NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

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STO TECHNICAL REPORT **TR-HFM-268**

Synthetic Environments for Mission Effectiveness

(Environnements synthétiques en vue de l'efficacité des missions)

This report documents the findings of NATO HFM-268 and describes the application of Synthetic Environments for Assessment (SEA) to understanding the capabilities of operators and warfighting systems during early warning command and control missions.

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The NATO Science and Technology Organization

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In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

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The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

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

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised 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 under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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List of Acronyms

2D/3D	2 Dimension / 3 Dimension
AFSC	Alliance Future Surveillance and Control
AOR	Area of Responsibility
AWACS	Airborne Warning and Control System
C2	Command and Control
CAS	Close Air Support
CAP	Combat Air Patrol
CRM	Crew Resource Management
CSAR	Combat Search and Rescue
DCA	Defensive Counter Air
DOTMLPF	Doctrine Organisation Training Materiel Leadership and education Personnel Facilities
ECM	Electronic Counter Measure
ES	Electronic Support
ESM	Electronic Support Measures
EW	Electronic Warfare
FA	Fighter Allocator
HBM	Human Behaviour Model
HFM	Human Factors and Medicine
HSCB	Human, Social Cultural, Behavioral
ID	Identification
IFF	Identification Friend-or-Foe
INT	Interdiction
ISRT	Infrared Search and Track
JTAC	Joint Terminal Air Controller
LVC	Live, Virtual, and Constructive
MEZ	Military Exclusion Zone
MSG	Modelling and Simulation Group
NATO	North Atlantic Treaty Organization
NAV	Navigator
NGTS	Next Generation Threat System
OCA	Offensive Counter Air
OPLANS	Operational Plans
OPORDS	Operational Orders
Ops	Operations
PC	Passive Controller
PDU	Protocol Data Unit
PETS	Performance Evaluation and Tracking System

RF	Radio Frequency
RTG	Research Task Group
SA	Surface to Air
SAM	Surface to Air Missile
SC	Surveillance Controller
SEA	Synthetic Environments for Assessment
SMEs	Subject Matter Experts
SOs	Surveillance Operators
STs	System Technicians
SW	Spartan Warrior
TACON	Tactical Control
UAV	Unmanned Aerial Vehicle
USAFE	United States Air Force Europe
WCs	Weapons Controllers
WPC	Warrior Preparation Center
XINT	Airborne Alert Interdiction

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Synthetic Environments for Mission Effectiveness

(STO-TR-HFM-268)

Executive Summary

This report follows the steps outlined by the Research Task Group (RTG) HFM-216's technical report (TR-HFM-216) to apply the concept of a Synthetic Environments for Assessment (SEA) in conducting trade-off analyses and exploring very complex design spaces. The general goal of RTG HFM-268 Synthetic Environments for Mission Effectiveness was to build a realistic synthetic environment, accessible/reproducible by NATO members, that provides the means to design and evaluate new alternative military systems and assess their effectiveness in mission relevant scenarios. A critical component of this type of evaluation is the ability to measure and analyze the human-system performance and/or the effective interaction of the human as they utilize the system's hardware and software.

While scoping this RTG, NATO expressed interest in using SEA to explore alternative methods of providing airborne warning command and control. Specifically, assessing functions typically handled by NATO Airborne Warning and Control System (AWACS) that would be taken over by a new mixed asset process of air/ground based airborne warning command and control; called Alliance Future Surveillance and Control (AFSC). This is considered a complex design space since the mission impact of such a concept is not fully understood and the human performance impact of such a design is equally unknown. Thus, the targeted goal of this RTG was to support NATO by creating a synthetic environment capable of assessing current and future human/machine capabilities and limitations while conducting Surveillance and Control missions utilizing theoretical mission systems; thus taking the concept of SEA and applying it to a current NATO need.

Having the opportunity to collect data at the Warrior Preparation Center's (WPC) Spartan Warrior AWACS exercises, this RTG was able to demonstrate the potential benefits of SEA as a tool for capability development. All the key components of a SEA were installed at the WPC and the results demonstrated a workable way to gather realistic mission efficacy data that decision makers could use in the acquisition processes, specifically early design decisions. In the process of setting up the SEA, the RTG managed to initiate the development of a simulation environment (utilizing pre-populated Jane's model data) that is available to NATO members and industry (with proper coordination). With the combination of the accompanying performance measurement tool, the acquisition community (AFSC decision makers) can utilize this SEA to compare alternative designs through objective, realistic mission-based metrics.

Environnements synthétiques en vue de l'efficacité des missions

(STO-TR-HFM-268)

Synthèse

Le présent rapport suit les étapes décrites par le rapport technique du groupe de recherche (RTG) TR-HFM-216 pour appliquer le concept des environnements synthétiques d'évaluation (SEA) aux analyses du facteur de mérite et à l'exploration de domaines de conception très complexes. Le but général du RTG-268 « Environnements synthétiques en vue de l'efficacité des missions » était de construire un environnement synthétique réaliste, accessible/reproductible par les membres de l'OTAN, qui fournisse le moyen de concevoir et évaluer de nouveaux systèmes militaires alternatifs et d'évaluer leur efficacité dans des scénarios pertinents pour les missions. L'aptitude à mesurer et analyser le fonctionnement humain-système et/ou l'interaction réelle de l'humain pendant qu'il utilise le matériel et le logiciel du système est un élément capital de ce type d'évaluations.

Lorsqu'elle a établi la portée de ce RTG, l'OTAN a manifesté son intérêt à utiliser les SEA pour examiner d'autres méthodes de commandement et contrôle de la détection aéroportée. Il s'agissait en particulier d'évaluer des fonctions habituellement gérées par le système aéroporté de détection et de contrôle (AWACS) de l'OTAN, qui seraient transférées à un nouveau processus mixte de commandement et contrôle aéroporté/terrestre de la détection aéroportée, appelé « futur système de surveillance et de contrôle de l'Alliance » (AFSC). Ce domaine de conception est jugé complexe, parce que l'effet d'un tel concept sur les missions n'est pas entièrement compris et que l'effet d'une telle conception sur les performances humaines est également inconnu. L'objectif de ce RTG était donc d'aider l'OTAN par la création d'un environnement synthétique capable d'évaluer les capacités et limites humaines/mécaniques actuelles et futures tout en menant des missions de surveillance et de contrôle à l'aide de systèmes de mission théoriques, ce qui consistait à appliquer le concept de SEA à un besoin actuel de l'OTAN.

Ayant eu l'occasion de recueillir des données lors des exercices AWACS Spartan Warrior au Centre de-préparation de la force (WPC), le RTG-268 a pu démontrer les avantages potentiels du SEA en tant qu'outil de développement de la capacité. Tous les éléments clés d'un SEA étaient installés au WPC et les résultats ont démontré qu'il était possible de réunir des données réalistes d'efficacité d'une mission, données que les décideurs pourraient utiliser dans les processus d'acquisition, en particulier pour les décisions initiales de conception. Pendant la mise en place du SEA, le RTG a commencé à développer un environnement de simulation (à l'aide de données d'un modèle de Jane prérempli), qui est mis à la disposition des membres de l'OTAN et de l'industrie (avec une coordination appropriée). La communauté d'acquisition (décideurs de l'AFSC) peut utiliser ce SEA en association avec l'outil de mesure des performances qui est joint, pour comparer différentes conceptions au moyen d'indicateurs objectifs et réalistes basés sur les missions.

