NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

organization

www.sto.nato.int

NATO STO CPoW Technical Reports 2021
Book of Abstracts

January 2022

INFORMATION

This document, published by the STO Collaboration Support Office, contains the collection of Abstracts of the Technical Reports stemming from the NATO STO Collaborative Program of Work in 2021. Abstracts are arranged in chronological order according to the date of publication.

The reference number of each abstract is an active link pointing to the document in the STO Publications database on the STO website.

TABLE OF CONTENTS

STOCHASTIC DESIGN OPTIMIZATION FOR NAVAL AND AERO MILITARY VEHICLES

STO-TR-AVT-252

AVT-252 Task Group "Stochastic Design Optimization for Naval and Aero Military Vehicles," demonstrates stochastic design optimization capability for real-world fluid/thermal/structural military vehicle design problems of NATO interest with geometric/operational/environmental uncertainties and/or constraints, including management of large number of uncertainties; thereby, providing new methods, best practices and identification of future collaborative research. The scope is Robust Design Optimization (RDO), Reliability-Based Design Optimization (RBDO) and combinations, including single/multiple objective functions. The focus is methodology development/implementation with demonstration and assessment applications for naval/aero military vehicles. The methodologies include problem formulation; standard terminology; Uncertainty Quantification (UQ) methods; optimization methods; design variables; geometry representation; shape optimization, structural optimization, combinations and others. Four disciplines were selected for model problems: external/internal aerodynamics; aero-elasticity; and ship-hydrodynamics, which cover a broad range of multidisciplinary physics, range of boundary conditions and compressible/incompressible flows. The problems included multiple operational and geometric uncertainty parameters, UQ methods, design parameters, single and multiple objective RDO and/or RBDO, objective functions and optimizers. A benchmark NACA-2412 Airfoil problem is used to assess and compare the performance of the UQ methods. The overall conclusion is that current stochastic design optimization methods are sufficiently mature for the practical application in the design of naval and aero military vehicles.

MISSION-ORIENTED RESEARCH FOR AI AND BIG DATA FOR MILITARY DECISION MAKING

STO-TR-IST-173

The impact and importance of AI and data science on military decision making has been recognized by STO and led to the launch in 2017 of the theme approach initiative on Artificial Intelligence (AI) and Big Data (BD) for Military Decision Making (AIBDMDM). As part of this effort, the first multi-domain specialist team (including not only scientists from different panels/group but also military and industry representatives) IST-173 Mission Oriented Research for AI & BD for Military Decision Making was established to develop a "living roadmap" to support STO in bringing military AI and big data to its full potential. The team has identified the need for a "Centaur approach": leveraging AI and Data Science to enable NATO to fight and operate with machine speed and power while maintaining meaningful human control. This need has been operationalised using a mission oriented research approach that focused on the NATO Main Capabilities Areas, INFORM and COMMAND, CONTROL, CONSULT (C3) to develop a first version of such a "living" S&T roadmap in a wiki STO framework to enable easy access and adaptation. In particular, grand challenges that NATO faces in these areas were jointly identified, and research missions that leverage ongoing STO research were developed, with the aim to identify the key areas where new research is needed to inform Panel/Group efforts.

ASSESSMENT OF PREDICTION METHODS FOR LARGE AMPLITUDE DYNAMIC MANOEUVRES FOR NAVAL VEHICLES

STO-TR-AVT-253

The focus of AVT-253 Task Group "Assessment of Prediction Methods for Large Amplitude Dynamic Manoeuvres for Naval Vehicles" is on benchmark validation experiments and prediction assessment for surface combatant 5415 and Japan Bulk Carrier (JBC) in pure sway motion for improved physical understanding and prediction capabilities for three-dimensional unsteady separation. The studies include static drift at the maximum sway motion condition and pure sway motion for both 5415 and JBC. The membership included 10 NATO countries represented by 17 members. Overall CFD capability is somewhat reduced for dynamic vs. static conditions with turbulence modelling being the limiting issue. URANS capabilities are in some ways better than expected in consideration of the large errors for vortex strength and turbulence; however, clearly higher resolution spatial and temporal experiments are required and advancements are needed for HRLES to provide resolution of the turbulence anisotropy and instantaneous flows, which should be given the highest priority for code development. Connecting the outcomes of AVT-253 indicates the need for improved understanding and prediction capability for the local flow around manoeuvring ships and its relationship to the forces, moments and motions, which is sorely lacking and a priority for free running conditions. Nonetheless continued focus on captive tests is of benefit for higher resolution studies.

MULTI-DISCIPLINARY DESIGN AND PERFORMANCE ASSESSMENT OF EFFECTIVE, AGILE NATO AIR VEHICLES

STO-TR-AVT-251

The Task Group AVT-251 was established to use the outstanding knowledge base, expertise and qualified methods from the predecessor Task groups to demonstrate the capabilities of a computational multi-disciplinary design approach. The aim of AVT-251 was to re-design the SACCON UCAV concept based on selected design requirements and to document and evaluate the design strategy and use of advanced design tools with respect to applicability and reliability. The main achievement of AVT-251 was the design of a new UCAV concept called MULDICON. The design trade studies were conducted within a framework of several design teams, focusing on aircraft design, aerodynamics, controls, structures, and engine integration; the time and resource requirements used for the study were recorded. This study represents a good example of how modern design and analysis tools can streamline the design process, as well as being able to come up with a feasible configuration within a reasonably short period of time and limited resources. 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.

EARLY STAGE WARSHIP DESIGN AND PROCUREMENT FOR OPERATIONAL EFFECTIVENESS AND AFFORDABILITY

STO-TR-AVT-238

Many NATO navies are renewing their fleets. A key issue for these replacement efforts is finding and maintaining a suitable balance between operational effectiveness and affordability, thus ensuring future warships fit within limited budgets, benefit from the rapid development of technology, and can cope with increasingly complex threats. This Research Task Group (RTG) was established under the flag of the Applied Vehicle Technology Panel of the NATO Science and Technology Organisation to enable NATO nations to include effectiveness and affordability evaluation in their early stage warship design process in order to assess and improve cost-effectiveness early on. Working in collaboration with the NATO Naval Armaments Group's working group on Total Ship System Engineering, the RTG succeeded to develop both the required processes and software tools to enable the assessment of effectiveness and affordability simultaneously during early stage warship design. The resulting process and tools were used in four test-cases dealing with surface combatants and mine-countermeasure vessels (including a comparison between manned and unmanned mine-warfare systems). In addition, the participating nations used them nationally to support multiple warship procurement projects. To further improve this capability, the RTG proposes a future RTG will improve decision support and data visualisation tools and consider cost and effectiveness at a task group or fleet-level to better capture how a future warship interacts the units she fights with.

