JOINT MILITARY SPACE OPERATIONS SIMULATION: A SURVEY

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ABSTRACT
Space capabilities must be integrated into joint operations, which requires a common and clear understanding on space capabilities, their effects and the procedures for their employment by the joint force commanders and staff. Therefore, they need to be practiced during joint computer assisted exercises. In this paper, the military space mission areas and simulation tools that can be used for them are surveyed. The conclusion is that the joint military space operations simulation capabilities are limited and do not suffice to fulfil the requirement.

Keywords: modelling, simulation, space, joint military space operations

1. INTRODUCTION

Space capabilities are complex systems made up of various components including satellite production, checkout and storage facilities, launch facilities, user terminals, ground stations, manned or unmanned spacecrafts, payloads (e.g., sensors) and communication links (Rainey and Davis 2004). Many space capabilities require multiples of these components, such as tens of satellites and ground stations. The components of a space capability are typically procured from different commercial or governmental organizations. Recently, the vendors for space capabilities, including the space lift, are more and more frequently commercial companies.

Space technologies, capabilities and their components used to be controlled only by few nations. They are now available and affordable not only to state but also non-state entities. Moreover, it is not necessary to own all its components for having the space capability. It is possible to access the services by the space capabilities that the others own. Therefore, space is not a safe and secure place for the sophisticated intelligence, surveillance, reconnaissance (ISR), communications and navigation technologies for few nations anymore, but a challenging and integrated part of the joint military operations especially when defending against hybrid threats (Cayirci, Bruzzone, Longo and Gunneriusson 2016). Moreover, many terrestrial systems critical to military operations, such as navigation and communications, depend on space systems, although it is sometimes not easy to recognize this dependence. Therefore, military must have processes:

- To determine the space capability requirements for reaching the strategic and operational goals
- To contribute the development of new space technologies applicable for military
- To use the available space capabilities optimally
- To defend the components of the space capabilities
- To prevent the belligerents/adversaries from using space capabilities effectively

For these processes, and to realize the global advantages provided by space forces, all space capabilities and the means to protect them should be integrated into all kinds of military planning including defense, advance and response planning. Hence, the commanders and their staff *must understand the applications of space capabilities, have access to space-based support sufficient to accomplish their missions, use space systems to the degree needed for completing required tasks expeditiously, and make recommendations to deny or limit an adversary's access to space and use of space systems* (NATO 2009). Therefore, it is necessary to provide computer assisted exercises and wargames especially in the operational and higher levels with joint military space operations simulation (JMSOS) support. However, we can say that JMSOS support especially in

the international collective training events do not suffice to fulfill the requirement. The main contributions of this paper are analyzing these shortcomings related to JMSOS support to operational level computer assisted exercises/wargames and making recommendations for eliminating them.
In Section 2, we elaborate on the need for military space operations simulation. We pay a special attention on collective training and exercises in operational level. In Section 3, we report the results from our literature survey on the available tools that address these requirements. Section 4 is about the potential future M&S approaches, such as modelling and simulation as a service (Cayirci 2013; NATO MSG-136 2017; Taylor et al. 2015; Zehe et al., 2015) applicable for JMSOS. We conclude our paper in Section 5.

2. MILITARY SPACE OPERATIONS SIMULATION REQUIREMENTS

We categorize the requirements for JMSOS into five classes of joint military processes in strategic and operational level as follows:

- JMSOS Support to Defense Planning Process: As depicted in Figure 1, defense planning process determines the military capability requirements for the potential scenarios given by the political level. Where and how the simulation support is needed within this process are explained in detail in (Cayirci and Ozcakir 2016). To the best of our knowledge, the capability for JMSOS support as explained in (Cayirci and Ozcakir 2016) is not available to any armed forces or alliance.

