permits rapid access and dissemination of information to a wide audience. However, it may also provide adversaries with a channel to influence the opinion of communities (e.g., by distributing fake news to a wide audience with Bots relaying the data as if they were true actors). It has been argued that NATO needs to consider a proactive stance against such threats.


Figure 33: Smart City (retrieved from a presentation by ARL).

HYBRID/ELECTRIC AERO-PROPULSION SYSTEMS FOR MILITARY APPLICATIONS (AVT-323)

Hybrid/electric propulsion for military applications may benefit from the current level of research in the area of commercial aviation, while offering very different application scenarios that are relevant to the military end user. To exploit the potential of this promising new technology, the interaction between scientists, industry, and the military user needs to be intensified. This was the main focus of this Symposium

Dr Askin ISIKVEREN, AUS, SAFRAN TECH; Dr Frank GRAUER, DEU, MTU Aero Engines AG

> *"There are lots of different mission types that we need to undertake where we deliver assets by air. So resupply is one, but troop insertion is another big area that could be traditional forces or special forces. Being able to do that in a much stealthier fashion by having more electric air vehicles would be of benefit." - Mr. Neil Martin, Platform Systems Devision, Defene Science and Technology Laboratory, 2019*

BACKGROUND

There is an increasing amount of international research and development emphasis on electrification of aircraft Propulsion and Power Systems (PPS). The term "hybrid-electric" refers to the adoption of integrated systems based on advanced electrical machines, power electronics, and secondary energy storage.

Figure 34: US DARPA's CRANE program, using Aurora Flight Science's Vertical Take-Off and Landing Experimental Aircraft.

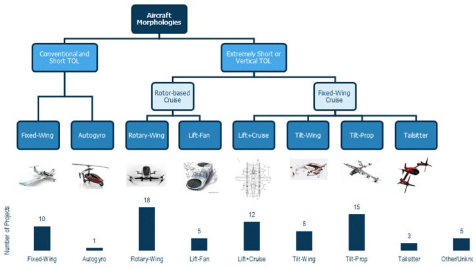


Figure 35: Urban Air Mobility Morphologies by M. Shamiyeh.

MILITARY RELEVANCE

Advanced propulsion system technologies and associated architectures applied to military aircraft have several goals. These include realizing peak performance during all flight phases, having low-observability attributes (i.e., minimize external noise and visible emissions), improving dispatch reliability, ameliorating turn-around as well as maintenance related down-time, reducing procurement cost and operating economics, and minimizing human-in-the-loop workload by offering a platform compatible with future aspirations of facilitating autonomous operations.

OBJECTIVES

The objective of this symposium was to convene an international array of scientists and engineers together with other important stakeholders, to cover aspects associated with the design, certification, and operation of future aircraft utilizing hybrid/electric and coupled aero-propulsion technologies. The context was to familiarize all participants with what technical aspects should be considered when aiming to create effective, efficient, and agile NATO aerial vehicles.

S&T ACHIEVEMENTS

By convening a symposium dedicated to the topic of advanced vehicles utilizing hybrid/electric and coupled aero-propulsion systems, an opportunity was provided for multi-disciplinary specialists to disseminate their latest findings, and to introduce other stakeholders to emerging technological trends and operational implications. In addition, the symposium served as a stage for all stakeholders to communicate future operational requirements and, more specifically, use cases pertinent to military applications to be finally adopted by other complementary Technical Teams.

SYNERGIES AND COMPLEMENTARITIES

The following AVT activities are deemed complementary to the symposium initiative, such as Towards Improved Computational Tools for Electric Propulsion(AVT-294), Airworthiness Tools and Processes for Complex Rotorcraft Systems Safety(AVT-312), Balancing Energy Storage with Safety in Large Format Battery Packs (AVT-227), and Hybrid/Electric Aircraft Design and STAndards, Research and Technology (HEADSTART) (AVT-310).

EXPLOITATION AND IMPACT

The symposium gathered and compiled the current status of mainly civilian-driven research in this area to provide a starting point for further operationally driven discussions in complementary Technical Teams.

CONCLUSION(S)

There appears to be much more work required to improve the connection between science and te military user. The symposium delivered an initial view on the customer needs and the technology potentials, but further activities will be required to close the gaps.

QUANTUM MAGNETIC SENSORS FOR ANTI-SUBMARINE WARFARE APPLICATIONS (CMRE)

The CMRE carried out preliminary research and a study on the application of the latest generation of quantum magnetic sensors for anti-submarine warfare (ASW) applications, with funding by NATO Allied Command Transformation (ACT).

Dr Roberto ZIVIERI; Dr Massimo CHIAPPINI; Dr Valerio IAFOLLA; Dr Paolo Palangio; Dr Alessandro CARTA; Dr Alessandra TESEI; Dr Kevin LePAGE; STO-CMRE

BACKGROUND

Anti-submarine warfare (ASW) has always been a challenge for maritime forces. Unlike for the air, land and space domains, detection of submerged submarines using electromagnetic energy is not useful because of the attenuation of electromagnetic propagation in water. As a consequence, traditional means of submarine detection have focused on using both active and passive acoustic methods, to detect a submerged submarine. Additionally, for the last 50 years, magnetic anomaly detection (MAD) sensors have been in service with Allied forces, particularly using airborne capabilities to assist with the classification and localization of detected underwater acoustic contacts that could be a submerged submarine. MAD relies on sensing the disturbances created in the earth's magnetic field by the presence of the metallic hull of a submarine. Traditional magnetometer technologies, apart from being relatively bulky and having high power consumption, have a limited range capability and therefore have been used only for classification and localization purposes and not for submarine detection capability.

OBJECTIVES

The objective of this study was to carry out preliminary research into the extent that the latest generation of quantum magnetic sensors could contribute to the detection, classification, and localization of submarines.

S&T ACHIEVEMENTS

This study initially focused on understanding the main sources of magnetization signatures that characterize underwater objects. A simplified analytical model was developed to predict the magnetic signature of a submarine moving underwater, with the major contributions to the magnetic signature of an object expected to be both its dipole field and also the magnetic field caused by eddy currents in the metallic hull.