SYSTEM-OF-SYSTEMS APPROACH TO TASK DRIVEN SENSOR RESOURCE MANAGEMENT FOR MARITIME SITUATIONAL AWARENESS (SoSMSA)

STO-TR-SCI-280

Driven by the need for a well-coordinated management of the large diversity and the high amount of sensor resources needed to cover large marine areas, the SCI-280 RTG has developed a generic functional architecture for the observation cycle to achieve maritime situational awareness. The central paradigm for the functional decomposition is sensor management as an iterative process by stepwise refining the degree-of-belief distribution over the set of interesting activities. The Bayes network methodology has been selected as a well-suited concept to calculate the utility of observable properties of such activities. With the detection of piracy threats, a relevant maritime scenario has been elaborated to prove the strength of the Bayes approach. For sensor allocation and scheduling an ontology approach has been taken under consideration. It allows the matching between tasks, sensors, and platforms to select the best suitable sensor/platform combination with respect to the task. Even though the effort of this research task group has been inspired by and directed to a maritime application, the results achieved are generic and transferable to reconnaissance and surveillance task in other domains.

FLIGHT TEST SAFETY AND RISK MANAGEMENT

STO-AG-300-V32

This AGARDograph investigates the current approaches across the NATO Nations in the field of Flight Test Safety and Risk Management. It originates from a view held by the NATO STO Flight Test Technical Team (FT3) that there was broadly common process and a wish to demonstrate this through capturing examples of practice and analysing them. This became the mission of Task Group SCI-236 and this AGARDograph records the findings. It offers examples of practice captured in a broadly common format from a representative sample of Flight Test Organisations and an analysis of their content. It concludes that the views of FT3 are substantiated and that at the baseline level there is significant commonality of approach in relation to people, process, facilities and tools. Detailed content is clearly different, but the similarities offer a framework that can be used to support those embarking upon the creation of a Flight Test Safety Management System or desiring to compare and contrast an existing one.

REFERENCE ARCHITECTURE FOR HUMAN BEHAVIOUR MODELLING

STO-TR-MSG-127

A Human Behaviour Model (HBM) can be applied for a variety of military purposes: training, policy development (e.g., “which doctrine is most effective?”), organizational design (e.g., “which task allocation in a team has the most acceptable workloads?”) or system and interface design (e.g., “evaluating new military systems for usability and human performance”). HBMs are difficult to create and often are built from scratch every time. Once created they often are inflexible and difficult to adapt to new missions or expand with new components and thus hard to reuse. This document is the final report of MSG-127, a task group which brought together NATO scientists with expertise in human behaviour modelling and simulation, and human factors. The group has leveraged previous NATO explorations related to HBM and Modelling and Simulation as a Service (MSaaS), along with the scientific literature across relevant areas to establish a set of recommendations for improving the fidelity, flexibility, and interoperability of HBMs. MSG-127 concludes that a Reference Architecture (RA) for HBM would be valuable to address the need for more modularity and improved opportunities for reuse and cost-effective deployment. A common framework solution benefits all stakeholders and should be developed using (open) extensible standards.

MODELLING PERSONNEL FLOWS AND IDENTIFYING POTENTIAL SOLUTIONS TO RECRUITING AND RETENTION CHALLENGES

STO-TR-SAS-128

This is the final report of the NATO SAS-128 Research Task Group (RTG). The RTG was conceived broadly to investigate mitigation strategies that address personnel shortages in military occupations or groups. The work was divided into two lines effort, the first being the development of a Reserve Force personnel model. The intended use of the model is to investigate how a country's Reserve Force can be used to augment the Regular Force in meeting operational requirements and offsetting personnel shortages. This model and the simulation software in which it was developed are available to other NATO countries. The second line of effort consisted of compiling an inventory of shortage cases and mitigation approaches experienced by the SAS-128 countries. The information collected includes the underlying causes of the shortage and diagnostic analyses that identified those causes. The template for the shortage cases in the inventory was designed to allow others to benefit from the experiences of the SAS-128 countries with respect to selecting and designing mitigation strategies for ongoing or emerging personnel shortage situations.

PRINTED STANDARDS FOR STANDOFF DETECTION

STO-TR-SET-237

The NATO SET-237 established a collaborative Program Work that included two iterations of round-robin benchmark exercises followed by a field trial event held at ENEA Italy to validate the recommended methodologies for test standards. Over the past three years, the Task Group (TG) has been engaged in printing nearly 800 contaminated coupons and exchanging samples to determine metrics of importance, such as crystalline phase of materials, surface coverage, particle size distribution characteristics and mass loading. The goal of the benchmarks was to determine accuracy, precision, and mass transportation efficiency of samples produced by the three deposition (printing) systems. Over the course of the work a set of common Standard Operating Procedures (SOP) for each printing technology were established as well as an imaging methodology for calculating particle statistics. This Task Group brought together international expertise in inkjet deposition to develop common practices between nations, share information, and advance deposition methodologies to produce test standards for a variety of optical technologies.

FEDERATED AUTONOMY THROUGH COMMON COMMUNICATION

STO-TR-SCI-288

Leveraging in the participation of NATO scientists and engineers from multiple nations, Research Task Group SCI-288 successfully negotiated a protocol to enable autonomous collaboration of squads of vehicles under communication constraints. This solution allows multi-national operations to share tasking and information over a shared standard and is designed to do so without loss of existing autonomy capabilities. The approach defines five core messages: two for high-bandwidth a priori information sharing and three for execution under limited communications. It also uses a task model to define libraries of capabilities that are extensible to support integration of new capabilities and modular to separate tasks for deconfliction and security. The protocol was demonstrated in simulation and allowed systems from the Centre for Maritime Research and Experimentation (CMRE), the Netherlands, the United Kingdom, and the United States to receive tasking from a common command and control actor and share information to inform execution.

THE MILITARY IMPACTS OF COVID-19 ON THE ALLIANCE: CHALLENGES AND OPPORTUNITIES

STO-TR-SAS-169

The COVID-19 pandemic will have widespread and far-reaching impacts on NATO and its member nations. In response, the STO Specialist Team SAS-169 has analysed the impacts of the pandemic on military functions in the context of possible short-term (1–6 years) futures developed around the COVID-19 environment. The report provides national and NATO planners and decision makers with high-level recommendations to address these impacts. SAS-169 developed two analytical frameworks: a Futures Framework determining three possible futures within a baseline/worst/best case structure and a Military Impact Framework describing the impact of these futures across the complete spectrum of military functional areas such as personnel, intelligence, operations, logistics, planning, communications, training, finance and civil affairs. The report also makes available the detailed frameworks, references and data collected for future analysis.