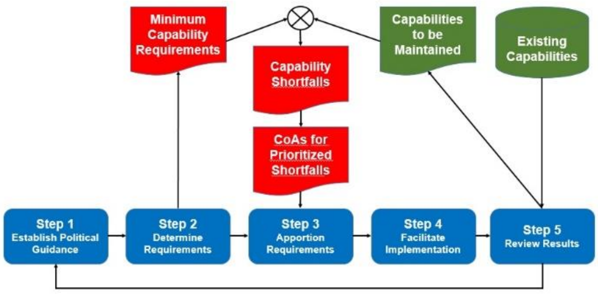

Figure 1: NATO Defense Planning Process.

- JMSOS Support to Capability Design and Acquisition Processes: The capability design and acquisition processes of the US DoD are illustrated in Figure 2 (DoD 2015). JMSOS support is needed for exploring the alternatives, analyzing the measurements, assessing the designs, evaluating the operating procedures, and predicting the performance during capability design and acquisition (Rainey and Davis 2004). Modelling and simulation (M&S) can be useful for the design of an overall space capability or solving complex engineering problems related to various topics, such as spacecraft, payload and orbit design. There are various tools commercially available for these purposes, and we can say that this is a mature field especially in civilian domain (ESA 2017; NASA 2010; Rainey and Davis 2004).
- JMSOS Support to Joint Operations Planning Process: Joint operations planning can be made advanced as standing defense plans and contingency plans or as a response to a crisis. Planning space capabilities must be an integrated part of the joint operations planning especially in operational level (SHAPE 2013). M&S tools are available for joint operations and logistics planning. However, JMSOS capabilities of these M&S tools are very limited.

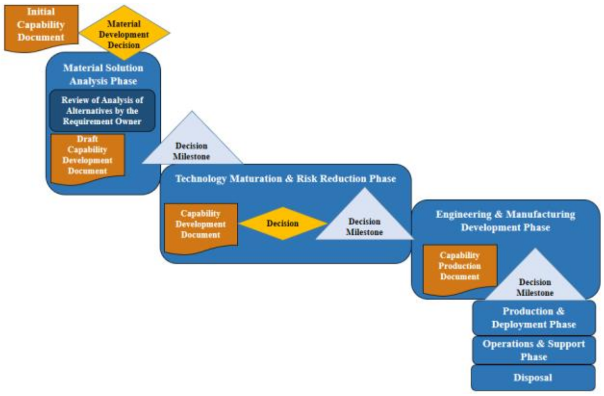

Figure 2: Capability Design and Acquisition Process.

- JMSOS Support to Joint Operations: Plans need to be adapted according to the evolving situation in current operations, which requires situational awareness and forecasts. Orbits and payloads of satellites, their sensing capabilities, their effects on operations need to be known and predicted. Similarly, space weather forecasts are important not only for the space assets but also many other military capabilities. Models and simulators are available for these purposes.
- JMSOS Support to Education and Training Processes: Models and simulators are available also for education and individual training. These include virtual simulators for spacecraft crew. However, constructive simulations in JMSOS domain do not suffice to fulfil the requirements for the collective training, exercises and wargames especially in joint operational level, which is the area that this paper focuses on.

For the collective training, exercises and wargaming purposes, JMSOS support should be provided in four space mission areas given in Table 1 (NATO 2009) and explained below:

- Space control operations (SCO) are conducted to attain and maintain the space superiority which involves the counter measures against the adversaries' space capabilities. These measures include actions by air, land, maritime, space and special forces. SCO requires space situational awareness about space related conditions including space weather, constraints, capabilities and activities in, from, toward and through space. The details like orbits, payloads, frequencies are all of interest. SCO can be offensive or defensive. Offensive operations can be against not only the assets in space but also ground facilities and stations. Electronic control measures, such as, jamming an uplink or downlink are among the offensive SCO. Available combat models can be adapted to simulate a large subset of offensive and defensive SCO.