SYNTHETIC ENVIRONMENTS FOR MISSION EFFECTIVENESS

1.0 INTRODUCTION

Synthetic Environments for Assessment (SEA) was defined in the Research Task Group (RTG) HFM-216 technical report (TR-HFM-216) which also outlined several steps needed to utilize SEA across the NATO Research and Technology communities. The general goal of RTG-268 Synthetic Environments for Mission Effectiveness is to build a realistic synthetic environment, accessible/reproducible by NATO members, that provides the means to design and evaluate new alternative military systems and assess their effectiveness in mission relevant scenarios. A critical component of any evaluation is being able to measure and analyze the human-system performance and/or the effective interaction of the human as they utilize the system's hardware and software.

While exploring the development of this RTG, NATO expressed interest in using alternative methods of providing airborne warning command and control. Specifically, passing functions typically handled by NATO Airborne Warning and Control System (AWACS) to a new mixed asset process of air/ground based airborne warning command and control; called Alliance Future Surveillance and Control (AFSC). However, the mission impact of such a change is not fully understood and the human performance impact of such a change is unknown. Would a new AFSC concept with several geographically separated assets, communicating across a network, produce unintended time lapses and delays in human performance that could impact overall mission effectiveness? Answering this question was a perfect use case for the application of SEA.

Thus, the targeted goal of this RTG was to support NATO by creating a synthetic environment capable of assessing the human capabilities and limitations while conducting Surveillance and Control missions; thus, taking the concept of SEA and applying it to a current NATO need.

1.1 Organization of this Report

This report begins with a description of SEA concept and discuss its application for the surveillance and control use case. The report covers:

1) What components are needed for SEA.
2) Which components were selected for demonstrating the use case.
3) How performance parameters were selected.
4) How data was collected.
5) How the final SEA product could be used by NATO members.

This report concludes with a summary and recommendations for how the current SEA could be leveraged by AFSC for future studies and for NATO in general.

2.0 SYNTHETIC ENVIRONMENTS FOR ASSESSMENT

2.1 What Is SEA?

The working definition of SEA created by RTG HFM-216 is:

A modeling and simulation approach to assessing human-system performance and trade-offs in representative mission scenarios.

SEA is intended to radically expand our ability to assess new operational assets by providing a process to explore unconventional designs or system concepts. The increasing complexity of automation combined with the accelerated pace of technology applied to a hazardous and variable operational environment creates unprecedented levels of uncertainty, limiting our complete understanding of what our advanced systems will do and blinding designers to possible second and third order effects of innovative designs.

Current practice relies heavily on testing of physical prototypes; thus, advances tend to be incremental rather than evolutionary, and stuck in the mind-set of how we have fought the previous war. The SEA is a framework of exploration, not limited only to the proposed hardware and software of a new system, but the complete human-system and system-of-systems impact tested in mission relevant scenarios.

SEA is not a product, but an approach to drive new designs through simulation in valid warfighter scenarios to assess performance through objective metrics. Through calibrated scenarios and tools, competing design concepts can be compared during the early development phase, identifying capabilities and requirements that are objectively assessed for their impact on mission outcomes.

SEA focuses on reconfiguring interoperable, reusable models and simulations to create a comprehensive synthetic environment in which to test any hypothesis or evaluate any design feature. The reuse of data, software, models, metrics, and scenarios is encouraged to not only increase speed of follow-on analysis, but also to hold factors constant; providing repeatability and the ability to compare across different analyses.

2.2 Components of SEA

This application of SEA is focused on capability development, thus hypothesis testing and discovery. Engineering focused on the art of the possible can often lead to complex design spaces. In those instances, the ability to explore the design spaces quickly is needed in order to prune down the options to those that enhance mission capability. Thus, SEAs need to be rapidly reconfigurable.

The simulation needs to be realistic to known capabilities, environments, threats, and CONOPS, but not to the extent that it impedes modifications or creates undue security barriers to collaboration.

A SEA should ideally have the following capabilities:

1) Reconfigurable;
2) Realistic but shareable;
3) Networked;
4) Live, Virtual, and Constructive (LVC);

5) Automated with artificially intelligent behaviors; and

6) Capture performance measures.

The reconfigurable nature of SEA provides a cost-effective approach that focuses on a system that is flexible and reusable (Figure 1).

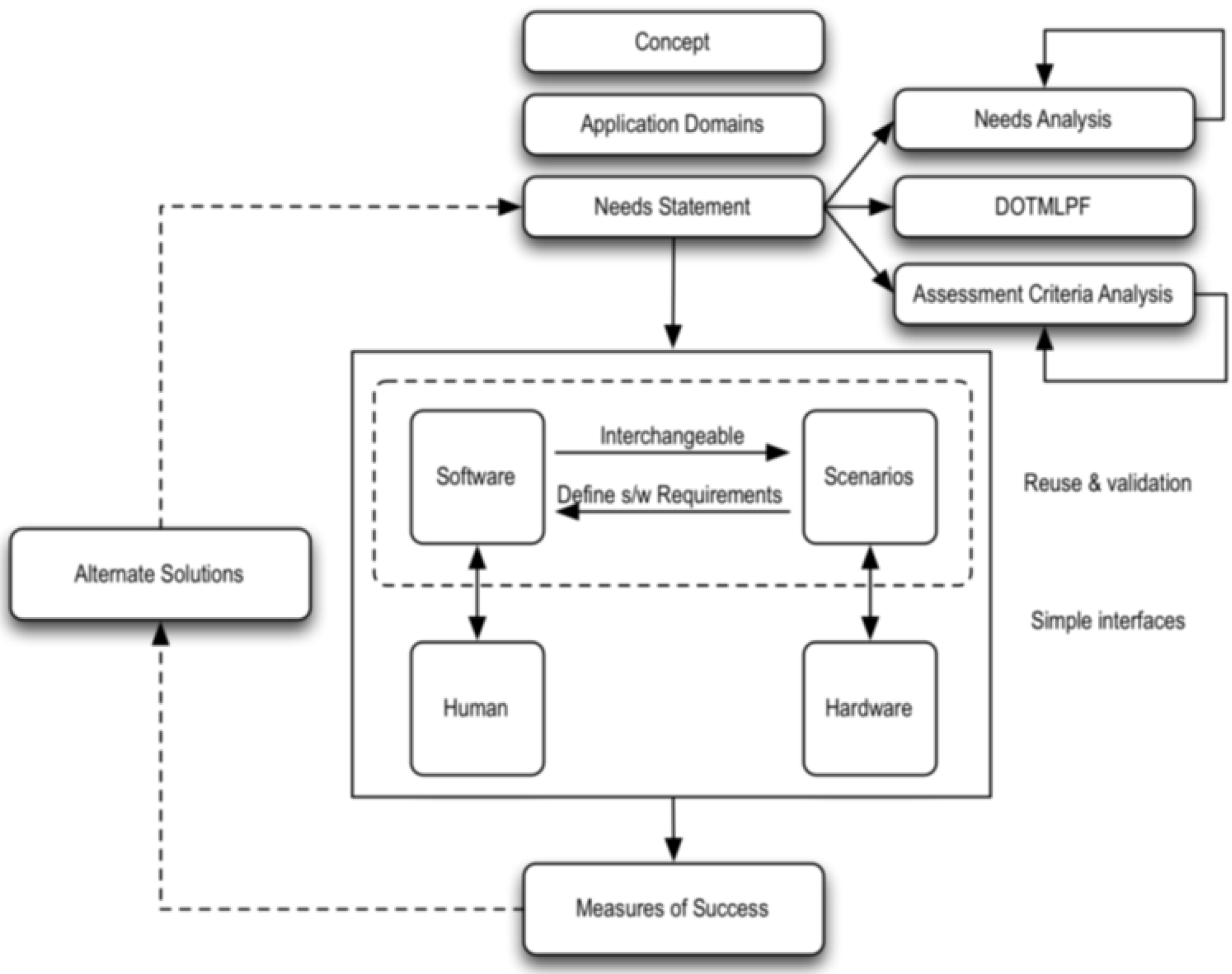

Figure 1: A Schematic Diagram of SEA.