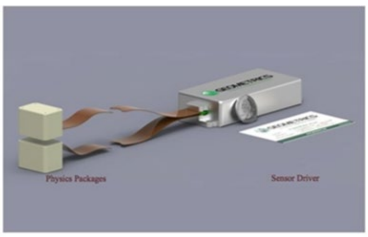


Figure 36: Prototype Miniature Fabricated Atomic Magnetometer.

Concurrently, CMRE conducted an overview of quantum magnetic sensors that are commercially available or are likely to be in the near future. Most of them belong to the "historical" magnetic sensors that were commercially available for several decades for their various applications with special regard to timing switches for cars, buses and other vehicles, magnet-triggered switches, magnetic compasses, hard disks, mobile phones, and so on. However, during the latest two decades, university laboratories and research centres have pioneered a revolution in this field with the creation and fabrication of a new generation of quantum magnetic sensors that was stimulated by the discovery of new quantum effects and miniaturization techniques. The features of these sensors could potentially overcome the drawbacks in terms of size, cost and power requirements of the old generation of sensors. Sensors belonging to this generation might potentially represent promising candidates for detecting magnetic field anomalies induced by the presence of underwater vehicles.

Figure 37: MAD Boom on a RCAF Lockheed CP-140 Aurora.

EXPLOITATION AND IMPACT

As one of the study outcomes, three types of novel quantum magnetic sensors were selected for ASW applications because of the special advantages that they offer with regard to their low size, weight and power requirement, and their improved sensitivity. Such sensors could be readily deployed at the sea surface on small unmanned surface vehicles, on unmanned aerial vehicles, in autonomous underwater vehicles, or in portable bottom sensors as a network to detect magnetic objects such as submarines.

CONCLUSIONS

In recent years, scientific and technological advancements, coupled with increasing commercial applications has driven down the size, cost, and energy requirements of magnetic sensors. Indeed, many smart phones incorporate such sensors. The latest generation of quantum magnetic sensors may now show promise as a capability to detect and track submarines.

NATO STO Programme of Work

EXCELLENCE

COHERENT MID-INFRARED FIBRE SOURCE TECHNOLOGY (SET-224)

From 2015 to 2018, SET-218 achieved advances in scaling the power, efficiency, and spectral coverage of fibre-based coherent sources to provide materials, technologies, and components for use in countermeasures, active imaging, and other military systems.

Dr. Rita PETERSON, USA, Air Force Research Laboratory, Chair SET-224,

BACKGROUND AND MILITARY RELEVANCE

Mid-infrared laser technology is critical to the active sources required for military applications like countermeasures and remote active sensing of targets and threats. These coherent sources must be resistant to environmental changes, and be sufficiently compact and conformable to fit in a variety of platforms, including large transports, combat aircraft, helicopters, and even UAVs. Commercial development in telecommunications and manufacturing has driven significant development of fibre-optic technology, mostly focused on sources based in silica fibre-optics for operation in the visible and near infrared (NIR). Midwave and longwave infrared (IR) operation in the military environment requires development of analogous solutions in these wavebands. This, in turn, depends on advances in new materials, and spectrally tailored fibre-based components.

> *By working together to address key challenges in power/energy, efficiency, spectral coverage, and size, we can provide coherent sources suitable for military applications like countermeasures and active imaging.*

OBJECTIVES

The objective of SET-224 was to improve the wavelength versatility, efficiency, power/energy, ruggedness, and simplicity of fibre-based coherent sources, through collaboration involving leading researchers in participating nations, focusing on three technical areas:

1. Fixed wavelength sources based on rare-earth-doped lasers

2. Broadly tunable sources based on fibre-pumped nonlinear devices

3. Highly broadband supercontinuum sources

S&T ACHIEVEMENTS

The tasks undertaken by SET-224 activity resulted in numerous power, efficiency, and spectral coverage records, the first demonstration of several novel fibre devices, and several dozen journal and conference publications.

SYNERGIES AND COMPLEMENTARITIES

SET-224 combined the strengths of Panel nations to pursue good science in the service of military needs (e.g., modelling capabilities in NOR, spectroscopic facilites in the US, and laser testbeds in FRA/GER).

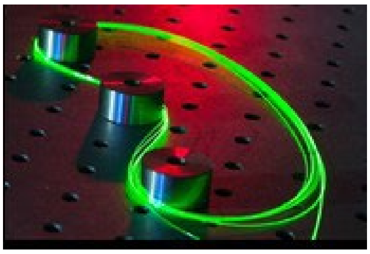


Figure 38: Twisted fibre on a kidney-shaped spool for improved pump absorption.

The sharing of material samples expanded the scope of experiments that could be conducted. The invitation of Australia to the panel provided valuable fibre laser expertise across the board.

EXPLOITATION AND IMPACT

The advances made by SET-224 enable efficient, spectrally diverse coherent sources that benefit from the optical confinement and inherent geometry of fibres to make them more compact and robust for use in the military environment. Primary applications that will benefit are IR countermeasures, standoff detection and spectroscopy, and active imaging.

CONCLUSIONS

Fibre-based sources offer distinct advantages for the military environment, but must improve in energy, efficiency, and spectral coverage to satisfy key applications. By sharing expertise, data, materials, and facilities, these challenges are addressed more quickly to provide components that system integrators can eventually incorporate into fielded systems.

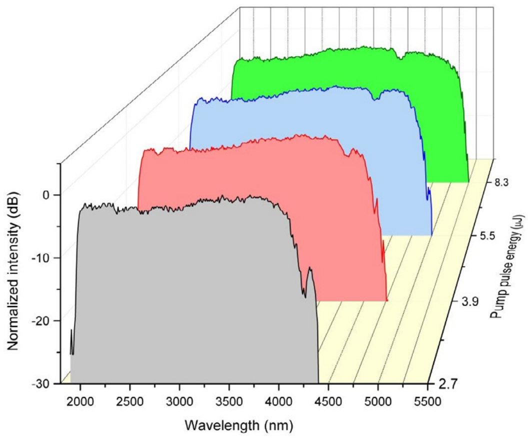


Figure 39: Supercontinuum spectra obtained from 9-m-long InF3 fibre pumped at 2.02 μm, for pump pulse energies of ~2.7 μJ (36.3 kW), 3.9 μJ (52.4 kW), 5.5 μJ (73.9 kW), and 8.3 μJ (111.5 kW).