- Space force enhancement operations (SFEO) are to support the warfighter and to enhance the battlespace awareness. *There are five force enhancement functions: ISR; integrated tactical warning and attack assessment; environmental monitoring; communications; and position, velocity, time, and navigation* (NATO 2009). The combat models available for operational level exercises in NATO provide functions to simulate the results of a subset of SFEO. However, they are far from being sufficient.
- Space Support Operations (SSO) include space lift, satellite operations, reconstitution of space forces. Space lift delivers satellites, payloads and material to space. Satellite operations are conducted to maneuver, to configure and to sustain on-orbit forces and to activate on-orbit spares. Finally, reconstitution operations are for replenishing space forces when the existing forces degrade due to various reasons. SSO is seldom practiced in operational level exercises.
- Space Force Application Operations (SFAO) carried out by the weapon systems operating in or through space against terrestrial based targets. SFAO includes ballistic missile defense (BMD), theater ballistic missile defense (TBMD) and force projection. Please note that TBMD and BMD can be conducted also by means other than SFAO. This mission area is not practiced very often because there is not any known asset available in space for this purpose.

The following characteristics special to military space operations (NATO 2009) (Rainey Davis 2004) have to be taken into consideration in the design of the simulation services for these space mission areas:

- Global access and persistence: Satellites can fly over any location on Earth, and stay on orbit for extended period of time. However, except for geostationary satellites, they stay over a location on earth only a limited time.
- Coverage and propagation delay in communications: As the orbit altitude gets higher, the coverage area gets larger, nevertheless, the propagation delay in communications also gets longer. The return trip time for an electromagnetic signal from earth to a geostationary satellite is around 500 msec.
- Design life: Most satellites cannot be maintained or repaired. They also can have limited fuel on board to maintain the orbit or making changes in the orbit. Therefore, the lifetime of satellites is limited.
- Older technology: Although software defined technologies are changing this fact, typically the technology in a satellite is not the latest but the technology available before the launching day.
- Increasing affordability: New technologies introduce smaller and smaller satellites, such as, micro, nano, pico and femto satellites. More sophisticated satellites can be produced in less sophisticated production facilities and lifted into space more easily and less costly.
- Predictable orbits: Satellite orbits are predictable.
- Vulnerability: Ground to satellite links are susceptible to electronic counter measures and ground facilities and stations can be attacked.
- Resource considerations: Replacing or replenishing space forces need long lead times.
- Legal considerations: Numerous national and international laws must be considered during planning.
- Space treaties: Although currently there is no treaty that forbids the deployment of weapons other than weapons of mass destruction in space, many of them introduce constraints to the military use of space.

Table 1: Military Space Mission Areas.

Abbreviation	Name	Mission Types
SCO	Space Control Operations	-Space situational awareness -Offensive SCO -Defensive SCO
SFEO	Space Force Enhancement Operations	-Intelligence Surveillance Reconnaissance (ISR) -Tactical warning and attack assessment; -Environmental monitoring -Communications - Navigation
SSO	Space Support Operations	-Space lift -Satellite operations -Reconstitution of space forces
SFAO	Space Force Application Operations	-BMD/TBMD -Force projection

3. SIMULATION SYSTEMS FOR JOINT MILITARY SPACE OPERATIONS

In this section, we elaborate on the JMSOS capabilities of the constructive simulation systems available for joint operational and higher-level computer assisted exercises (CAX) and wargames. Although, our list is not exhaustive, it covers all the tools used in major coalition or alliance CAX known to us. Please note that, not only models and simulators but also the following tools are required for the successful employment of M&S including JMSOS during a CAX (Cayirci, 2006):

- Setting and scenario management tools
- Training objective management tools
- Main event list, main incident list management tools
- Command and control system data population and stimulation tools

There have been two main approaches followed for integrating JMSOS into joint operational CAX: federating a JMSOS system into a federation of simulators or incorporating JMSOS functionalities into a joint or service simulation system. Well known examples of both approaches are listed in Table 2 and elaborated on below:

Table 2: Examples for the Constructive Simulation Systems with the Models Related to the Space Mission Areas.