The inner box of Figure 1 contains four key elements: software, scenarios, human, and hardware.

- *Software* represents the various configurations combined to address a specific question or set of questions. Software modules need to be flexible to address various mission scenarios. Figure 2 lists some of the types of software modules that SEA may contain. Software automated with artificially intelligent behaviors greatly improves the consistency when running scenarios and may reduce the need for Subject Matter Experts (SMEs) to play various roles in a scenario.

- *Scenarios* represent the realistic mission parameters that stress the critical elements, resulting in objective data for key design criteria or requirements decisions. Not all aspects of the scenario must be realistic, only those relevant to the question at hand. For example, if mobility of a ground vehicle is a critical criteria, the fidelity of the environment (topography and vegetation) would be important, where this would not be important for an air vehicle analysis (where weather may be a more important element). Figure 2 lists some of the variables that a SEA scenario might specify. Realism sometimes has the drawback of creating security issues, so there is always a trade-off with the level of realism and who can access the SEA or its resultant data.

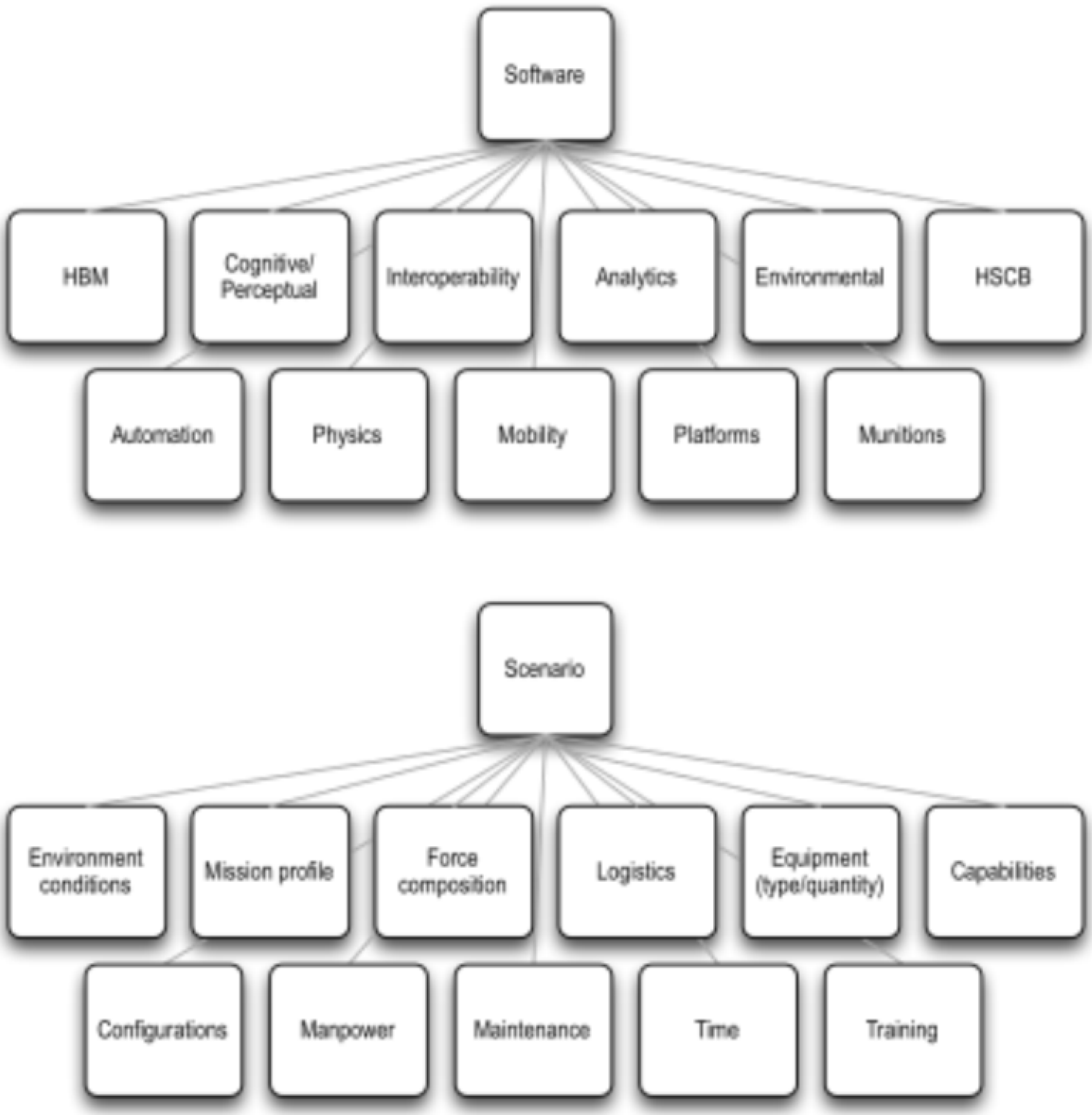

Figure 2: Elements of Software and Scenario.

Although SEA could be used in a fully synthetic way, using Monte-Carlo simulations to tease out system performance, it is really intended to incorporate human action as part of the overall system.

- *Human* represents individuals or teams of people interacting with the system. Their response times, decisions, and situational awareness of their environment is important to realistic mission-based assessments. Extensive networked kill-chains that rely on time critical decision making and reactions have an enormous impact on mission effectiveness estimates. Introducing and seeing the impact of the "fog of war" provides key data points.
- *Hardware* represents everything from actual systems to mock-ups that can sufficiently replicate the actual or proposed systems. Live, Virtual, and Constructive (LVC) components, networked together (although not all required) will provide extensive flexibility and greatly improve the mission realism capability of the SEA.

The "Measures of Success" provide the data points that helps the decision maker understand the trade space around the different design parameters, thus informing the systems requirement and actual capabilities for successful missions.

2.3 SEA for Capability Development

Simulated environments continue to improve. High fidelity models and simulations that used to take days to calculate can now be done in real time. Simulated scenarios are able to represent an unprecedented level of mission realism, and with that, the ability to assess mission success. Using simulation to focus on incremental improvements is not a new concept but having measures of effectiveness at a mission level has typically been too expensive or too complex for practical use.

Ideally, a validated SEA could be used by governments and industry partners to assess proposed prototypes. When simulated components and operational scenarios represent the real system and theatre, comparisons can be made, and proposed systems can be evaluated on critical requirements to improve the mission outcomes the customer is looking for. This is a much more cost-effective approach than developing multiple hardware prototypes for a competitive comparison. Alternatively, at a minimum, such SEA approach can be used during preceding prototype development as a cost effective and rapid way of narrowing down the key features and capabilities that will make up an expensive prototype.

As an example, if there are two display designs A and B, it is typical for a researcher to obtain a suitable user group and test their performance in the given scenario. One of the designs will emerge as the better of the two. There will be a price tag associated with the change, so a decision needs to be made as to whether or not the improvement is worth the cost. But the information that the one display is better than the other does not quantify how the better display will improve mission effectiveness. This is the type of question a SEA based on Mission effectiveness can answer. Does a slight improvement in reaction time with an upgrade to design A result in less damage taken or more kills in a time critical kill chain? This is the type of informative data a SEA approach affords.