REDUCING THE BURDEN ON THE DISMOUNTED SOLDIER

STO-TR-HFM-238

Throughout history, the dismounted soldier has been required to carry heavy loads. Soldiers often need to march long distances carrying loads over demanding terrain and in extreme environmental conditions. Once they arrive at the enemy's location, whilst soldiers can remove their packs and much of their sustainment load, they must still be fit to fight whilst wearing assault or fighting loads. Loads currently carried by NATO soldiers are at record highs and anecdotal evidence suggests that, on occasion and for some roles, current combat loads may be approaching the soldier's own body mass. NATO Human Factors and Medicine (HFM) Research Task Group (RTG) 238 "Reducing the Burden on the Dismounted Soldier" was established to develop an international consensus on the best approach to address the systemic problem of soldier burden. The specific objectives of this RTG were to: Define the burden; Identify factors known to influence the size and nature of the burden; Identify strategies to mitigate the threats in order to maintain operational effectiveness; and Identify an exploitable strategy for burden reduction. This report details the outcomes, findings and recommendations for strategies to mitigate soldier burden.

COMPENDIUM OF NATIONAL ACQUISITION PROCESSES OF GERMANY, TURKEY AND THE UNITED STATES WITH ADDITIONAL INFORMATION ON BELGIUM, FINLAND, GREECE AND SLOVENIA

STO-TR-SAS-125

Military acquisitions are one of the central elements for meeting the national security strategy goals. A military acquisition is a complex procurement process, which involves many activities such as project management, requirement management, risk management, contract management and many others. Failure in defence acquisition is costly and is defined simply: new equipment approved for development was never fielded, but instead was cancelled somewhere along the development process. For example, over the past 30 years, the USA has experienced about a 33% failure rate in its acquisition programs. Acquisition failure is an unacceptable resource drain on defence budgets among NATO Nations in an era when most nations are experiencing shrinking defence budgets. The objective of this work was to create a compendium to help nations improve their national defence Acquisition Processes (APs). The compendium summarizes the information on national APs of Germany, Turkey and the United States. The compendium provides information on the following areas: organization of the governments, defence acquisition parties, APs including budgeting, contracting, training, multinational acquisition, and defence industries. Furthermore, the report contains additional information on defence APs of the following nations: Belgium, Finland, Greece and Slovenia. The compendium is still in its early stages and must be updated on a regular basis since through time APs change. The results of this report can be used for the analysis and the comparison of national APs to identify solutions to specific challenges within nations' defence APs like budgeting, resource allocation, exceptions in legislation and policies, responsibility areas, joint defence projects, etc.

NATO Core Services profiling for Hybrid Tactical Networks

STO-TR-IST-150

Federated Mission Networking (FMN) is the main context and motivation for our work. IST-150 “NATO Core Services Profiling for Hybrid Tactical Networks” is intended to provide knowledge about services at the tactical level, and possibly feed into future spirals of FMN targeting the tactical level specifically. We target Service-Oriented Architecture (SOA) in the tactical domain, and specifically the Message-Oriented Middleware (MOM) Core Service. MOM covers two communication patterns: Publish/subscribe communication and request/response communication. In IST-150 we have experimented with both these patterns, evaluating industry standards in typical tactical network settings, using both military radio hardware and network emulators. Based on our findings, we recommend the industry standard Message Queueing Telemetry Transport (MQTT) for publish/subscribe, and we recommend using REST-based services replacing the HTTP/TCP transport with CoAP for request/response type services. The report covers these findings in detail, supporting these recommendations. Our work should be taken both as input to future FMN spirals as well as continuing IST research task groups where MOM services play a role.

INTEGRATION OF WOMEN INTO GROUND COMBAT UNITS

STO-TR-SAS-120

This report provides an interdisciplinary review and analysis of the social, cultural, and psychological factors that impact gender integration in military organizations with particular focus on the integration of women into ground combat units. The analysis builds upon evidence-based research related to integration such as that which considers cohesion, masculinity, critical mass, and sexual harassment. This knowledge is coupled with historical experience, lessons learned, strategies, and implementation plans that are rolling out across military organizations today. Drawing from culture change frameworks, the analysis highlights the importance of: engagement with all impacted members to contribute to change strategy; commitment to assessment and monitoring to expedite response through continuous feedback loops, as well as long-term monitoring and assessment to facilitate leadership response to values and beliefs expressed through social dynamics such as cultural narratives, and patterns of conduct; and, follow through to ensure that all members, and leaders in particular, have the opportunity and necessary resources to develop skills and competencies necessary to respond to change imperatives. Finally, the analysis suggests that integration strategy should not be limited to existing standards and security challenges but provide opportunities for emerging practices and social inclusions to contribute to operational effectiveness.

MOBILITY ASSESSMENT METHODS AND TOOLS FOR AUTONOMOUS MILITARY GROUND SYSTEMS

STO-TM-AVT-ET-194

This effort has delivered a document providing a concise summary of existing capabilities, planned future activities on the subject, and strategic direction for the follow-on Research Task Group (RTG). This summary report will detail those accomplishments and provide recommendations for the development and implementation of an autonomous navigation framework. The ET follow-on activity will be an RTG which will work on this cooperative research project through the 2020 – 2023 timeframe.

MODELLING AND SIMULATION GROUP 145: OPERATIONALIZATION OF STANDARDIZED C2-SIMULATION INTEROPERABILITY

STO-TR-MSG-145

The interoperation between Command and Control (C2) systems and simulation systems is a common theme in the transformation of modern military forces. This is required to support the military enterprise in the execution of business activities and mission threads such as forces readiness, decision support and acquisition. This implies the ability to seamlessly integrate C2 and simulation systems and to provide the means for a meaningful and unambiguous information exchange. This applies to systems of systems functioning toward a common goal at different levels: 1) Within services; 2) Across services; (i.e., joint) and 3) Across Nations in a multi-national or coalition context. In 2016, the NATO Research and Technology Organization started the three-year Modelling and Simulation Task Group "Operationalization of Standardized C2-Simulation Interoperability" to further the development of the C2 to Simulation interoperability standards developed by SISO with a view to recommending them for adoption by NATO as a STANAG. This final report documents the completed work of this Task Group, designated MSG-145. It includes the continued progress made to demonstrate the utility of C2-Simulation interoperability. This report draws on the knowledge of C2-Simulation experts to merge current standards towards a unified, more manageable and easier to deploy C2SIM interoperability suitable to be recommended for adoption as a NATO standard.