Tool	Type	Federation	Mission Areas	Status
PSM	Space Model	JTC and JLVC	SCO (partial), SFEO (partial), SFAO (partial)	Availability is unknown.
AWSIM	Service (Air) Model	JTC and JLVC	SCO (partial)	Available
JECEWSI	Electronic Warfare Model	JTC	SCO	Availability is unknown.
STORM	Air Heavy Joint (analysis)	HLA	SCO, SFEO, SSO (partial)	Available
FLAMES	Air	ITC, HLA	SCO (partial)	Available
ACE-IOS	Air	JLVC	SCO (partial), SFEO (partial)	Available
JTLS-GO	Joint	JLVC, NTF	SCO (partial), SFEO (partial)	Available
hTEC	Joint	MSaaS	SCO, SFEO, SSO, SFAO	Not available in 2017
ASCCE	Joint		SCO, SFEO, SSO (partial)	Available
MDST	Air, Missile Warning	-	SFAO	Available
Serious Games	Gaming	-	-	-
Communications / Network Simulators	Communications and Network System/Scheme Design	-	SCO (partial), SFEO (partial), SSO (partial)	Available

- **Portable Space Model** (PSM): One of the early attempts in integrating a space simulator into a federation is Joint Training Confederation (JTC) with Portable Space Model (Cayirci and Marincic 2009). JTC is an Aggregate Level Simulation Protocol (ALSP) federation, and one of the pioneering works for federating military constructive simulation systems. Joint Simulation System (JSIMS) and high level architecture (HLA) (IEEE 2010; Tolk 2012) made both JTC and ALSP obsolete before 2000. PSM is a US Space Command (SPACECOM) model. It is a discrete event simulation written in C that models satellite detection and early warning for tactical ballistic missiles. In other words, it partially covers SCO, SFEO (i.e., tactical warning) and SFAO (i.e., TBMD/BMD) domains.
- **Air Warfare Simulation** (AWSIM): AWSIM is the primary model of the Air Force Modeling and Simulation Training Toolkit (AFMSTT). It was a federate in JTC, and later became a federate also in Joint Live Virtual Constructive (JLVC) Federation, which was an HLA federation maintained by US Joint Forces Command (USJFCOM 2010). AWSIM was developed in the 1980s, and the favored simulation system of the US Air Force for conducting simulation exercises in Air Warfare and Space Operations (Tolk, 2012). AWSIM can support the SCO mission area.
- **Joint Electronic Combat Electronic Warfare Simulation (JECEWSI):** JECEWSI is an electronic warfare simulation system and was a federate in JTC (Cayirci and Marincic 2009). The JTC was composed of nine simulations or actors, and one of them was JECEWSI (Strickland 2011). JECEWSI focuses on electronic warfare and electronic combat environments in support of tactical air, electronic warfare defense and air defense operations (Cayirci and Marincic 2009; Tolk 2012). It can provide partial support for SCO and SFEO.
- **Synthetic Theater Operations Research Model** (STORM): STORM is the successor of

the air force comprehensive theater level analytical campaign simulator, called THUNDER. STORM is a campaign level simulator and supports in depth analysis of the contributions of air and space power to a campaign (Pugh 2000). It is designed as an aid to senior decision makers across the acquisition, policy and operations communities. The focus of the model is on the air-air and air-ground combat. However, since the models in STORM includes space objects and their interactions with the air and surface/ground objects, the relations between air/ground combat and space capabilities, and therefore SCO and SFEO can be simulated. Partial support for SSO can also be provided by STORM.