3.0 SELECTED COMPONENTS FOR THIS DEMONSTRATION

Several components were explored as possible options to develop our SEA. The Next Generation Threat System (NGTS) was selected as the primary software tool. This is a simulated environment with computer generated military assets for combat simulation. It is highly reconfigurable. The computer-generated assets are realistic and can be modified to fit the appropriate security level. They can be run fully automated (have computer generated behaviors) or they can have a warfighter controlling them for Live/Virtual capabilities. The system is capable of running on a network, and computer-generated behaviors can be inserted at the scenario level to keep the scenarios relatively constant.

The Performance Evaluation and Tracking System (PETS) was selected as the tool to collect performance measures from the scenario simulations. It was compatible with the NGTS data recorder and could be used to process the scenarios quickly and automatically during or after completion.

Finally, there is the Warrior Preparation Center (WPC). This facility runs training events. WPC had the hardware and skilled the human SMEs who could play operators roles and connections to NATO operators getting AWACS training. Their facility was networked to various training sites giving it LVC capability, and they had AWACS scenarios already developed to challenge AWACS Operators that were in for training events. Although at the time this RTG started, the WPC had done some work with NGTS and were looking at the licensing process for PETS, this RTG's interactions helped accelerate their adoption of these tools into their facility. We were also able to initiate funding for a NATO sharable NGTS version that the WPC completed funding for and now NATO has a Jane's populated NGTS version that can be shared with all NATO countries and industry.

Pulling these components together created a NATO accessible facility that met all our component needs: reconfigurable, realistic but shareable, networked, Live, Virtual, and Constructive (LVC) capabilities, automated with computer generated behaviors, and the ability to capture performance measures.

The following paragraphs will explain these components in more detail.

3.1 Next Generation Threat System

NGTS is a synthetic environment generator that models threat and friendly aircraft, ground units, ships and submarines, associated weapons, sensors, and subsystems. NGTS is used by the Navy and Air Force to support test and evaluations, training, and research and development.

The system is able to provide constructive threat and friendly aircraft entities with configurable capabilities, such as:

- Radar
- Weapons
- Fire Control
- Infrared Search and Track (IRST)
- Jammer

It also provides Surface to Air (SAM) target engagement radar and missile fly out zones. The software comes equipped with a Battle Monitor mode which allows for a primary simulation viewer for scenario planning and execution (Figure 3). The Battle Monitor provides a clear picture of the overall battlespace in a 2D/3D viewer. It provides a visualization of flight paths, radar beam, weapons fire/detonations, and entity states.

An unclassified version of NGTS can be delivered with default military asset behaviors populated with Jane's date for all of its entities. The behaviors can be easily altered to allow for exploration of today's or tomorrow's adversary tactics. The default behavior approach simplifies operator use and allows users to modify an existing functional behavior if changes in tactics are desired. Behaviors can be displayed textually and in a dynamic graph (Figure 4) on the Battle Monitor.

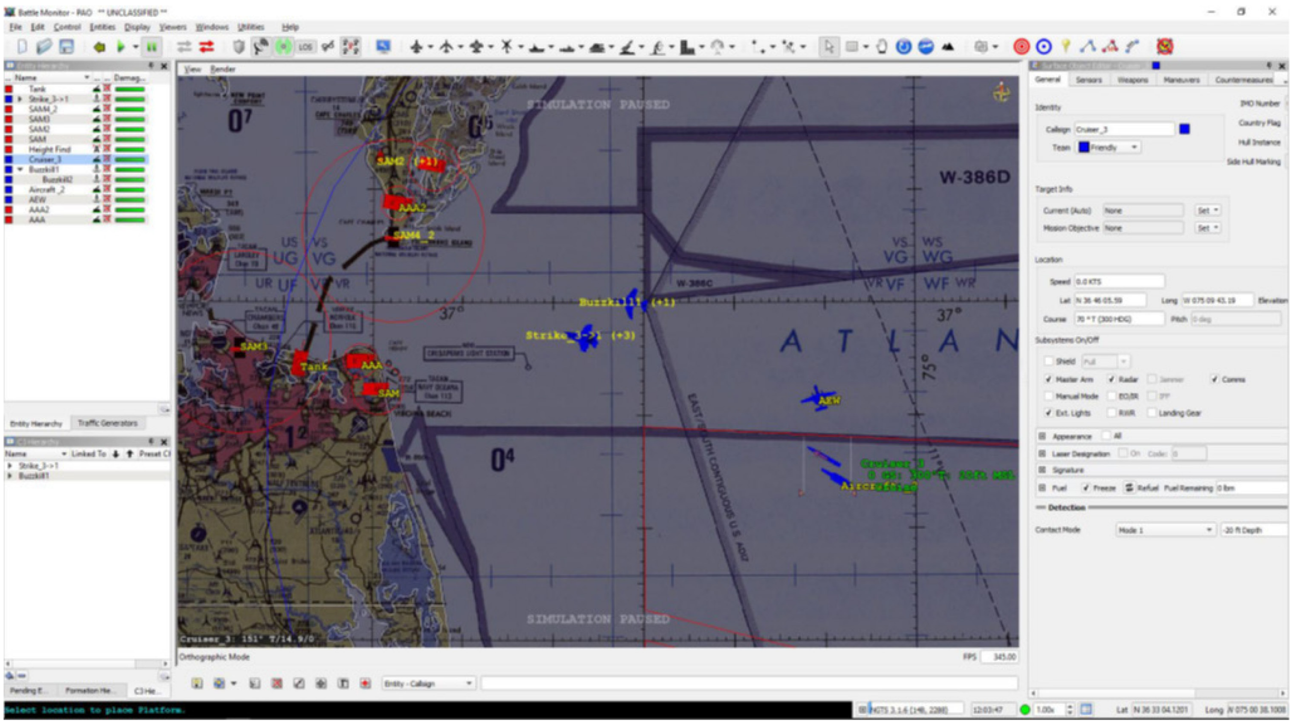

Figure 3: Battle Monitor Simulation Viewer.