DESIGN AND ANALYSIS OF COMPRESSIVE SENSING TECHNIQUES FOR RADAR AND ESM APPLICATIONS

STO-TR-SET-236

Current military operations are facing new challenges, such as spectral congestion, intelligent jamming, and the need for multi function systems. While traditional approaches seems to be insufficient to effectively deal with these issues, Compressive Sensing (CS) is a relatively novel technique that provides a new framework under which such issues can be tackled. CS holds promise to enable reconstruction of sparse signals from a set of non-adaptive measurements sampled at a much lower rate than required by the Nyquist-Shannon sampling theorem by exploiting the fact that the information bandwidth of the signal is much smaller than the full signal bandwidth. The use of CS may lead to several benefits, including but not limited to significant hardware reductions in Electronic Support Measures (ESM) receivers; unambiguous signal recovery from incomplete measurements in interleaved radar modes and sparse arrays; high resolution imaging via MIMO radars or multi-pass with significantly less data and/or hardware. This reports describes the findings of the NATO Task Group SET-236, whose objectives were to 1) identify and assess the performance of CS based radar and ESM architectures, and 2) determine the operational benefits and potential challenges in the transition to operational CS based Radio Frequency (RF) systems.

THE TRANSITION OF MILITARY VETERANS FROM ACTIVE SERVICE TO CIVILIAN LIFE

STO-TR-HFM-263

In every nation within NATO, service members at some point leave the military. The military-to-civilian transition is the term used to refer to the process by which service members and/or their families rejoin their civilian community. Transition out of the military includes a series of adjustments. These include changes in location, career, relationships, family roles, support systems, social networks, community and culture. This transition has implications for post-service well-being and functioning. Despite this little has been done to conceptualize how transition occurs, identify factors that promote or impede transition, or operationalize outcomes associated with transition success. Many veterans transitioning from the military to the civilian life encounter unexpected challenges such as finding meaningful employment, adjusting to "civilian" culture or dealing with unresolved mental and physical health issues. In this report, we present the current practices and policies of military-to-civilian for those nations who participated in this RTG. In addition, we also present the findings of a survey of NATO nations conducted focusing on practices and policies of NATO and non-NATO nations. Nine key principles were identified that very nation, both NATO and non-NATO nations, should consider in supporting service members and families in re-joining their civilian community.

ACOUSTIC TRANSIENT THREAT DETECTION SENSORS AND SIGNAL PROCESSING FOR BATTLEFIELD SITUATIONAL AWARENESS

STO-TR-SET-233

SET-233 achieved significant improvements in acoustic transient event detection, localization, classification, propagation effects mitigation, and distributed sensor fusion through joint and collaborative research, field experimentation in diverse environments, data exchange and algorithm development

FUTURES ASSESSED ALONGSIDE SOCIO-TECHNICAL EVOLUTIONS (FATE)

STO-TR-SAS-123

The NATO SAS-123 was initiated in order to study both scenarios of the future and Socio-Technical Systems (STS) concurrently; develop and assess the criteria for their interactions; and determine how these interacting variables may cause disruptions within the defence and security sectors. The resultant of our research is the FATE method. This method evolved through an iterative process with a search of literature, exploration of various existing theories to assess how such interactions occur and evolve, presentation at academic fora and conducting trials in several defence settings. The literature search found little on the simultaneous interaction of the STS in concert with scenarios of the future even though the discipline of foresight studies these two variables independently. The prospective multilayer framework theory lay the foundation for FATE. The method provides a tool that enables a better understanding of synergistic impacts of socio technical systems that influence development, adoption, use and impacts of technologies, which in turn, would allow defence and security organisations to make more informed decisions about longer-term plans and strategies that will have to be, to the extent possible, future-proofed.

EVALUATION OF PREDICTION METHODS FOR SHIP PERFORMANCE IN HEAVY WEATHER

STO-TR-AVT-280

AVT-280 Task Group "Evaluation of Prediction Methods for Ship Performance in Heavy Weather," assesses experimental and prediction capability for course keeping including heavy weather, added power and speed loss. The assessment of deterministic and stochastic validation methods of a naval destroyer in extreme weather conditions was based on free-running potential flow and CFD including comparison to experiments. The objectives were achieved: potential flow validation in deterministically; and CFD stochastic validation for heavy weather, identification of extreme and rare events, and deterministic reconstruction as a proof of concept. Assessment of experimental and CFD capability for KCS added power in head and oblique waves was conducted based on experiments from three facilities using three different model sizes and CFD from five facilities using commercial and research CFD codes and one potential flow code. Self-propulsion and added power course keeping are reasonably well understood, including scaling laws for model size and waves. Course keeping in waves computational studies was performed by three teams with two different CFD and one potential flow code. Compared to T2015, the present results show overall improvement. In consideration present, previous and concurrent studies for course keeping even in extreme conditions experiments and CFD show satisfactory capability.

ROTORCRAFT FLIGHT SIMULATION MODEL FIDELITY IMPROVEMENT AND ASSESSMENT (UU)

STO-TR-AVT-296-UU

Rotorcraft flight simulation models require high levels of fidelity to be suitable for use in support of life cycle practices, particularly vehicle and control design/development, system certification, and training qualification. More rigorous and systematic practices for fidelity assessments and enhancements could pay significant dividends in reducing life cycle costs for both military and civil rotorcraft. The AVT-296 Research Task Group has examined a range of rotorcraft simulation fidelity improvement methods and assessment metrics. Seven different model update methods, from simple to more complex, for improving the fidelity of a flight simulation model have been presented using eight comprehensive flight test databases made available through this working group. Fidelity assessment metrics in the time- and frequency-domains are considered, including those in current use by simulator qualification authorities (Qualification Test Guide, QTG) and others widely used in the research community for specific applications such as vehicle design improvement, development of handling-qualities requirements, and flight control design/evaluation. The benefits and limitations of the various methods/metrics for different engineering applications have been reported and recommendations made for future activities. The methods and metrics presented herein will find use in military and civilian applications to set criteria that will underpin the use of modelling and simulation in certification to accelerate development and acquisition and reduce the cost of new rotorcraft systems and legacy system upgrades. The criteria may also set standards for training devices to support the expansion of synthetic environments for training to offset the high costs of flying hours.

CAPABILITY CONCEPT DEMONSTRATOR FOR INTEROPERABILITY WITHIN UNMANNED GROUND SYSTEMS AND C2

STO-TR-IST-149

This report describes the research and experiment efforts of the NATO STO group IST-149-RTG Capability Concept Demonstrator for Interoperability within Unmanned Ground Systems and C2. Unmanned Ground Vehicles (UGVs) are becoming increasingly relevant in the modern battle-space. The main purpose of the group was to investigate possible standards for controlling UGVs from Operator Control Units (OCUs) and receiving data back, and tests them in a real world scenario. The efforts in the project have been two folded. The Belgium contribution is work done in the EU project ICARUS. The second effort was a combined effort in the group to have an experiment demonstrating interoperability between the UGVs and OCUs available within the group. Both efforts used the Joint Architecture for Unmanned Systems (JAUS) with the Interoperability Profile (IOP) to successfully enable interoperability between the systems. The trials showed that it is possible to extend the systems quite easily and achieve compliance with parts of the standard in a relatively short time. Both Fraunhofer FKIE and TARDEC had developed software to pass information from the IOP domain to the Robotic Operating System (ROS). As this was a successful trial, the next step would be to test interoperability using higher level functions.