- **FLAMES**: FLAMES is an air simulation system, and a part of NATO Integrated Training Capability (ITC). ITC is used for training NATO combined air operations centers (CAOCs). Flames is also available in NATO Integrated Command and Control (ICC) system to provide a testing environment for air tasking orders (ATO). Its support to space mission areas is limited and indirect. FLAMES addresses many aspects of constructive simulation development and use, including customizable scenario creation, execution, visualization, and analysis, as well as interfaces to constructive, virtual, and live systems (Ternion 2009). It can partially support SCO.
- **Air and Space Constructive Environment Information Operations Suit** (ACE-IOS): The Air Constructive Environment-Information Operations Suite (ACE-IOS) provides the authoritative representation of Air Force information operations. ACE-IOS is comprised of models that support training and mission rehearsal for the Air Force, Joint Task Force commanders, and battle staffs during Joint and Service exercises and experimentations (DTIC 2013). ACE-IOS is the Joint Network Simulation (JNETS) tool for using to create the cyber range environment (Wells and Bryan, 2015).
- **Joint Theater Level Simulation Global Operations** (JTLS-GO): *The Joint Theater Level Simulation - Global Operations (JTLS-GO) is an interactive, Internet-enabled simulation that models multi-sided air, ground, and naval civil-military operations with logistical, Special Operation Force (SOF), and intelligence support. JTLS - GO development began in 1983 as a project funded by the U.S. Readiness Command, the U.S. Army Concepts Analysis Agency, and the U.S. Army War College. The simulation was originally designed as a tool for development and analysis of joint as well as combined (coalition) operations plans. Today, JTLS is primarily used as a training support model that is theater-independent and does not require a knowledge of programming to operate effectively* (Rolands and Associates 2017).
  The primary focus of the JTLS - GO system is conventional joint and combined operations at the Operational Level of War as defined by the Joint Staff's Universal Joint Task List. JTLS explicitly models air, land, sea, amphibious, and SOF operations. The Simulation supports limited nuclear and chemical effects, low-intensity conflict and pre-conflict operations, as well as support of Humanitarian Assistance and Disaster Relief (HA/DR) Operations (Rolands and Associates 2017).
  JTLS has been a federate to various federations including JLVC and NATO Training Federation (NTF)(NATO MSG-068 2016).
  JTLS-GO is the main simulation tool to support NATO's operational and higher level CAX. In the NATO's exercises, it is used to simulate/visualize satellite orbits, and ISR based on satellite payload. Therefore, it provides partial support for SCO (i.e., situational awareness) and SFEO (i.e., ISR). Please also note that space weather forecasts are injected as an incident content in NATO CAXs, but not simulated by JTLS-GO.
- **HAVELSAN Training and Experimentation Cloud** (hTEC): hTEC has been developed following modelling and simulation as a service architecture (Cayirci, Karapinar and Ozcakir 2017). At the time that this paper is written, it is being implemented on a testbed called BSigma (Cayirci, Karapinar and Ozcakir 2017). hTEC includes services that covers SCO, SFEO and SFAO completely and SSO partially.
- **The Air Space Cyber Constructive Environment** (ASCCE): *ASCCE simulations are the authoritative representation of air, space, and cyber power for U.S. ASCCE is used throughout the USAF for warfighter events. It is the air, space, and cyber representation for certifying Joint Force Air Component Commanders and their staff* (Deforest 2009). *It includes the Air Force Modeling and Simulation Training Toolkit (AFMSTT), which provides the representation of Air Force and Joint theater-level air and space power and is used to train Air and Space Operations Center (AOC) personnel and Combat Commanders (COCOM) staffs.* (DTIC 2013).
- **Missile Defense Space Tool** (MDST): MDST supports live or simulated exercises. *MDST can be used for simulating Military Space Operation by injecting messages into operational communication and simulation networks* (Rainey and Davis 2004). *It provides space simulation support, and space exercise by conducting National Missile Defense and*

Theater Air and Missile Defense activities. It provides partial support SFAO and SFEO.