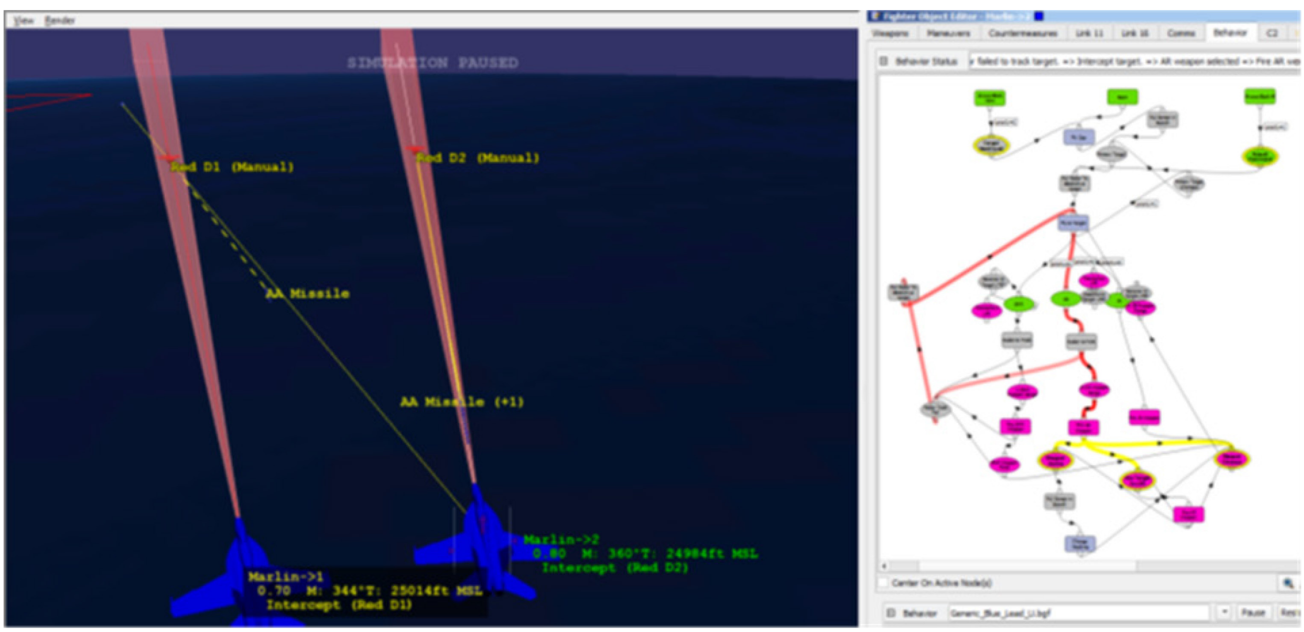

Figure 4: Fighter Entity Editor.

For the intent of this evaluation, the behavior of all simulated entities for these exercises were based on data uploaded from current Jane's Information Group.

3.2 Performance Evaluation and Tracking System (PETS)

PETS measures, assesses, and tracks operator and crew performance on critical knowledge and skills during live-virtual-constructive training exercises. During a given exercise, PETS passively monitors network traffic from interoperable distributed training devices and computes real-time measurements and assessments of mission progress and warfighter performance.

Before implementing and employing PETS measurements and assessments, a team of subject matter experts, software systems engineers, and psychologists must collaboratively identify competencies associated with the warfighters' jobs, observable performance indicators, and candidate performance measures [1]. Multiple established processes for this exist within military training literature and practice. Some performance measures are observer-based while others are system-based and feasible for automation through software like PETS [2]. Available externally observable data may limit feasible system-based performance measures [3]. For example, a measure requiring data that is not available might not be feasible or might require modification of the training systems. An effective performance assessment strategy combines a variety of assessment methods, such as automated surveys or guided expert observations, with system-based approaches. Following implementation and deployment of warfighter-driven measures, PETS monitors all data passing through the network, computes mission/team/individual statistics, and filters accumulated information to locate examples of demonstrated operator competencies and deficiencies.

Although originally designed for training, the comprehensive PETS assessment capability provides mission performance data that informs capability design decisions. PETS provides objective data characterizing the performance of warfighters in synthetic environments and supports comparisons between candidate environments.

3.3 Warrior Preparation Center (WPC)

The United States Air Force Europe (USAFE) WPC is located at Einsiedlerhof Air Station, Germany. The facility was designed to provide combat readiness training for Joint, Allied and Partner Nations through live, synthetic, and blended training capabilities. The WPC supports Tier 1 through 4 training (Strategic through Tactical) via a Distributed Training Center connecting with other bases throughout the world. For this RTG the focus was on WPC's Spartan Warrior Events that were specifically designed for NATO AWACS tactical training. These where large force employment exercises conducted for several hour intervals over several days.

- For this evaluation, the WPC provided the following support:
- Acted as the Exercise Lead;
- Acted as the Testing Lead;
- Generated Air Models;
- Provided the White Force;
- Provided Ops Material;
- Provided the Intel Scenarios (Road to War); Notional States in Central Europe dealing with a land grab from an autonomous, breakaway republic.

The test events were 3 – 4 day exercises conducting a different mission scenario each day.

3.4 Scope of Test

The key components identified for the WPC Spartan Warrior assessment were as follows:

1) Next Generation Threat System (NGTS);
2) Performance Evaluation and Tracking System (PETS); and
3) Warrior Preparation Center (WPC) in Einsiedlerhof, Germany.

This evaluation utilized an existing LVC training environment and incorporated supplemental tools to enhance the realism of the exercise through the use of NGTS, as well as provided the tools to measure human performance during the exercise with PETS. The evaluation was conducted during two of the Spartan Warrior events in 2018. The first event was Spartan Warrior 18-2 (April 2018) and the other was Spartan Warrior 18-4 (August 2018).

Spartan Warrior 18-2 and 18-4 were 4-day exercises with additional participation from NATO Air Base Geilenkirchen (GK), where NATO E-3 AWACS resided. Other locations include the Royal Air Force (RAF) Waddington, UK (Rivet Joint 51 Squadron); the Control and Reporting Centre (CRC) (711 Squadron) Nieuw Milligen, NL, Eurofighters (Airbus) Manching, DE, and the Joint Terminal Air Controller (JTAC) Einsiedlerhof, DE.

3.4.1 Event Scenarios

The training scenario escalated over the 4 day event, with a primary execution Air Tasking Order designation as follows: Day 1, Offensive Counter Air (OCA); Day 2, Defensive Counter Air (DCA); Day 3, Interdiction (INT); and Day 4, Close Air Support (CAS) / Strike. Overall planning for the event addressed other elements including but not limited to: Electronic Warfare (EW), Combat Search and Rescue (CSAR), Airborne Alert Interdiction and (XINT). The AWACS aircrew participated in events across all 4 days.

3.4.1.1 AWACS Crew Positions

The AWACS aircrew is composed of multiple sections that provide a range of skills to accomplish the E-3 mission for integrated command and control battle management, surveillance, target detection, and tracking. An AWACS aircrew is composed of the following positions: a Tactical Director (TD), a Weapons Section composed of a Fighter Allocator (FA) and Weapons Controllers (WCs), a Surveillance Section including a Surveillance Controller (SC) and Surveillance Operators (SOs), a Passive Controller (PC), System Technicians (STs), and flight deck aircrew (e.g., pilot, navigator).

Each role or section has specific duties that impact the aircrews overall mission success. NATO documentation provides an overview of each of these positions, including duties associated with phases of the mission including pre- and post- flight requirements. Below is a brief overview of each position.

- **Tactical Director:** The TD provides overall mission coordination, maintaining communication with section leadership on-board the AWACS aircraft and with other command and control or tasking agents at various locations within the area of operation. The TD maintains responsibility to ensure that the mission is executed in a safe and efficient manner and maintain successful conduct of the mission. As such, the TD is “responsible for the leadership, management, supervision, and training of the crew with regards to mission accomplishment.”