CONTENT BASED MULTI-MEDIA ANALYTICS (CBMA) (IST-144)

IST-144-RTG brought together information retrieval strategies from heterogeneous media sources (text, video and images) and human assessment. As a result, multiple heterogeneous data sources can be exploited by content-based information retrieval and multimedia analytics to deliver timely and accurate synopses of data, with information that can be combined with human intuition and understanding to develop a comprehensive "view" of the problem/solution space. Such interoperable tools that cross-cue knowledge obtained from one method to generate taskings in another are needed by NATO coalition military leaders, commanders, and intelligence analysts to accelerate situational awareness and decision making and deal with the complexity of the defence information space.

Dr. Elizabeth K. BOWMAN, USA, United States Army Research Laboratory; Prof. Bhopinder MADAHAR. GBR, Defence Science and Technology Laboratory,

BACKGROUND AND MILITARY RELEVANCE

NATO and coalition military leaders, commanders, and intelligence analysts need interoperable tools that cross-cue knowledge obtained from one content based multi-media analytics (CBMA) method to generate taskings in another. This requires a focus on building the cross-cued solution from advances in multi-media data analytics (e.g., text/image/audio). CBMA allows military analysts and decision makers to exploit data from multiple sources in a rapid fashion for decision support and knowledge generation.

OBJECTIVES

Following the state-of-the-art review from an exploratory study (IST-ET-86) and recommendations from a specialist meeting (IST-158-RSM), IST-144 aimed at enhancing 'real-time' analytics of heterogeneous multi-media streams (image, video, text, speech etc.) enabled by enhancements in the contextual understanding Following the state-of-the-art review from an exploratory study (IST-ET-86) and recommendations from a specialist meeting

> *Results will significantly improve NATO abilities to generate knowledge from extremely large stores of text, imagery, and video caches to speed situational awareness and decision making.*

(IST-158-RSM), IST-144 aimed to enhance the "real-time" analytics of heterogeneous multi-media streams (image, video, text, speech etc.) enabled by enhancements in the contextual understanding of complex events through advances in computational/human processing techniques. Developments were focused on four key technical aspects and research gaps, namely intelligent capture and indexing of motion imagery; expansion of machine learning (ML)/Deep Learning (DL) approaches to semantic video analytics; cross-cueing from text analytics to drive/exploit video and imagery indexing and retrieval; and exploring potential architectures and frameworks that could optimize the implementation of multi-media analytics in distributed coalition environments..

S&T ACHIEVEMENTS

IST-144 outlined a framework and developed components that capture shared data, algorithms, and processing results for rapid contextual understanding of dynamic environments through integrated multi-media analytics. These achievements were brought to light by conducting multi-nation technology concept demonstrations with shared resources and integrating research capabilities. As shown at the 2018 NATO Chiefs of Transformation Conference (COTC) and the 2019 US Army Enterprise Challenge, the specific analytics capabilities developed are: Overall, in tabular summary, the specific analytics capabilities developed are:

TEXT ANALYTICS	IMAGE/VIDEO ANALYTICS	SEMANTIC CORRELATIONS
• Text analytics of unstructured data • Social-media Understanding and Reasoning Framework (SURF) • Inferring entities of interest and relationships	• Live social media video analytics • Fast indexing on-line videos • Searching and identifying objects of interest	• Semantic analysis of images/ videos • Cross-cueing between social media and images/videos

SYNERGIES AND COMPLEMENTARITIES

Work performed by HFM-293-RTG (Digital and Social Media Assessment for Effective Communication and Cyber Diplomacy), IST-177-RTG (Social Media Exploitation for Operations in the Information Environment), and a Specialist's Meeting (IST-158-RSM) focused on Content Based Real-time Analytics of Multi-media Streams. The four nations that participated in this activity contributed to the team's efforts and to the demonstration by providing different capabilities that together were integrated within a relevant military scenario. These included text analytics capabilities that classify social media users and followers as likely to belong to a terrorist group (USA), a text analytics capability that extracts entities and relationships from a variety of source documents (GBR), an image classification and indexing capability that allowed images to be searched for video frames, including target objects (NOR), and an image classification capability that allowed rapid scanning of video frames for location, object, and behavioural activities of interest in a very large video repository (NLD).

EXPLOITATION AND IMPACT

Several publications were published in peer-reviewed journals and presentations were delivered at conferences and workshops as evidence of the high S&T quality of the work. Concept demonstrations were shown at two key events—2018 NATO COTC Conference organized by Allied Command Transformation (ACT), and the 2019 US Army Enterprise Challenge. The final report has been produced and is awaiting publication.

CONCLUSIONS

The research and demonstrations conducted by the IST-144 RTG has shown the 'art-of-the-possible' in intelligent capture and indexing of motion imagery; expansion of the machine learning/ deep learning approach to semantic video analytics; and cross-cueing from text analytics to drive/exploit video and imagery indexing and retrieval. These are key enablers that allow military analysts and decision makers to process '"heterogeneous" multi-media streams (image, video, text, speech etc.) from distributed sensors for fast analysis and decisions. Their utility has been demonstrated by application to a realistic military scenario using a story board outlining applied analytics processes. These were mapped to, and represented by, processes for intelligence analysts that the project has defined in an abstract cartoon form and is offered to other researchers as a complement to Boyd's OODA loop and the Pirolli and Card Intelligence Process Cycle.