EXPLOITATION METHODOLOGIES FOR LONGWAVE INFRARED AIRBORNE HYPERSPECTRAL DATA

STO-TR-SET-240

SET-240 RTG achieved significant advances at understanding the variability of reflective and longwave infrared hyperspectral signatures by focusing its attention on: 1) The measurement of the optical properties of materials; 2) The sensor specifications and its calibration; 3) The environmental conditions including atmospheric compensation; 4) The observation geometry including the effects of polarization; 5) The indirect illumination generated by surrounding structures. Application to target detectio/identification and change detection questions are reported. Recent advances in revisiting target/anomaly detection algorithms using deep learning strategies are opening totally new ways of exploiting hyperspectral data. Application to IED/UXO detection is reported.

FLIGHT TEST TECHNIQUES FOR THE ASSESSMENT OF FIXED-WING AIRCRAFT HANDLING QUALITIES

STO-AG-300-V33

This AGARDograph gives a guideline for flight testing of Handling Qualities for fixed wing aircraft. After a more theoretical part on what are Handling Qualities and how they can be evaluated, a detailed catalogue of dedicated flight test techniques is given. At the end various examples illustrate how Handling Qualities can be flight tested.

LONG-TERM SCIENTIFIC STUDY ON CBRN DEFENCE

STO-TR-HFM-273

The report STO-TR-HFM-273 with its supplement STO-TR-HFM-273(S) presents the NATOSTO HFM-273 study group's assessment of the challenges and opportunities for CBRN defence through 2030. Rapid advances in Science and Technology (S&T) combined with a deteriorating security environment will likely broaden the CBRN hazard and threat spectrum. However, advances in S&T may also address existing and future CBRN challenges. CBRN defence capabilities should be developed and evaluated as integrated parts of the overall defence system. Advances in data science, Artificial Intelligence(AI) and communication and information systems will improve CBRN knowledge management. An evolving threat from new chemical and synthetic biological agents will require new developments in detection and identification as well as in hazard management. Individual protective equipment will continue to improve with new barrier materials and greater system modularity. Hazard management will need new and improved decontamination systems and a better understanding of the most relevant exposure factors. Significant gaps in medical countermeasures are evident and should be addressed in research and development programmes. Modelling and simulation, AI and digitalization will offer new approaches for education and training of all actors within the CBRN defence system. An increased focus is needed on preventing CBRN incidents, including efforts in arms control, disarmament and non-proliferation.

COOPERATIVE NAVIGATION IN GNSS DEGRADED/DENIED ENVIRONMENTS

STO-TR-SET-229

The NATO Science and Technology Organization (STO) Research Task Group (SET-229) on "Cooperative Navigation in GNSS Degraded/Denied Environments" was formed to focus on how to enhance NATO military effectiveness through the improved use of advanced, cooperative/collaborative Position, Navigation, and Time (PNT) technologies and techniques. NATO and Partners for Peace experts from government, academia, industry, and the military designed, developed and demonstrated Cooperative Navigation technologies and techniques to demonstrate PNT operations and PNT Situational Awareness (SA) in GNSS Degraded / Denied environments. The group demonstrated advanced Complementary PNT technologies and techniques allowing precision indoor/outdoor mapping, precision navigation, and personnel tracking (friend and foe) in hostile GNSS environments that might be present in a Search and Rescue (S&R) operation in a hostile territory. This report summarizes the work of the RTG, includes a description of the products generated by the group, and provides an overview of new and emerging navigation sensor and system technologies that will impact future NATO military operations worldwide.

PLASMA BASED FLOW CONTROL FOR PERFORMANCE AND CONTROL OF MILITARY VEHICLES

STO-TR-AVT-190

AVT-190 focused on understanding the capability for plasma flow control using dielectric barrier discharge, laser and microwave discharge. A series of benchmark experiments were established combining previously published data and new experiments conducted during the course of the AVT-190 activity. The experimental diagnostics provide detailed analysis of the dynamic effects of plasma actuation on the flowfield structure. Experimental configurations varied from plasma generation in quiescent air using dielectric barrier discharge to the interaction of a laser or microwave discharge with hemisphere-cylinder at supersonic speeds. Computational fluid dynamic simulations were performed for each experiment to assess the accuracy of the modeling and to analyze the details of the flowfield structure. Experiments were also performed to assess the effect of different dielectric materials on the effectiveness of dielectric barrier discharge devices.

ANALYSIS OF IDENTIFICATION AND NEUTRALIZATION METHODS AND TECHNOLOGIES FOR COUNTERING IMPROVISED EXPLOSIVE DEVICES (C-IED)

STO-TR-SCI-298

The SCI-289 Research Task Group (RTG) was established in 2017 to analyze the performance and efficacy of technologies for IED Identification (ID) and Neutralization. To accomplish this analysis, SCI-298 group members created an inventory of all conceivable technologies and methods for the identification and neutralization of IEDs, defined of a representative set of threat items, and created a description of relevant scenarios. The members then assessed of the suitability and current and future performance of these technologies and methods for the defined threats and scenarios. SCI-298 group members used the results from their analysis, in conjunction with their technical expertise and operational experiences, in order to characterize technology performance, discern trends, and identify areas for future research and investment.

DEVELOPMENTAL RESEARCH TO CREATE AN ASSESSMENT FRAMEWORK FOR SCIENCE AND TECHNOLOGY USED IN INTERNET EXPLOITATION DEVELOPMENT

STO-TR-SAS-142

In 2018 a Specialists Team under the Systems Analysis and Studies (SAS) Panel was established on “Development of an Internet Exploitation Grading System” (SAS-142). The scientific objective of this Specialist Team was: “To develop a comprehensive, robust and easily applicable grading system for the functionality of tools and applications, designed for use in exploiting the internet”. Not only a theoretical methodology was developed, but also a demonstrator was built that implemented this methodology: FIESTA (Framework for Internet Exploitation Science & Technology Assessment). Therefore, it was possible to test the practical use of the methodology as well.

OPERATIONS RESEARCH AND ANALYSIS (OR&A) MODEL SHARING GUIDANCE TO THE ALLIANCE

STO-TR-SAS-155

The objective of this NATO STO Specialist Team (ST) has been to produce updated model sharing guidance for Analysis from earlier material developed by The Technical Cooperation Program (TTCP) Joint Systems and Analysis (JSA), for publication and dissemination through the NATOSTO Collaboration Support Office. To achieve this the team has conducted a review of the unpublished draft of the earlier advice, incorporating recommendations made by NATO STO Specialist Team SAS-115 titled SMART Cooperation on Operation Analysis Simulation Models. The contemporary relevance and completeness of this advice has been tested and validated through a Workshop, primarily involving representatives of the supply chain, at the 2019 International Symposium for Military Operational Research (ISMOR). The specific purpose of this work has been the dissemination of the revised and updated guidelines within national and NATO OR&A capabilities and their supply chains.