- **Weapons Section:** The FA and the WCs are responsible for the direction, monitoring, and flight following of assigned aircraft during tactical and air-refueling missions. Specifically, they are responsible for extracting data from Operational Orders (OPORDS), Operational Plans (OPLANS), and other theatre and command directives that are available pre-flight or dynamic tasking received during flight to ensure the employment and weapons mission execution.
- **Fighter Allocator:** The FA communicates with the TD to ensure the control of all assigned aircraft and weapons systems via delegation and supervision of all WCs. The FA must maintain tactical situation awareness of available assets and contextual factors (e.g., weather) to support coordination of airspace and direction of appropriate weapon/target pairing.
- **Weapons Controller:** The Weapons Section is composed of 4 or 5 WCs who under supervision of the FA are responsible for the control and safe regulation of air traffic for assigned missions. As part of this responsibility, individual WCs maintain situation awareness and control assigned aircraft in the area of operation to ensure that assets are assigned to target missions and expeditiously recovered. These duties require coordination internally and with external agencies to ensure safety of flight and mission success.
- **Surveillance Section:** The SC and SOs are responsible timely surveillance management to establish an air picture to support aircrew situation awareness throughout on-station mission execution. Specifically, they are responsible for leveraging aircraft systems including Radar and Identification Friend-or-Foe (IFF) to monitor and supervise optimum detection and tracking in the assigned area. As part of this responsibility, the Surveillance Section is responsible for adhering to proper procedures in Electronic Counter Measure (ECM) environments.
- **Surveillance Controller:** The SC communicates with the TD to ensure the appropriate and timely use of all surveillance functions. Specifically, the SC supervises the SOs to coordinate and monitor the collection, display, and dissemination of surveillance data, as well as coordination with the TD to advise of any surveillance capabilities and limitations.
- **Surveillance Operator:** The Surveillance Section is composed of 2 to 3 SOs who under supervision of the SC are responsible for track initiation, identification, and monitoring in the assigned area of operation based on assignments by the SC. The SOs communication with the SC any abnormalities identified and/or any emergency indications. One member of the SO team, the Link SO, is responsible for Link Management. The Link SO coordinates with external agencies via Link systems to ensure an accurate multi-link picture and configures filters per tasking messages for the aircrew.
- **Passive Controller:** The PC analyzes Electronic Support/Warfare (ES/W) data from on-board and off-board sensors to ensure data fusion with other on-/off-board data/information. The PC is responsible for the dissemination a comprehensive EW picture both internally and externally (via links and communication nets). The PC communicates with the TD for all EW issues, including tasking received through Tactical Control (TACON) authority.

3.4.1.2 AWACS Aircrew Composition for Events

For the Spartan Warrior exercise, a limited subset of the full aircrew participated. The training was focused on the Tactical Director (TD), Weapons Section including Fighter Allocator (FA) and Weapons Controllers (WCs), and Surveillance Section including Surveillance Controller (SC) and Surveillance Operators (SOs), and Passive Controller (PC). However, it was noted by the white force operators that the Passive Controller role was not fully representative of real-world tasking due to limitations in system capabilities during these networked events that were required to address classification concerns.

A graphical representation of the communication flow highlighted in the sections that follow is provided in Figure 5. As indicated in the figure legend, some positions of the aircrew remained consistent throughout the exercise, while other individual positions rotated with two or more people playing those roles throughout the week.

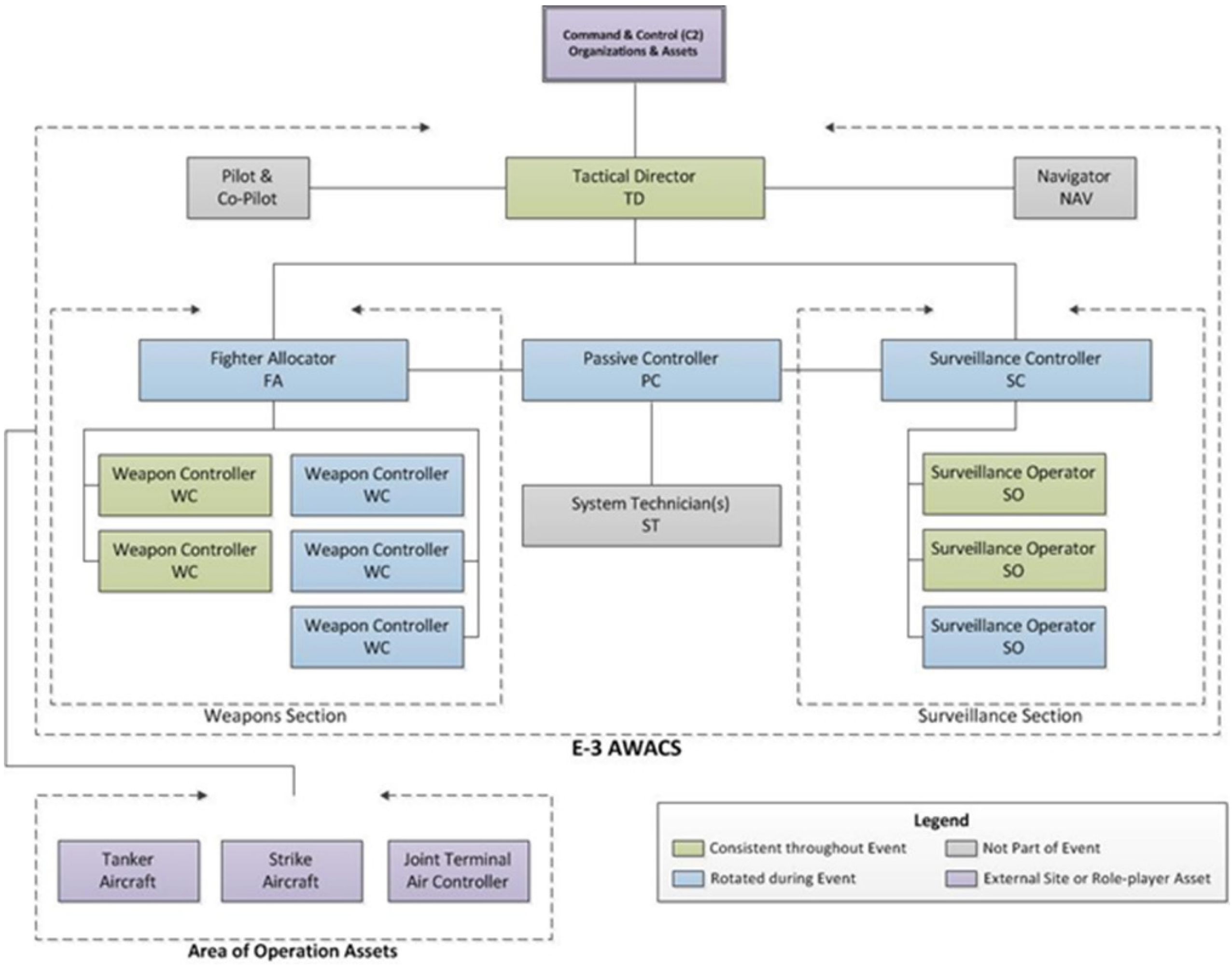

Figure 5: E-3 AWACS Aircrew and Communication Flow.

One interesting element of aircrew coordination noted was with respect to the seating layout of the teams. While there is a generally accepted configuration provided by NATO, each terminal aboard the aircraft can be configured for any position. This allows the TD or aircrew as a whole to modify seating arrangements that they feel support the most effective and efficient flow of information amongst the aircrew.

4.0 DATA COLLECTION AND ANALYSIS

The mission scenarios that were conducted during the Spartan Warrior exercises were consistent with how the AWACS squadrons conduct their mission currently (as much as could be conducted in an unclassified environment). The human factors evaluation focused on several areas.

4.1 Event Data Capture

Human Performance Data was collected and captured using traditional and non-traditional resources. The PETS software was provided to WPC to ensure that the SW 18-2 and SW 18-4 events were recorded using this tool. In addition, questionnaires were provided to collect human performance measurements. Performance data was assigned to categories which consisted of the following:

1) Contact Identification;
2) Force Accountability;
3) Asset Allocation;
4) Workload;
5) Crew Resource Management Characteristics;
6) Measures of Difficulty; and
7) Communication.

Each performance category had specific performance measures to grade, which was based on specific tasks performed by the operators during the Spartan Warrior exercises. Workload was a primary concern of the aircrew during these exercises.