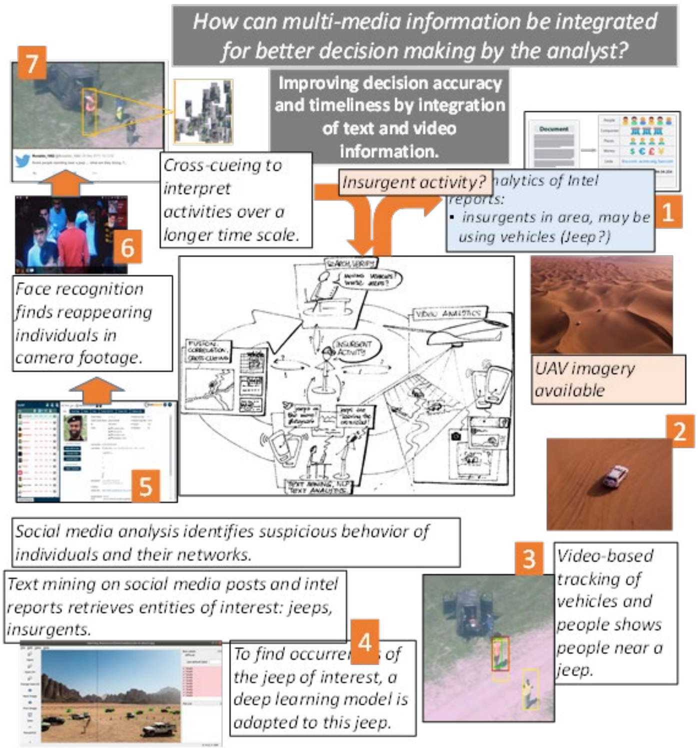


Figure 40: Montage of applied analytics to military scenario.

DEEP LEARNING FOR MINE COUNTERMEASURES (CMRE)

Naval mines are inexpensive to produce and deploy, and they can cause immense damage to expensive assets. This is the epitome of asymmetric warfare. It is logical, then, that mine countermeasures (MCM) be a NATO priority. For the Alliance to meet its MCM ambitions, artificial intelligence and autonomous systems provide a promising solution.

Dr David WILLIAMS, STO-CMRE

BACKGROUND

Autonomous platforms equipped with side looking sonars are being deployed by National MCM forces to perform wide area search, detection, and classification missions. And in concert with those operations, the Centre for Maritime Research and Experimentation (CMRE) has developed with funding from Allied Command Transformation cutting edge deep-learning-based automatic target recognition (ATR) algorithms to detect and classify mines in that sonar imagery.

OBJECTIVES

The objective of CMRE's deep-learning-based ATR is to demonstrate that the use of innovative machine-learning algorithms can enable superior classification performance compared to conventional MCM approaches, and thereby ease operator workload and provide better support both in-mission and post mission.

S&T ACHIEVEMENTS

CMRE's ATR approach employs novel convolutional neural network (CNN) classifiers, a state-of-the-art technique from the computer-vision community for image-classification tasks. Traditional so-called "shallow" classifiers (based on manually defined features) hit a performance plateau: beyond a certain point, more data fails to improve performance. In contrast, deep learning approaches like CNNs continue to improve as the data available increases. As such, they are a natural way to leverage huge (and ever-increasing) amounts of measured experimental data.

CMRE has leveraged data sets of centimetre-level resolution synthetic aperture sonar (SAS) imagery collected in extensive experiments to train CNN classifiers ab initio for MCM. In particular, we have developed novel CNN classifier architectures that rely on orders of magnitude fewer parameters than commonly used in the literature. This breakthrough decreases training-data requirements and reduces the need for costly data-collection experiments. But even more importantly, it has been demonstrated that these original, smaller deep-learning classifiers can match and even surpass the performance achievable by a human subject-matter-expert. Moreover, extensive experimental results on challenging real-world SAS image data sets collected in diverse environments and conditions illustrate that the CNNs possess strong generalization ability. .

SYNERGIES AND COMPLEMENTARITIES

Over the past decade, CMRE has conducted dozens of MCM-focused sea experiments in various geographical locations and environmental conditions. These experiments utilized CMRE's Mine hunting UUV for Shallow water Covert Littoral Expeditions (MUSCLE), an autonomous underwater vehicle (AUV) capable of providing detailed sonar imagery to train the CNN classifiers.

EXPLOITATION AND IMPACT

In 2019, a version of the CMRE deep-learning software was officially released, and it is now readily available to the Nations for exploitation.

CONCLUSIONS

The CNNs developed at CMRE provide a blueprint for achieving excellent classification performance even with limited computing power or limited data. At the same time, they increase the level of automation, remove the man from the minefield, and provide a sound way to accelerate time-critical MCM mission timelines.

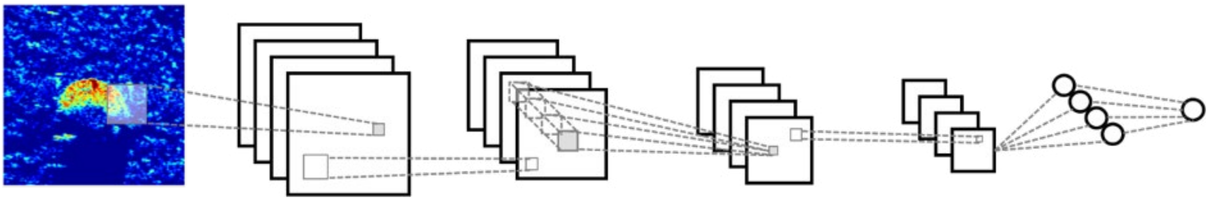


Figure 41: Schematic showing intermediate data representations in a basic CNN architecture with a SAS image chip of a truncated-cone as input.

MILITARY APPLICATIONS OF INTERNET OF THINGS (IST-147)

This activity aimed to assess potential risks and demonstrate benefits for the implementation of the Internet of Things (IoT) concept into the military domain. Some scenarios were selected and described that examine the applicability of IoT to militarily significant operations. The most important challenges identified were security, trust management and heterogeneity. IST-147 proposes possible approaches to solving these challenges, having organized demonstrations of the concepts studied and key solutions identified in a realistic military scenario.

Dr. Niranjan SURI, USA, US Army Research Laboratory; Dr. Zbigniew ZIELINSKI, POL, Military University of Technology

BACKGROUND AND MILITARY RELEVANCE

Modern military operations are conducted in a complex, multidimensional, highly dynamic and disruptive environment usually with unanticipated partners and irregular adversaries. For this reason, decision support tools need to draw upon all possible sources to ensure that the most complete and relevant picture can be created of the situation almost in real-time mode. Exploiting Internet of Things (IoT) capabilities and technologies has the potential to significantly increase the speed and breadth of obtaining Situation Awareness (SA) for military operations. This will allow military commanders to better leverage IoT applications, and improve efficiency and effectiveness, namely in combat applications (C4ISR) systems, and in non-combat settings that would improve the efficiency and effectiveness of back-end processes (e.g., Logistics, Smart base).