GUIDELINES FOR MODELLING AND SIMULATION (M&S) USE RISK IDENTIFICATION, ANALYSIS, AND MITIGATION

STO-TR-MSG-139

M&S use risk is recognized as a critical component to M&S assessment and use. Despite the consensus in the M&S community on the importance of this topic, there are no accepted methods available for qualification or quantification of M&S use risk that account for project-specific M&S requirements and constraints. The primary objective of NATO Modelling and Simulation Group (NMSG) 139 was the assessment of methodologies that would support Modelling and Simulation (M&S) use risk identification, management, and mitigation. Effective management of risk requires both identification of the risk and a means by which to balance investments to mitigate them. Such an evaluation is made based on an assessment of the likelihood of the realization of the risk and the impact of that realization. When the risks are identified and assessed, mitigation strategies can be developed. The M&S Use Risk Methodology (MURM) was identified early on as a framework that addressed the identification, management, and mitigation of risk. This document reports the results of MSG-139 efforts with a specific focus on the formalization and application of the MURM.

GAS TURBINE ENGINE ENVIRONMENTAL PARTICULATE FOREIGN OBJECT DAMAGE [EP-FOD]

STO-TR-AVT-250

NATO militaries must operate and perform in environments deemed harsh – often due to the presence of Environmental Particulates (EPs: aerosols, sand/dust, sea spray, and volcanic ash). EP ingestion can degrade propulsion system performance, life, and increase ownership cost. Past guidance for EP exposure was to avoid the particulate. Advances in tools and models to assess what our systems can tolerate will assist flight authorizers, mission planners, mission executors, and fleet maintainers to make informed, risk-based decisions when EP encounters are anticipated. This report has three main thrusts: Thrust 1 compiles critical reference material of the different EP types found in regions of interest to NATO nations and their interaction with prevailing/projected meteorological conditions; Thrust 2 analyzes real world encounters and EP exposure levels, utilizing modeling and simulation and testing capabilities, to couple particulate type and dosage to effects and impacts on aircraft components, systems, extending to entire platforms and fleets; Thrust 3 begins with the likelihood of EP encounter for given missions, projected EP doses, and the understanding of the effects on aircrew and aircraft systems to assess impact to operations. Technology roadmaps are provided along with a series of supplemental annexes for additional elaboration and useful technical information.

AVT-292-CDT Cooperative Demonstration of Technology on Munition Health Management Final Report

STO-TR-AVT-292

This document is based upon Munitions Technology and supporting assessments on current andfuture health conditions. This is termed 'Munition Health Management'. The report addresses the application of sensors and IoT technologies to missiles and the resulting benefits on operational capability, interoperability, and life-cycle cost. This report describes the background, structure and relevance to NATO. The document also provides information on the preparation, delivery and feedback of the second Cooperative Demonstration of Technologies (CDT) that was held at NATO HQ, 7 – 11 October 2019. Topics covered include: Life-Cycle Cost of missile systems ;Safety requirements; In-Service Surveillance and Life Extension of missiles; Differences between guaranteed and actual service life; Missile systems and rocket motor technology; Sensor technology; Platform technology; Networking/Communication; Modeling; Data handling; Life assessment methodologies.

MODELLING AND SIMULATION TECHNOLOGIES FOR TRAINING MEDICAL/HEALTHCARE PROFESSIONALS

STO-TR-HFM-257

This NATO effort focused on identifying ways to use modelling and simulation technologies to prepare and train military medical professionals for operational and peacekeeping deployments. These tools should help healthcare providers recognize and deal with combat casualty care issues, perform under highly stressful conditions, and function effectively as a member of a medical team. Modelling and Simulation tools are important across the spectrum of military medicine, from forward care through evacuation to definitive care at fixed facilities. Validation studies need to be conducted on currently available modelling and simulation technologies, and metrics for accurate assessment of learning/skill improvement need to be established. Given the international scope of modelling and simulation industries, NATO is strategically placed to leverage national expertise and devise innovative strategies to best utilize current and future technologies in these areas. These strategies will be important to meet the ever-increasing demands of combat medicine and peacekeeping missions, especially in Joint/Multi Domain Environments.

CORRELATED DYNAMIC SYNTHETIC ENVIRONMENTS FOR DISTRIBUTED SIMULATION

STO-TR-MSG-156

In contrast to real world environments, synthetic environments used in distributed military simulations are often static and unable to represent changes in a consistent way, e.g., changes due to deteriorating weather conditions or combat engineering during scenario execution. To better train and prepare military personnel for dynamic real-world conditions, the synthetic environment needs to support such dynamic modifications in a standardized and interoperable way to provide a consistent representation across dissimilar simulation systems. The objective of MSG-156 is to define best practices, required methodologies and technologies and requirements for standards needed to achieve a correlated dynamic SE in future distributed simulation exercises

INFORMATION FILTERING AND MULTI-SOURCE INFORMATION FUSION

STO-TR-IST-132

The complexity of operations covering large geographical areas over extended time periods with reliance on heterogeneous sensors and human sources is an on-going research challenge. Fusion and modelling approaches and methodologies which work well for lower-level data are not necessarily sufficient when the scope of the problem expands to weeks, months or years. Whereas a tracking algorithm fuses individual data points to deliver a single track, a long-term intelligence operation may require that each track becomes a single data point in a more complex process. Context may change (regime shifts due to elections, legal context modified by lawmakers, etc.) and HUMINT or OSINT information may prove to be inaccurate or invalid due to any of a variety of reasons, requiring a mechanism to identify and remove such information. We examined challenges facing the synergic information processing as scenario complexity grows with the changing data and information incorporating structured and unstructured human generated information with device-generated data needs for fusion in increasingly complexity, we have tried to identify the important elements which need to be taken into consideration to build a fusion system which is robust enough to deal with a changing and dynamic situation, and make recommendations on those.

CYBER SECURITY RISK ASSESSMENT PROCESS FOR MILITARY SYSTEMS

STO-TR-IST-151

Military platforms are more computerized, networked and processor-driven than ever. The consequence is an increased exposure to cyber attacks and thus, an amplified risk. However, the continuous and stable operation of these platforms is critical to the success of military missions and public safety. Military systems and platforms are targets of choice for cyber attacks not because of their prevalence, like consumer electronics, but because of their potential strategic impact. Once compromised, all sorts of short-term and long-term effects can be achieved, ranging from denying a capability to covertly reducing its effectiveness or efficiency, on demand. Therefore, military forces must address cyber security at all levels: strategic, while acquiring platforms and systems, operational, while planning military missions and tactical, while in operations. Perfect cyber security does not exist. Cyber security must be continuously managed through iterative risk assessments. Many cyber security risk management frameworks and processes exist for traditional IT systems. However, this is far from being the case when it comes to military systems. This document presents a cyber security risk assessment process tailored to military systems. The process can be applied to both traditional IT and firmware-based embedded systems, which are everywhere in military platforms and systems.