During this effort, the team had limited access to AWACS subject matter experts for performance measure development and validation. The team had significant NGTS and PETS expertise but had limited expertise with other systems in the Spartan Warrior environment. The team drew on existing professional relationships, subject matter expertise from related U.S. military platforms, and prior PETS measure development work for the AWACS, which allowed the team to satisfy the research objectives. Future measure development and data capture strategies would benefit from greater involvement of platform-specific subject matter experts, psychologists, and systems engineers.

4.2 Event Participant Discussion

During engagement with the NATO AWACS fleet representatives, we discussed several stressors that would impact performance of particular sections and/or individuals. These are broken down by aircrew section/position:

- For Weapons: CSARs, IFF problems, lost Link/UAV capabilities.
- For PC: increasing contact density, lots of unknown/ambiguous contacts, lots of Surface to Air (SA) and other threats.
- For SC: Link problems, inept SOs, radar and IFF problems.
- For Surveillance Section: increased red air, gaining numerous contacts all at once.
- For TD: reliability of key positions (FA, SC, PC), having to coordinate with the flight deck, coordinating with technicians, retrograde/slide.

4.3 Event Data Analysis

4.3.1 Performance Measures

In these evaluations, the workload on the AWACS crew was gradually increased and task shedding was measured. The workload at which task shedding occurs indicate key effectiveness metrics for performance comparisons. AWACS crew workload was increased by:

1) Loss/jamming of Link-16 and/or IFF.
2) Increasing the number of threats in Area Of Responsibility (AOR).
3) Increasing the number of friendly assets in AOR.
4) Increasing the number of neutral assets in AOR.
5) Increasing the size of the AOR.
6) Adding assets crossing lanes.
7) Adding surface to air threats.
8) Increase radio chatter, overload some channels.
9) Ambiguous intel/contacts not squawking.
10) Reducing support assets to accomplish mission.
11) Adding airspace restrictions.

In general discussions with the AWACS crews, they identified what they believed should be the basis of performance measures. These measures are:

1) 100% ID: The crew must identify (e.g., friend vs hostile) all contacts.
2) 100% Link-16: The crew must ensure that the Link-16 picture is complete and correct.
3) 100% Force Accountability: The crew must manage assets to avoid fratricide, distribute fuel, and maintain Combat Air Patrols (CAPs).
4) Reduced delays in handling dynamic targeting and responding to troop-in-contact conditions.

The versatility of PETS is that it can use any number of the data points collected during a mission exercise to analyze human performance. The following measurements were identified as key mission effectiveness parameters for AWACS performance:

1) Fratricides;
2) Time from threats crossing DCA line, based on position, to DCA response, based assigned tasking;
3) Time from detection of a threat, possibly based on electromagnetic emission Protocol Data Units (PDUs), to creation of a Link-16 track and hostile identification;
4) Number of leakers, based on positions of friendly vs. threat aircraft;
5) Time from a new dynamic target, based on scenario design or targeting via chat, to destruction of the target;
6) Time from an active SA threat to clearing assets from the Military Exclusion Zone (MEZ); and
7) Number of lane handoffs via messages.

Although PETS data can be analyzed in real time, this data was recorded using NGTS and then analyzed post event. This process allows for data points that were not originally planned for, to be analyzed after the event. Being able to automatically analyze data with PETS is an invaluable capability, and when shared, allows for standard and consistent analysis across collaborating researchers.

4.3.2 Observed Limitations of Developed SEA

Overall, the Spartan Warrior linked AWACS simulation offered a training experience that instructors stated was "very close to reality." The simulator used real equipment and experienced the same malfunctions as would live systems. There were a few areas noted where the simulation environment did not represent the live environment.

1) The simulated environment did not replicate the noise level that would be experienced on the actual jet. Conversations between crewmembers were observed, while sitting in close proximity, which would not be feasible on the jet. This "sim-ism" makes it difficult to capture these communications without an observer present to hear them. On the jet, these communications would occur over the radio.
2) The PC's role was unrealistic, as the RF signals were not simulated, such that the PC had to rely on other role players to provide the Electronic Support Measures (ESM) information. This was due to a classification issue; however, workarounds could be possible.
3) Crew members have responsibility for emergency duties on the aircraft, a consistent mental stressor during flight, but that stressor wasn't present during the simulated exercises.

It is important to note that considerations must be made to determine whether performance assessments made in the simulation map correlate to performance assessments in the live environment.

4.3.2.1 Duration Fidelity

The training exercise execution lasted 1.5 – 2.5 hours each day. A typical mission can last 12 hours or longer, so the simulated events do not replicate a full end-to-end flight. However, the length of the exercise seemed more than adequate, as the crew appeared exhausted by the end, and the level of individual participation during the debriefs tapered over time.

4.3.2.2 Aircrew Teaming

A few limitations were observed during the test events. The participating squadrons were stretched thin due to competing activities, so several crew members had to be changed out over the course of the event (including key positions). It was observed that the FA, SC, SC, SO, and WC positions were filled by different personnel across the 4-day event. The TD was consistent throughout the event, however. Also, a full aircrew complement does not typically train together (i.e., no flight deck or technicians included). On some days, someone played the role of the AWCAS pilot, so some of the typical chatter was replicated. Simulated events do not include technicians and engineers (because the assumption is that the equipment will be functional).

4.3.2.3 Instructional Support

There were no dedicated instructor-observers to support the events to provide assessments of the crews. Debriefs were led primarily by the Exercise Director with opportunities for the crew's TD, white force members, and/or simulation drivers to offer constructive comments on the performance. However, the debriefs centered largely on technical issues and scenario events rather than performance. No formalized assessments were conducted during the exercise, except for one individual who was participating in qualifications for his individual role on one of the days. Structured Crew Resource Management (CRM) training did not appear to be a part of the debrief activities, however the crew may have performed a CRM debrief on their own time during an after-action session. The aircrew used a self-report form to identify training accomplishments from the event. These forms account for accomplished training requirements, for each individual, via a check in the box review. It does not require a detailed performance assessment to quantify or validate accomplishments.

4.3.2.4 Miscellaneous Information

Instructors reported that the two main training issues were communication problems and lack of experience. With respect to communication, the NATO crews were multi-national, so accents and phraseology were the biggest barriers for the crews to overcome. The second barrier was that crew members came in with limited knowledge about their assigned role. Each crew member was required to read the crew position document (E3A M 3.2-17) prior to coming on station, but they lacked experience operating the equipment (in training in flight) and performing the task.

5.0 RELATIONSHIP TO OTHER NATO STO ACTIVITIES

5.1 Live-Virtual-Constructive Training (LVC) (RTG HFM-221)

Live-Virtual-Constructive Training (LVC) is becoming pervasive in the international training and mission rehearsal community due to the maturity of enabling technologies and the push to drive costs down. However, RTG HFM-221 recognizes that there is still little agreement as to what constitutes L, V, and C or what the aggregate LVC means in terms of training and mission rehearsal. The lack of agreement in definition as well as tools for interoperability and synchronization are also barriers. A key objective of RTG HFM-221 is to seek common goals and opportunities across NATO partners that will enable joint exercises and training as well as the sharing of technologies where appropriate.

A current focus is on what it will take to develop a continuous learning (or training) environment that integrates LVC as a seamless and persistent part of all training. If it can be shown that learning can be accelerated in this manner, then the international community can leverage this in many ways. Other objectives include identifying best practices for LVC across Member Nations, methods of measuring performance in LVC environments, exploring the differences of LVC training as compared to other methods, and identification of candidate exemplars that can be shared among members and could be expanded into an RTG LVC demonstration.