OBJECTIVES

IST-147 (COM) had four main objectives: to demonstrate through proof of concept trials the value of application of the Internet of Things (IoT) in significant military situations/operations; to explore IoT architecture(s) that might be used in military situations taking into account existing IoT architectures used in other domains; to identify the risks associated with the use of commercial IoT technology in the military domain, and identify possible mitigations or open challenges; and, finally, to facilitate the discussion on the topic taking into account military aspects of IoT, NATO bodies, academia, industries, and nationally funded initiatives.

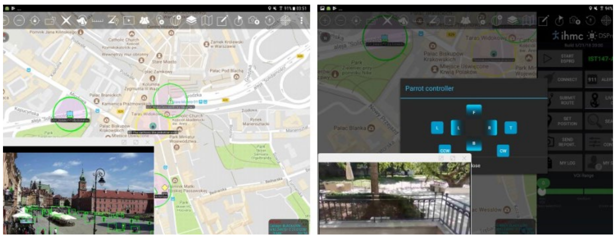


Figure 42: Screen Captures from the ICMCIS 2018 Demo.

S&T ACHIEVEMENTS

IST-147 finalized a description of overall scenario and vignettes for IoT, defined IoT architecture for applications in military operations in smart cities and HADR. The first demonstration of the use of IoT in military operations in a Smart City was performed for IST Panel Members and ICMCIS 2017 participants. IST-147 also developed capabilities demonstrated by NCIA at CWIX 2017.

> *Exploiting Internet of Things (IoT) capabilities and technologies has the potential to significantly increase the speed and breadth of obtaining Situation Awareness (SA) for military operations.*

Synergies and Complementarities IST-147 was a result of IST-ET-076 on Internet of Military Things and IST-ET-075 on Integration of Sensors and Communication Networks. Its development and conclusion showed good cooperation with the industry via NIAG, nominating 6 companies who participated in the activity.

EXPLOITATION AND IMPACT

A total of 24 papers have been published in relation to this activity, and a final report is almost finalized to be published at Springer's Open Access. IST-147 successfully explored the application of IoT to military operations, having organized seven workshops. As a follow-up, IST-176 will focus on the integration of IoT technology and capabilities into military C2 and logistics systems.

CONCLUSIONS

IST-147 established the utility and relevance of IoT for the military domain, namely under Humanitarian Assistance and Disaster Relief (HADR), Collaborative Resilience, Counter-terrorism, Physiological Monitoring, and Logistics and Supply Chain Management. Ultimately, IST-147 members concluded that exploiting IoT can significantly increase the speed and coverage of obtaining Situation Awareness information, thereby proposing a new RTG to work on integrating IoT technology and capabilities into military C2 and logistics systems.

MUNITION HEALTH MANAGEMENT TECHNOLOGIES: EFFECTS ON OPERATIONAL CAPABILITY, INTEROPERABILITY, LIFE-CYCLE COST AND ACQUISITION OF MISSILE STOCKPILES OF NATO NATIONS (AVT-292)

This Cooperative Demonstration of Technology activity demonstrated improved munition stockpile/fleet management, acquisition, and stockpile sharing options. The new options are made possible through existing technologies such as sensors and sensor integration technologies derived from the emerging Internet of Things (IoT) industry, and management of data and information fused together in an open architecture framework.

Dr. Robert MUELLER, USA, Micron Instruments; Dr. Giuseppe TUSSIWAND, DEU, MBDA / Bayern-Chemie

BACKGROUND

Figure 43: Logo of the NATO AVT Integrated Munition Health Management technology demonstration.

Emerging Munition Health Management (MHM) technologies derived from civil applications are expected to have improved safety and reduced Life Cycle Cost. Munition Life Consumption can be defined and measured non-destructively applying MHM technology. In addition, the user can compute depreciation of its stockpile based on actual consumption reducing the yearly life-cycle cost by a large amount as well as using “performance-based acquisition” frameworks to ensure supply and availability. Finally, the MHM technology provides a quantifiable cost basis for NATO nations to establish a common stockpile, in which countries agree to assign a portion of their munitions under a smart framework contract without physical conveyance.

OBJECTIVES

The Technical Team demonstrated the application of sensors and IoT technologies to munitions and the benefits on operational capability, interoperability and life-cycle cost to the Conference of National Armament Directors (CNAD), NATO Support and Procurement Agency (NSPA), and other NATO organizations at the NATO HQ.

S&T ACHIEVEMENTS

The demonstration highlighted that it is feasible to integrate MHM technologies in complex, expensive munitions and it is expected that MHM enabled capabilities will be included into NATO’s and Partner Nations’ weapons systems procurement requirements. Furthermore, the event informed high-ranking decision makers including the NATO Chief Scientist, the Assistant Deputy Secretary General for Defense Investment (DASG DI) and NSPA.

> *Munition Health Management technologies improve Operational Capabilities, boost Interoperability, and lower Life-Cycle and Acquisition Cost of complex, expensive munitions for NATO nations..*

SYNERGIES AND COMPLEMENTARITIES

The fundamental ethos of the AVT-292 approach to Munitions Health Management is centred upon and is aligned with NATO’s MHM Smart Defence Initiative. The core framework supports linked force capability that encompasses infrastructure, personnel, logistics, and assets, including platforms and munitions.

EXPLOITATION AND IMPACT

Exploitation includes the application of wired and wireless sensing with IoT gateways embedded in munitions, electronic health and usage monitoring systems, augmented reality and software applications enabling linked force capability.

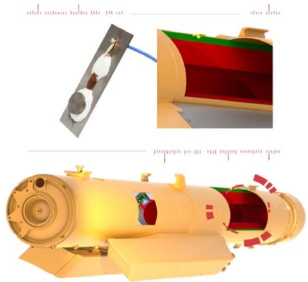


Figure 44: Embedded propellant sensor in a Meteor Rocket Motor by Bayern-Chemie, an MBDA company.