FINDINGS OF THE AVT-255: UNMANNED SYSTEMS MISSION PERFORMANCE POTENTIAL FOR AUTONOMOUS OPERATIONS

STO-TM-AVT-255

The AVT-175 workgroup explored procedures for the assessment of unmanned system mission performance as a function of platform autonomy for unmanned land, sea, and air vehicles. They discovered that current methodologies were insufficient in defining an Unmanned Systems (UMS) mission performance or autonomy level. The AVT-175 developed a new performance assessment tool that predicts platform performance for a given mission at a given autonomy level. This assessment tool is called the Mission Performance Potential (MPP) and is described in this report. The AVT-255 workgroup sought to further validate the MPP tool by executing validation experiments and updating the MPP software. Unfortunately, the AVT-255 was not able to achieve this goal because 1) Many key members dropped out early in the effort; and 2) The AVT-255 research did not yield significant results. Indeed, assessments of UMS have changed greatly over the last five years, making the core MPP product less valuable to the military UMS community than it was in 2016. To that end, this memo provides the history and timeline leading up to the AVT-255, the limited results of the workgroup, and recommendations for future work in the area of autonomy testing, evaluation, and assessment

AEROACOUSTICS OF ENGINE INSTALLATION ON MILITARY AIR VEHICLES

STO-TR-AVT-233

In the AVT-233 Task Group a comprehensive research program was executed to identify and validate appropriate acoustic prediction methods as a basis for low noise military aircraft design with a focus on acoustic shielding of engine noise. A set of related aeroacoustic shielding tests was carried out in four different wind tunnels for three different geometries of ever-increasing complexity to establish a fundamental aeroacoustic shielding database for the validation of acoustic prediction codes of partners. Generic 2D diffraction (NACA0012), diffraction at a convex, sharp-edged (SACCON) and a generally convex-concave shaped, sharp- and round edged (HWB)configuration were all measured successfully. For this purpose, two aeroacoustic pulse test sources were developed successfully. A cross validation of the measurements over three wind tunnels showed excellent reproducibility of test results, even better than expected. The various simulation approaches were validated against measured data. The overall outcome showed that for the majority of problems the use of some fast low- to mid-fidelity prediction approaches to the aircraft shielding problem is justified. Validated tools have been established with which to take the next logical step toward full simulation based low noise design modifications of realistic NATO military air vehicles.

LOW, SLOW, SMALL THREATS MODELLING AND SIMULATION

STO-TR-MSG-154

The proliferation of Low, Slow, and Small (LSS) flying platforms brings with it a new and rapidly increasing threat to national defence and security agencies. Thus, defence systems must be designed to face such threats. Modern operational readiness is based on proper personnel training that is performed on high fidelity simulators. The aim of MSG-154 is to take into account the variety of commercially available LSS aerial vehicles and to define LSS models from different points of view so that models may be made available for those analysis and design aspects that relate to Counter LSS systems (both detection and neutralization,) and to operational training. The ability to cross correlate friendly nation LSS capabilities among member nations and to extend LSS to existing categorizations is considered to be both useful and beneficial.

GUIDELINES FOR MITIGATING CYBERSICKNESS IN VIRTUAL REALITY SYSTEMS

STO-TR-HFM-MSG-323

The NATO HFM-MSG-323 Specialist Team (ST) addressed the best practice and design techniques and procedures that may reduce the incidence and severity of cybersickness by giving scientifically-founded information on how to mitigate cybersickness, with a focus on immersive virtual environments and virtual reality (VR) goggles as they are used in a defence setting. This has been achieved by making reference to the literature on the topic, explaining the different findings related to cybersickness and the technology which elicits cybersickness, addressing cybersickness in terms of symptoms and how they can be measured, giving an overview of all the individual, technological, and operational factors known to affect cybersickness, and providing an overview of scientifically proven countermeasures (and some noted as conjectural), from design, behavioural, and neurophysiological points of view.

AUGMENTED REALITY FOR IMPROVED SITUATIONAL AWARENESS AND SURVIVABILITY OF COMBAT VEHICLES

STO-TR-AVT-290

This report addresses the standardization of Augmented Reality for improved situational awareness and survivability of combat vehicles. The report assesses requirements for AR from a operational, functional, technical and human interaction perspective. Human Factor considerations are core to ensuring that the AR based solutions can provide enhanced situational awareness, however as part of the study other aspects such as wider benefits, limitations, costs and technology maturity and performance have been considered. The requirement to fully integrate AR solutions as part of the platform systems is addressed with a specific focus on the exploitation of NATO Generic Vehicle Architecture (NGVA). Use cases are defined which provide the context and requirements for AR enabled information displays to different crew members at different phases of representative missions. An overview of standards and guidelines how AR should be presented and how interaction should be enabled is covered. The report gives an overview of conducted experiments, explorations and interviews considering AR for Situational Awareness. An outlook and roadmap of AR is proposed and the report concludes with exploitation and recommendations.

TECHNOLOGY ROADMAPS TOWARDS STAND-OFF DETECTION IN FUTURE ROUTE CLEARANCE

STO-TR-SCI-286

The SCI-286 Task Group considered options to increase the detection stand-off distance in mounted route clearance in two ways: by enhancing the detection technologies itself or by deploying the detection equipment remotely on an unmanned ground or aerial platform. Technology roadmaps were developed for the five technologies identified as the most optimal combination of detection sensors for route clearance by the previous SCI-233 Task Group. Roadmaps of future detection technology developments should also take into account the Systems of Systems Engineering (SoSE) approach that will be required to integrate multiple detection technologies onto the platforms in the Route Clearance Package configurations. A number of SoSE activities are described, such as requirements analysis and performance prediction. Important aspects related with the realization of detection System-of-Systems modules have been identified, such as the fusion of data from the different detection sensors, and all related system integration issues. In order to assess the improvements in future route clearance operations, several possible assessment methods were considered. A set of Measures of Performance (MoPs) and Measures of Effectiveness (MoEs) is defined and are used to compare improvements of a number of notional future route clearance package configurations with two currently operational route clearance systems as a reference.