5.2 Human Behavior Modeling (HBM) (MSG-107)

5.2.1 HBM Agenda and Object

Human Behavior Modeling (HBM) is looking at modeling and simulation technologies that model humans at the individual and small team levels. There is an immediate tie to LVC in that HBM seeks to solve problems associated with the use of HBM models in exercises that include live players. They are looking at a wide variety of warfighting domains, from ground force applications, to air, and multi-service domains. Much of the work of HBM will deal with standards development that will allow them to utilize the many investments in HBM worldwide that currently cannot be unified into a single system. This same motivation for reusability of models is common to SEA.

This is likely an area for collaboration. The main objective of HBM is to develop a reference architecture for HBM that can be used in any military application. They will begin with conceptual modeling that crosses cognition, decision making, planning, and emotions. The plan calls for investigation of the architecture at the sub-level first working up to an overarching architecture that might be capable of unifying all sorts of models that already exist today. Finally, HBM will make recommendations as to the use of the architecture in practical applications.

5.2.2 HBM + SEA Opportunities

HBM is but one of the groups in MSG working in areas of interest to SEA. There are certainly more. SEA needs to pay attention to the reference architecture developed by HBM because it must be compatible with what we develop for SEA since the HBM models are going to be common candidate models for use in SEA assessments. In all likelihood, the HBM architecture may need to be more general than we need to be in SEA, which implies that letting HBM get out ahead of SEA may be useful.

5.3 NATO Mission Training Through Distributed Simulation (MTDS) (MSG-128)

The NATO AWACS and nations have a common need for training of air combined and joint collective tactical training, referred to NATO as Mission Training Through Distributed Simulation (MTDS). Several NATO and national activities have been conducted in this area and some nations have implemented them at varying levels. The MSG-128 Task Group's goal is to establish essential elements for a NATO MTDS environment, including concept, standards, and agreements, legal and security framework, services infrastructure, and standing operating procedures. MTDS has achieved a level of maturity which makes it feasible for NATO to implement a persistent capability to support operational readiness.

5.4 Alliance Future Surveillance and Control (AFSC)

The Airborne Early Warning and Control System (AWACS) has been NATO's key surveillance and control asset since 1980s. The NATO AWACS fleet is planned to retire in 2035, after 50 years of service. To plan for the required follow-on capability, in 2016 Summit in Warsaw, NATO launched Alliance Future Surveillance and Control (AFSC) specifically to develop options for future NATO surveillance and control capabilities.

In February 2017, the North Atlantic Council initiated AFSC Concept Stage with NSPA as the lead NATO agency to conduct studies and develop technical concepts. This RTG focused on putting together a SEA that could be used to inform the AFSC as it makes decisions to acquire new systems in time before the AWACS fleet retirement. Since the AFSC had not identified possible alternative replacements for the AWACS, this RTG baselined existing AWCAS performance and developed a SEA that could be used objectively to compare future replacement design alternatives.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Having the opportunity to collect data in the WPC's Spartan Warrior exercises, this RTG was able to demonstrate the potential benefits of SEA as a tool for capability development. SEA was demonstrated as a workable way to gather realistic mission efficacy data that decision makers could use in the acquisition processes. The mission scenarios in the SEA can result in comparable data that governments or industry can objectively use to explore and evaluate a larger number of potential solutions using trade-off techniques for design comparisons. Most importantly, the acquisition community can use SEA as a communication mechanism. If a new technology for Early Warning looks promising, they can objectively test it for mission impact. This will either demonstrate its utility and its return on investment, or it'll be dropped as a non-value-added proposition. Such SEA approach provides valuable information prior to costly prototype development and greater confidence in the final design outcome.

SEA strives to use simulation for conducting trade-off analyses and exploring very complex design spaces. SEA is intended to accelerate the slow pace of incremental improvements for disruptive innovation – radically new ideas that change the rules of warfare and national defence. This is the goal of SEA at its highest level.

This report took the conceptual model of SEA outlined by RTG HFM-216 and applied it to a real NATO product (AWACS), where real design decisions are needed. This RTG demonstrated how the technical risks to realize SEA, as identified in RTG HFM-216, could be overcome. This RTG was able to work with NATO partners (WPC) and develop a SEA with all the required components. The RTG also managed to initiate the development of a NGTS version (using prepopulated Jane's model data) that is available to NATO members and industry (with proper coordination). With the combination of a performance measurement tool like PETS, the acquisition community can utilize this SEA to compare alternative designs through objective, mission-based metrics.

6.2 Recommendations

The evaluations that took place during the Spartan Warrior exercises brought to attention improvements needed to the human performance data gathering and to the overall SEA performance.

6.2.1 Recommendations for Improving Human Performance Data

The AWACS crew missions are complex involving interactions between crewmembers and interactions with external Warfighters. System-based human performance measurement is challenging. Within the team, many interactions are "side conversations", such as discussions between crewmembers, exclamations, and pointing to displays. These discussions (and actions, like pointing to a screen) are not recorded by NGTS and cannot be analyzed by PETS, thus some human performance data is lost. Many interactions, both within the crew and with external Warfighters, occur via voice over radio. If the events were audio recorded, then this data would be captured, but analyzing audio recording can be a very time consuming. Although automated measurement of the voice communications with voice recognition is possible, this RTG did not explore any of the latest technology in this area. Also, many of the interactions occurred via Link-16 messages, IFF, and chat systems.

There are various complexities and constraints of trying to capture communications during these mission-based scenarios. SEA gets around these limitations by relying on the observable behaviors based on the communications. This is not an ideal solution, and methods for this type of communication data collection would improve current human performance assessment capabilities.

6.2.2 Recommendations for Improved SEA Performance

To date, all participants interviewed have been extremely pleased with quality of training and ability to network utilizing the Spartan Warrior's LVC facility. It has been noted that it provides critical training not found or provided elsewhere, within NATO. The system, which officially debuted in 2015, is an outstanding resource as a training asset. This RTG was interested in its ability to be used as a SEA, and in this regard (with some improvements that have been made since the start of the RTG) it is an outstanding resource for system design and exploration. Even so, certain resource limitations were identified. Recommendations for further improvements would include the following:

1) A larger involvement from the squadrons and participating sites with regards to manpower.
2) Improved entity models for more realistic representation within the limits of an unclassified environment.
3) Improved fidelity of the maps to provide a more mission representative environment.
4) Improved simulator connectivity between the participating sites.
5) Find the necessary workarounds or agreements to get past some of the legal restrictions between partnering allies.
6) Involve subject matter experts, psychologists, and systems engineers early in the development process to identify operationally relevant and technically feasible performance measures.

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14. Abstract

This report follows the steps outlined by the Research Task Group HFM-216's technical report (TR-HFM-216) to apply the concept of a Synthetic Environments for Assessment (SEA). The general goal of RTG HFM-268 Synthetic Environments for Mission Effectiveness was to build a realistic synthetic environment, accessible/reproducible by NATO members, that provides the means to design and evaluate new alternative military systems and assess their effectiveness in mission relevant scenarios. A critical component of this type of evaluation is the ability to measure and analyze the human-system performance and/or the effective interaction of the operator as they utilize the system's hardware and software. This technique was specifically applied to exploring early warning command and control missions currently handled by NATO Airborne Warning and Control System (AWACS). This report documents the SEA development and results. All the key components of an SEA were incorporated and the results demonstrated a workable way to gather realistic mission efficacy data that decision makers can use in the acquisition processes, specifically performance metrics that will allow early design decisions by comparing alternative designs through objective, realistic mission-based metrics.

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