Impact includes lower acquisition and yearly life cycle costs; capability expansion; improved risk control over missile stockpile (safety and financial); condition-based maintenance of munitions through continuous life consumption measurement; and enabling creation and access of a shared, NATO-tagged stockpile (linked force capability)..

CONCLUSIONS

The Technical Team demonstrated benefits for operational capability, interoperability and life-cycle cost, through storyboards, movies, and live hardware demonstrations, showing the application of IoT Technologies, the guidelines of the Munition Health Management SDI, and NATO Life Cycle Cost Cycle methodologies.

ANNEXES

THE OFFICE OF THE CHIEF SCIENTIST

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

Beyond providing the executive support to the STB and its chartered responsibilities, the OCS acts as a focal point for the STO Programmes of Work (PoWs) and its users represented at NATO HQ. To that end, the OCS works with the S&T results generated through the STO PoWs and promotes their utilization in the political and military context. Engaging the committees and staffs at NATO HQ and beyond, the OCS coordinates generating 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.

As scientific advisor to NATO leadership, the Chief Scientist played a key role in a North Atlantic Council (NAC) Away Day and Military Committee (MC) Away Day, both of which were focused on the challenges and opportunities of the rapidly emerging applications of artificial intelligence (AI) in support of decision-making.

In July 2019, Dr Bryan Wells took office as the NATO Chief Scientist. Responding to the increasing focus of NATO leadership on innovation in general, and on a select set of emerging and disruptive technologies (EDTs) specifically, he oriented the work of the OCS to enhance the impact of S&T for the Nations and NATO and reinforce strategic communication about that impact.

In his capacity as a member of the newly established Innovation Board, he advised senior leaders on addressing emerging and disruptive technologies, promoting innovation, and maintaining the technological and knowledge advantage of the Alliance. As the emphasis on EDTs increasingly framed the forward-looking discussions of decision-makers, the OCS redirected the preparation of a broad technology trends analysis to tailor its upcoming report to the new demand signal, and to deliver a systematic assessment of those EDTs (including maturity, current developments, potential applications, and military impact).

Due to the growing recognition of the importance and challenge of maintaining a technology edge for the Alliance, there is increasing demand for the evidence-based advice and scientific insights that the STO can bring to NATO HQ. The Chief Scientist and his staff are dedicated to meeting that demand.

THE COLLABORATION SUPPORT OFFICE (CSO) AND THE COLLABORATIVE PROGRAMME OF WORK (CPOW)

The NATO Science & Technology (S&T) Collaborative Business Model sees NATO Nations and Partner Nations contributing their national resources to define, conduct, and promote cooperative S&T research and information exchange. The total spectrum of this collaborative effort is addressed by the following six Panels and one Group that manage a wide range of scientific research activities:

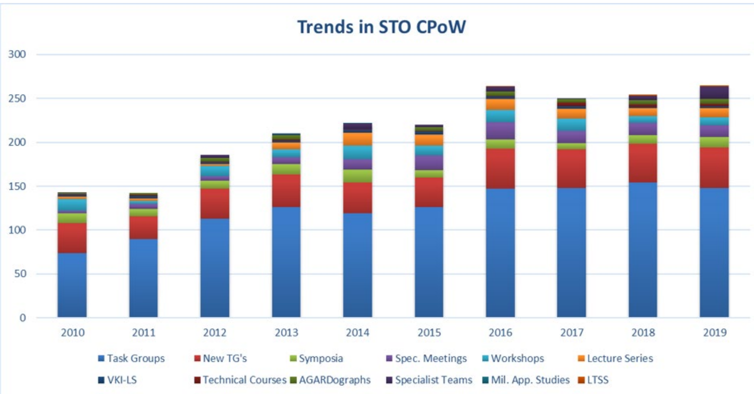
AVT	Applied Vehicle Technology Panel|
HFM	Human Factors and Medicine Panel
IST	Information Systems Technology Panel
SAS	System Analysis and Studies Panel
SCI	Systems Concepts and Integration Panel|
SET	Sensors and Electronics Technology Panel|
NMSG	NATO Modelling and Simulation Group

The six Panels and one Group are the powerhouse of the collaborative model and are made up of a network of approximately 6,500 national representatives, as well as recognized world-class scientists, engineers, and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

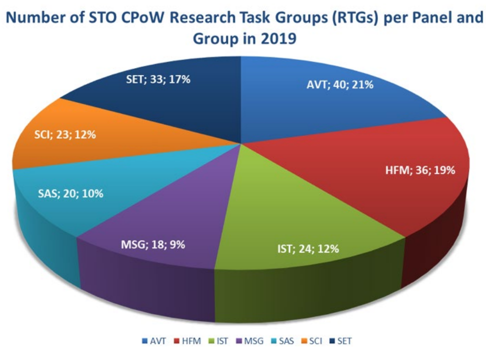
The scientific and technological work is carried out by Technical Teams, created inside one or more of the Panels and Group, for specific research activities that have a defined duration (usually, from one to three years). These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialist's Meetings, Lecture Series, and Technical Courses. All together, these activities represent the Collaborative Programme of Work (CPoW) that encompasses more than 280 activities in 2020. In all cases, these activities result in the publication of highly valued scientific literature published by the STO. The results of the research can also be found in some specific peer-review journals.

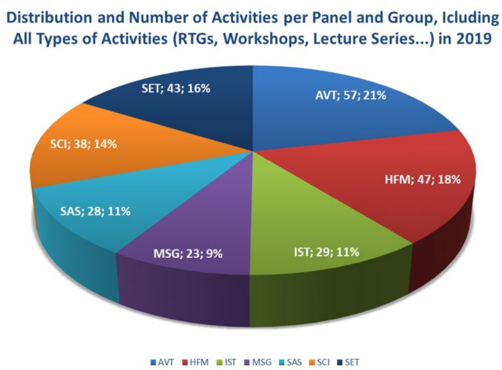

NATO STO RTG – meeting at the CSO

Within the framework of the STO Collaborative Business Model, the Collaboration Support Office (CSO), located in Neuilly-sur-Seine, France, provides executive and administrative support to the S&T activities conducted through the Panels and Group. The support provided by the CSO also includes a strong S&T information and knowledge management service through its website, the "Science Connect" sharepoint, and the S&T database.