MODEL-BASED ATR (AIDED/AUTOMATIC TARGET RECOGNITION) FOR SAR (SYNTHETIC APERTURE RADAR) IMAGING

STO-TR-SET-215

The development of a robust target recognition capability relies on having many example images of the targets of interest. For SAR imaging, it is not feasible to gather a sufficient number of real images given the variability of target appearance with imaging geometry and target articulation amongst other factors. SET-215 has studied the potential use of simulated SAR images for Assisted Target Recognition (ATR) by sharing data, models, simulations and methods. Comparison of actual SAR/ISAR measurements with their simulated counterpart were performed for the ATR utility. Modern methods based on recent findings by (deep) Convolutional Neural Networks (CNN) were introduced. Since these techniques often require larger databases, this creates new challenges and horizons for model-based ATR

HEALTH RISK ASSESSMENT FOR CHEMICAL EXPOSURES OF MILITARY INTEREST

STO-TR-HFM-262

Occupational and environmental exposure to toxic materials is inevitably related to military activities. The civilian, traditional approach for risk assessment of exposure to toxic materials does not include the dimensions that can apply during military operational situations. Therefore, a dedicated approach for the risk assessment is needed which takes into account the specific conditions relevant for the assessment of the exposure to chemicals of concern for military personnel. Currently, no well-established approach is available for an operational risk assessment due to the complexity of relating the source of the emission to a personal exposure level and translating these levels into potential health effects including those resulting from exposure to urban pollution. HFM-262 addressed the issue of health hazards resulting from exposure to chemicals in order to enable risk management, with special attention to operational risk assessment and short- and long-term health effects. The effort was aimed at: 1) Exploration of procedures to identify toxic materials from natural and anthropogenic sources relevant to operational conditions during deployment; and evaluation of: 2) Currently available and emerging technologies for sampling, identification and monitoring of the military operational environment for relevant toxicants; 3) Currently available and emerging methods/strategies for monitoring and sampling to quantify the dose to which personnel have been exposed; 4) Approaches to predict short- and long-term adverse health effects resulting from exposures during deployment; 5) Approaches to identify and validate early indicators of health effects (e.g., biomarkers); and 6) Identification of gaps in existing exposure guidelines with relevance for military deployment in urban settings. The outcome of HFM-262 contributes to enhancement of combat readiness and effectiveness, to an increase of the probability of mission success, as well as to a decrease of the risk of post-deployment illness and disability from exposures during deployment. In this Final Report the current research gaps identified for the various aspects mentioned above are presented. Also, recommendations are being made to fill these gaps. HFM-262 had liaisons with the COMEDS Force Health Protection Working Group, as well as with STO groups, not only within the HFM Panel, but also within the AVT and SCI Panels, i.e., HFM-253, SCI-273, AVT-277, and AVT-322. Activities of these groups were complementary to those of HFM-262, as these groups addressed other chemicals, i.e., smokes, obscurants and pyrotechnics; chemical warfare agents, and munition-related compounds, respectively.

BIOTECHNOLOGY, HUMAN ENHANCEMENT AND HUMAN AUGMENTATION: A WAY AHEAD FOR RESEARCH AND POLICY

STO-TR-HFM-ST-335-A

The NATO Human Factors & Medicine (HFM) Research Specialist Team (RST) 335 was convened to generate a high level, comprehensive overview of biotechnologies that may be used for improving human physical, cognitive, physiological, sensory, or social functions for defence applications. Biotechnologies and Human Enhancement/Augmentation (BHEA) are one of the eight Emerging and Disruptive Technologies (EDT) approved by the NATO Science & Technology Board. The RST used a five-pillar approach: 1) Warfighter systems; 2) Warfighter performance; 3) Force protection; 4) Military medicine; and 5) Security and compliance to identify areas of relevance to operators. While the first 4 pillars are capabilities, the security and compliance pillar extends across all of biotechnology and the other 4 pillars. BHEA is not only a key EDT, it is as such, of interest to the wider international S&T, and operational communities. The present document builds on the main high-level report of the RST to provide a focused understanding of the regulatory challenges around BHEA; highlighting the opportunities to create international coherence in the development of an appropriate governing framework. Keeping the Alliance, militaries, paramilitary security forces in mind, it elaborates a way head for research and policy for addressing the security and compliance challenges surrounding the deployment of biotechnologies in pursuit of human enhancement. It is intended for use by the NATO bodies, including but not limited to the HFM Panel, to steer their respective programmes of work.

RANGE DESIGN AND MANAGEMENT FOR REDUCED ENVIRONMENTAL IMPACT

STO-TR-AVT-291

The ability to realistically train for combat in military live-fire training ranges is critical to NATO nations. The alliance structure of NATO's forces requires large-scale intensive training to replicate combat conditions. This increased size and tempo of live-fire training is environmentally stressful to the ranges utilized, and losing one of these assets could potentially weaken the readiness of our military forces. If not managed properly, live-fire training can have considerable impacts on human health and the environment, which can jeopardize the existence of these ranges. Range contamination has led to water contamination, resulting in some cases in the loss of ranges, penalties, and significant clean-up costs. When designing new ranges, conducting range maintenance, or modernizing existing ranges, many factors must be considered, including safety and security, noise, contamination of soil and water, as well as human and environmental exposure to contaminants. The objective of this report is to share information and discuss current practices and research on the topics of military training range design and management to minimize environmental impacts. Implementing innovative monitoring, mitigation, and remediation technologies will lead to more sustainable ranges for all countries. By taking a technical approach to range design and maintenance, the increased size and tempo of NATO training in the Connected Forces Initiative can be safely implemented. This report presents range sustainability and management tools for a wide range of weapon systems.

5G TECHNOLOGIES: A DEFENSE PERSPECTIVE

STO-TR-IST-ET-096

This report provides an analysis of the relevance of next generation 5G technologies to defence scenarios. The 5G introduces disruptive concepts and innovative technologies. The 'IST-ET-096: Expeditionary 5G Technology' group's objective was to explore potential uses and dangers of the emergence of 5G technologies in NATO and NATO nations. The group consisted of one each member from Germany and the Netherlands, three members from Turkey and one member from the United States as the Lead Nation. The group conducted 15 meetings via teleconferences in 2017 and completed its final report by Q1 2018. The scenarios identified from an expeditionary perspective are: 1) Extreme coverage; 2) Satcom/high altitude platform integration; 3) Massive IoT; 4) Grant free non-orthogonal multiple access techniques (NOMA); 5) Massive MIMO techniques in mmW band for high data rate and low latency data; 6) Access network sharing using 5G on a multi-national military base; and, 7) MoD as an operator, to provide military network slices to different forces. The group recommends continuing 5G activities within one or more NATO RTGs. The identified areas within 5G, in their ranked order are: 1) Network Slicing; 2) Extreme long-range coverage in low-density areas; 3) Diverse mobility management for network offloading in edge scenarios; 4) Grant free NOMA techniques for MANET deployments; and 5) Massive MIMO techniques in mmWave band for high data rate and low latency data links.

www.sto.nato.int