- **Serious Games:** Gaming products may also provide solutions for the requirement. There are hundreds of space games. We surveyed tens of them, such as, Deliver the Moon, Limit Theory, Infinity Battlespace, The Mandate, Everspace and Dreadnought. We could not find any space game that can be useful for any of the space mission areas listed in Table 2. However, the game called Star Citizen (Star Citizen 2017) may evolve and become useful for the SSO and SFAO mission areas in the following years.
- **Communications / Network Simulators:** There are many tools used for simulating the communications/networking techniques, algorithms, schemes and systems in scientific and industrial research (Network 2017; Pan 2017), such as, Network Simulator (ns3) (NS3 2017), OPNET and OMNet++ (Pan 2017). Although these tools are designed for the technical evaluation of the schemes, protocols and systems, they may become useful also for the training in the SFEO and SSO mission areas.

Apart from the simulation systems listed in Table 2 which are mostly from the U.S., there are other military constructive simulation systems with air domain functionalities, such as the following (Cayirci and Dusan 2009):

- SCEPTRE, France
- Air land interactive conflict evaluation (ALICE), Germany
- Simulation Modell fur ubungen Operativer Fuhrung (SIMOF), Germany.
- Joint Operational Command and Staff Training System (JOCASTS), UK
- CATS-TYR, Sweden

However, to the best of our knowledge, their support to space mission areas are either very limited and indirect or not existing at all.

4. ALTERNATIVE APPROACHES FOR DEVELOPING JMSOS SYSTEMS

One of the following four approaches can be applied for developing a JMSOS capability:

- Models for military space mission areas can be included into the joint or air military simulation systems.
- An integrated JMSOS system that consists of functionalities for all the joint military space mission areas can be developed. This system can be federated with the other military simulation systems by using distributed simulation technologies, such as, HLA (IEEE 2010) or used standalone. They can populate and stimulate the command and control systems by using various C2 interoperability or military datalink protocols (Hura et al. 2000). Software as a service model can also be used for making this system available to the users (Cayirci 2013).
- Alternatively, multiple simulation systems can be developed for each of the space mission areas or even sub topics under the mission areas. They can be federated or used standalone.
- Finally service oriented cloud approach as described in (Cayirci Karapinar and Ozcakir 2017) can be followed.

For JMSOS, we follow the last approach in hTEC, i.e., service oriented cloud architecture, in which the following services are available as models ready to be integrated into a software as a service (Cayirci Karapinar and Ozcakir 2017):

- Spacecraft and orbit
- Space weather
- Weapon effects on space assets
- Space electronic warfare
- Space sensors
- Space ISR
- Space communications
- GPS
- Space weapon effects

These models are in the form of software libraries that can be composed into a simulator by the hTEC composition layer. The composed service can also be federated with the federates from the other domains by using HLA. Please note that, hTEC services (i.e., models) are not limited to only space mission areas. The hTEC architecture follows NATO recommendations on modelling and simulation as a service (MSaaS) (Cayirci Karapinar and Ozcakir 2017; NATO MSG-136 2017).

5. CONCLUSION

Although the domain of joint military space operations is critical for the success of joint operations and need to be integrated into joint operations planning and therefore practiced during CAXs and wargames, the JMSOS capability is typically not available or very limited for the exercises. We think that the main reasons for that are two folded:

- Operational space picture is very seldom of interest for the commanders and staff in operational and higher levels, although it must be.
- Changing the operational space picture during the execution phase of an exercise is typically not possible.

However, space mission areas are not limited to SCO and SSO but also SFEO, which has a major impact on joint operations and operational picture. Without a proper JMSOS capability, it is too difficult to portray a complete and realistic synthetic theater, and therefore it is important to employ the JMSOS tools especially in joint operational and higher level CAXs and wargames. Nevertheless, proper JMSOS tools are not available. Typically, a limited and indirect set of JMSOS functionalities are implemented in some military constructive simulation systems.

ACKNOWLEDGMENTS

This work is conducted as part of the HAVELSAN project titled as "Service Oriented Cloud Based Simulator/Simulation Development and Modelling Infrastructure" funded by TUBITAK 1511-BIT-BBIL-2015-2 program.

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