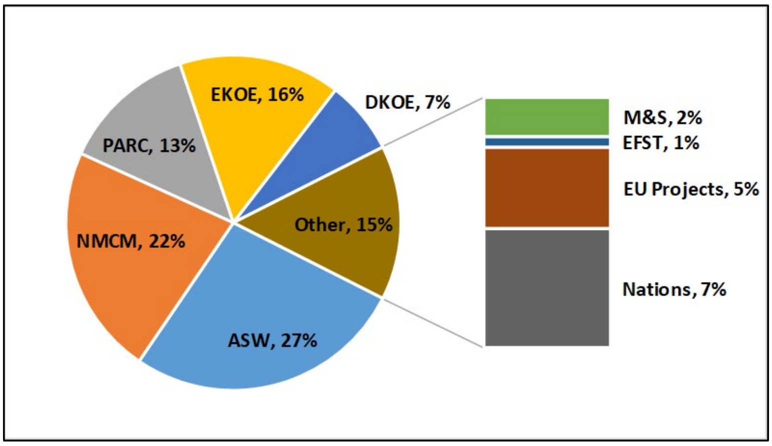
2019 was a pivotal year for the CSO, acknowledging the steady increase of the Programme of Work (+50% since 2012), the growing expectation for new cross-domain activities, and the need to better address strategic issues such as scientific messaging or partnerships development. It became obvious that the stagnating CSO workforce and its organization into silos were no longer fit for purpose. An internal study was conducted to identify solutions to remedy these difficulties, followed by a survey managed by the NATO Defence Manpower Audit Authority (NDMAA). 2020 should see substantial changes in the CSO organization to allow the Office to cope with demanding but exciting new challenges for the greatest benefit of the NATO S&T community.





CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION (CMRE)

The mission of the NATO Science and Technology Organization (STO) CMRE is to organize and conduct scientific research and technology development and deliver innovative and field-tested S&T solutions to address the defence and security needs of the Alliance, centred on the maritime domain. The Centre maintains its core capabilities in the maritime, and particularly the undersea, domain. The Centre is located in La Spezia, Italy and celebrated its 60th Anniversary in 2019. It has been a customer-funded executive body of the STO since 2013.



CMRE Research Activities in 2019 – Proportions by Revenue

CMRE conducts cutting-edge maritime scientific research and experimentation, including low technology readiness level (TRL) research, concept development, and prototype capability demonstration at sea. CMRE owns two research vessels on behalf of NATO: the global ocean going NATO Research Vessel (NRV) Alliance and the Coastal Research Vessel (CRV) Leonardo. CMRE has exceptional, organic ocean engineering and modelling and simulation (M&S) capabilities.

NRV Alliance (left) and CRV Leonardo

In October 2017, NATO's Supreme Allied Commander Transformation (SACT) provided a vision for NATO Maritime S&T Programmes for the period 2017 – 2025. The Centre's current NATO Allied Command Transformation (ACT) maritime S&T programme of work is shaped by this SACT vision, and fully aligned with it. This ensures that the research carried out is oriented by, and relevant to, military requirements. For 2019, the ACT maritime S&T programme of work consisted of six themes:

Antisubmarine Warfare (ASW): Requirements and advanced concepts for unmanned ASW capabilities and improved decision making through advanced decision aids.

Naval Mine Countermeasures (NMCM): Robotics to deliver autonomous, collaborative minehunting capabilities with onboard machine intelligence, supported by appropriate tactical decision aids.

Persistent Autonomous Reconfigurable Capability (PARC): Technology and engineering requirements for future unmanned maritime systems of systems, including communications, persistence, and interoperability aspects.

Environmental Knowledge and Operational Effectiveness (EKOE): Robotics and sensor integration for underwater data collection, processing, and exploitation using long-endurance autonomous underwater vehicles.

Data Knowledge and Operational Effectiveness (DKOE): Advanced approaches in statistical signal processing, machine learning, information and data fusion, and reasoning under uncertainty to enhance maritime situational awareness.

Exploring Future Science and Technology (EFST): Potential innovative, cost-effective and interoperable solutions to current and anticipated NATO capability shortfalls.

CMRE 60th Anniversary

In addition to the ACT-funded maritime S&T programme of work, the Centre currently executes a number of EU-funded projects. Furthermore, the Centre carries out work for governmental organizations and industry from several NATO Nations.

Dr Catherine Warner is the current Director of the CMRE. At the end of 2019, the Centre had a total of 13 military personnel, 145 NATO civilians from 19 NATO Allies, and 37 scientists visiting from NATO nations. The Research, Engineering and IT scientists and engineers—the teeth of the Centre's S&T capability—represent 76% of the work force; of these, over 61% have a master's degree or higher. The scientific staff are young, diverse, dynamic, and demonstrate excellence in their research activities, therefore generating the innovation in emerging and disruptive technologies necessary for NATO to maintain a technological edge in the maritime domain.

On-deck preparation of an acoustic buoyancy glider (left) and an autonomous underwater vehicle before deployment during DANS19 sea trial

LIST OF ACRONYMS AND ABBREVIATIONS

LIST OF ACRONYMS

3D Three-dimensional
A2CD2 Alliance Future Surveillance and Control
ACT Allied Command Transformation
AI Artificial Intelligence
AIS Automatic Identification System
ARL Army Research Laboratory
ASTRIAGraph Software program
ASW Anti-submarine warfare
ASW Rapid Acoustic Prediction Service
ATCD Achievability, Timeliness, Credibility and Disruptiveness
ATR Automatic Target Recognition
AUS Australia
AUV Autonomous Underwater Vehicle
AVT Applied Vehicle Panel
BIONDo Bi-modal Identification Or Neutralisation DemOnstor
C2 Command and Control
C4ISR Command, Control, Communications, Computers (C4) Intelligence, Surveillance and Reconnaissance (ISR).
CAN Canada
CBMA Content Based Multi-media Analytics
CCIEP Combat Clothing, Individual Equipment & Protection
CMRE Centre for Maritime Research and Experimentation
CNAD Conference of National Armament Directors
CNN Convolutional Neural Network
COI Community of interest
COM Communications and Networks
COP Common operating picture
COTC Chiefs of Transformation Conference
CRANE Control of Revolutionary Aircraft With Novel Effectors
CRV Coastal Research Vessel
CSSN Centro di Supporto e Sperimentazione Navale
CWIX Coalition Warrior Interoperability eXercise
DARPA Defense Advanced Research Projects Agency
DASG DI Deputy Assistant Secretary General for Defense Investmen
DEU Germany
DEW Directed Energy Weapons
DKOE Data Knowledge and Operational Effectiveness
DL Deep Learning
DLR German Aerospace Center - German Aerospace Center
DRDC Defence Research and Development Canada
DSTL Defence Science and Technology Laboratory
EA Electronic Attack
EDT Emerging and Disruptive Technologies
EKOE Environmental Knowledge and Operational
EFST Exploring Future Science and Technology
EM Electromagnetic
ET Exploratory Team
EU SatCen European Union's Satellite Center
EUR Euro
EUTELSAT European Telecommunications Satellite Organization
EW Electronic Warfare
FFI Norwegian Defense Research Establishment
FM Frequency Modulation)
FOI Swedish Defence Research Agency
FRA France
FST Fleet Synthetic Training
FUSION 23rd international conference in Information Fusion
GBR Great Britain (or United Kingdom)
GER Germany
HADR Humanitarian Assistance and Disaster Relief
HEADSTART Hybrid/Electric Aircraft Design and STAndards , Research and Technology
HFM Human Factors and Medicine Panel

HQ	Headquarters
ICMCIS	International Conference on Multimedia Computing and Systems
ICT	Information and Communications Technology
IE	Information environment
IFF	Iceland Faroe Front
IMX	International Maritime Exercise
IoT	Internet of Things
IR	Infrared radiation
IRC	Information related capabilities
ISL	French-German Research Institute of Saint-Louis
IST	Information Systems and Technologies
ITA	Italy
JAPCC	Joint Air Power Competency Center
LCdr	Lieutenant commander
LCG DSS	Land Capability Group of Dismounted Soldiers Systems
LIM	Louvain-la-Neuve sea-ice model
LS	Lecture Series
Lt	Lieutenant
LTC	Lieutenant colonel
LUX	Luxembourg
LVC-T	Live Virtual Constructive - Training
M&S	Modelling and Simulation
M/UCAV	Manned or Unmanned Combat Air Vehicles
MAD	Magnetic anomaly detection
MBDA	MBDA Deutschland GmbH
MCM	Mine countermeasures
MHM	Munition Health Management
ML	Machine Learning
MSA	Maritime Situational Awareness
MSc	Master of Science
MSG	NATO Modelling and Simulation Group
MTDS	Mission Training through Distributed Simulation
MTU	MTU Aero Engines AG
MULDICON	Multi-Disciplinary Configuration
Multi	Source Reasoning with Valuation Networks for Maritime Anomaly Detection – the Andromeda Case
MUSCLE	Mine hunting UUV for Shallow water Covert Littoral Expeditions
MV	Merchant Vessel
NAAG	NATO Army Armaments Group
NAMFI	NATO Missile and Firing Installation
NATO	North Atlantic Treaty Organization
NCAGS	Naval Cooperation and Guidance to Shipping
NCIA	NATO Communications and Information Agency
NCTR	Non Cooperative Target Recognition
NEMO	Nucleus for the European Modelling of the Ocean
NIAG	NATO Industrial Advisory Group
NIR	Near-infrared
NLD	Netherlands
NMCM	Naval Mine Countermeasures
NMIOTC	NATO Maritime Interdiction Operational Training Centre
NOR	Norway
NRV	NATO Research Vessel
NSAs	Non-state Actors
NSPA	NATO Support and Procurement Agency
NSWC	Naval Surface Warfare Center
OCS	Office of the Chief Scientist (NATO)
OODA	Observe–Orient–Decide–Act
PARC	Persistent Autonomous Reconfigurable Capability
PC	Personal Computer
PE-MCM	Planning and Evaluation for MCM
POL	Patterns of life
POL	Poland
PPS	Propulsion and Power Systems
RAAF	Royal Australian Air Force
RAF	Royal Air Force
RAPS	Rapid Acoustic Prediction Service
RCAF	Royal Canadian Air Force
RCAF	Royal Canadian Air Force
RF	Radio Frequency
RSM	Research Specialist's Meeting
RTG	Research Task Group
S&T	Science & Technology
S&T POW	Science & Technology Programme of Work
SA	Situation Awareness

SACCON	Stability and Control CONfiguration
SACT	NATO's Supreme Allied Commander Transformation
SAR	Synthetic-aperture radar
SAS	System Analysis and Studies
SCI	Systems Concepts and Integration
SDA	Space Domain Awareness
SD	Smart Defence Initiative
SET	Sensors and Electronics Technology
Sgt	Sergeant
SISO	Simulation Interoperability Standards Organization
STANAG	NATO Standardization Agreement
STANREC	NATO Standardization Recommendation
STO	Science and Technology Organization
SURF	Social-media Understanding and Reasoning Framework
SWE	Sweden
T&E	Training and Exercises
TAU	DLR's system for complex flow simulations on unstructured hybrid grids
TNO	The Netherlands Organisation for Applied Scientific Research
TV	Television
U- FOM	UCATT Federation Object Model
UAV	Unmanned aerial vehicle
UCATT	Urban Combat Advanced Training Technology
UCATT-LSS	Urban Combat Advanced Training Technology - Live Simulation Standards
UCAV	Unmanned Combat Air Vehicles
U-LEIS	UCATT Laser Engagement Interface Standard
U-NITE	UCATT Networking Instrumentation and Tactical Engagement
US	United States
USA	United States of America
USAF	United States Air Force
USN	United States Navy
UUV	Unmanned Underwater Vehicle