

## Creating Common Ground: The Impact of Terrain on Distributed Mission Operations

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### ABSTRACT

U.S. Special Operations Command (USSOCOM) is committed to providing its Service Component and Sub-Unified Command Commanders a synthetic environment enabling distributed mission operations/training, exercises, and no notice/short notice mission rehearsal.

In October 2016, the Under Secretary of Defense for Acquisition, Training, and Logistics and USSOCOM began an effort to improve Modeling and Simulation (M&S) systems interoperability, resulting in several standardization focus areas. One of these areas involved the National Geospatial Intelligence Agency (NGA) launching a wide-reaching project focused on the Open Geospatial Consortium's Common Database (OGC-CDB) as the standard for M&S geospatial data support. USSOCOM's Directorate of Operations, Training and Education Division, assisted by the Joint Staff J6, was tasked to assess NGA's CDB terrain delivery capability to support a USSOCOM distributed training event.

Bold Quest (BQ) 21.1 was the venue for this assessment. From 26 July to 12 August 2021, BQ 21.1 included all USSOCOM Components, the Joint Special Operations Command, the U.S. Army, and the Air National Guard. BQ 21.1's primary objective was to assess the interoperability of proprietary runtime databases built from CDB. The secondary objective was to support the development of USSOCOM's distributed training and mission rehearsal capabilities across its components and sub-unified commands. This paper describes the impact on simulator interoperability by using CDB-based terrain data and lessons learned about the process of creating a multi-component synthetic environment.

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### INTRODUCTION

Enacting change within the Department of Defense (DoD) is a challenging and often slow process. Multiple standards must be balanced regarding flexibility and security, and budgets must make space for the required support changes. Starting with an October 2016 Under Secretary of Defense for Acquisition, Training, and Logistics (USD(AT&L)) and U.S. Special Operations Command (USSOCOM) Acquisition Summit, USSOCOM proposed improving Modeling and Simulation (M&S) systems interoperability for DoD-wide distributed environment through DoD acquisition policy. The Joint Staff (JS) J7 and then USSOCOM J7-T&E agreed on the need for an acquisition policy to drive the Services to buy/develop M&S systems built to a common set of standards and technical approach. USD(AT&L) took the issue for action and tasked the Defense Modeling and Simulation Coordination Office (DMSCO) to coordinate a plan of action. After close coordination between DMSCO, USSOCOM, the Services, and the JS, a multi-pronged approach was proposed to address USSOCOM's challenges, which are symptomatic of similar challenges across DoD:

- Effective and timely joint training and mission rehearsal of conventional forces and Special Operations Forces (SOF) are hindered by incompatible, non-interoperable Service and USSOCOM-provided simulations and simulators
- This substantive interoperability challenge results in costly inefficiencies in acquiring cross-service simulators that provide an adequate and fair representation of the battlespace for Distributed Mission Operations (DMO)

One challenge was attributed to the lack of a standardized database (DB) used in Service provided simulators. The 17 October 2018, the Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)) Decision Memo – affirmed the problem statement and added:

- "USSOCOM and Joint Staff J6 will identify a future integration test event, such as Bold Quest, to exercise the NGA-CDB capability in a multi-Service demonstration"
- "USSOCOM and Joint Staff J6 will begin to collect metrics to show potential improvement opportunities using this capability"

### CREATING A UNIFIED STANDARD

Directed by OUSD(R&E), NGA led a wide-reaching project focused on using OGC-CDB as the standard for M&S geospatial data support throughout DoD. CDB was designed to not only be a non-proprietary runtime format using open industry standards, but also is structured in such a way to serve as a repository -- thus allowing for centralized content storage and, when needed, easily converted to specific end user runtimes (Graham, 2015). Theoretically, 'plug-and-play' interoperability would be increased between CDB-compliant simulators (using CDB as the runtime format) as the need to create various proprietary formats (often using expensive, proprietary tools) would be eliminated. However, the number of CDB-compliant systems within USSOCOM and the Services is small.

Representing the earth's surface in the same way across different simulators is a complex problem in the M&S domain. While most simulation standards specify the earth model, or ellipsoid, to use as an approximation of the earth's surface, simulation developers are generally free to select different types and formats of source data, most of which contain subtle differences that can result in vastly uncorrelated locations between two different vendor's simulators (Navalur.

Abrams, 2021). Additionally, there are differences in how different simulator developers correlate and compile source data into runtime formats to represent real world terrain and terrain features. The result is that disparate simulators frequently do not – and cannot – share a common view of the simulated environment. One of the goals of BQ 21.1 was to determine how OGC-CDB could help resolve this problem.

CDB showed promise to provide a common geospatial environment for DoD simulators, allowing distributed simulators to share a common view of the synthetic world and significantly reduce runtime correlation errors. Each of the simulators participating in BQ 21.1 used the same terrain source layers built by USSOCOM's SOF Planning, Rehearsal, and Execution Preparation (SOFPREP) Branch – except for the U.S. Army's participating system, with its internal DB known as "One World Terrain (OWT)."

As mentioned above, not all simulators could read CDB during BQ 21.1 in its native format. This required the construction of those proprietary formats participating in the exercise to be constructed in order to meet the other stated exercise purposes. USSOCOM's SOFPREP Branch constructed CDB for the exercise area of operation and converted either the CDB or the source data used to make the CDB into five different visual formats for each of the runtimes required by the participating simulators (Reed, 2017). The CDB was also successfully transferred to and hosted by NGA on their Geospatial Repository and Data Management System (GRiD). GRiD allows outside users to download CDB for the BQ 21.1 area of operations in various standard formats for their use.

An additional layer of requirements for using a DB in USSOCOM simulators are the requirements laid out in USSOCOM Directive 71-3, *Database Generation System Requirements, Prioritization, and Production Management (2018)*. The minimum acceptable tolerances for USSOCOM terrain databases includes two critical metrics: accuracy and speed. "The timeline for production of full-up simulator with associated sub-system crisis DBs should be kept within 96 hours. The timeline for production desk/laptop mission preview crisis DBs should be kept within 48 hours" (USSOCOM, 2018). The DBs SOFPREP created were broken into elevation data layers, imagery layers, and feature data layers. The geospatial accuracy standards, comparing the DBs against the standard simulation ellipsoid model, World Geodetic System 1984 (WGS84), are three meters (m) for a target and 10m for a corridor for the absolute horizontal and vertical.

## ASSESSING THE STANDARD

All parties involved in the decision memo agreed to execute this test at a Bold Quest (BQ) event in 2021, which is accustomed to flexibility in assessments, with its roots in the Advanced Concept Technology Demonstration world. The objective of BQ 21.1 was to demonstrate and assess improvements to geospatial interoperability between distributed simulators at USSOCOM Components, the Joint Special Operations Command (JSOC), and specified U.S. Army and U.S. Air Force units, leveraging the OGC-CDB standard. Improving geospatial interoperability supports the long-term development of USSOCOM's distributed training and mission rehearsal capabilities. The USSOCOM Directorate of Operations (J3), Training and Education Division (J3-T&E) is committed to providing its Service Component and Sub-Unified Command Commanders a distributed synthetic environment that is operationally representative of and consistent with SOF combat operations. An adequately architected distributed environment, with interoperable systems, enables distributed SOF mission training, exercises, and no notice/short notice mission rehearsals using the existing and future inventory of Service and SOF provided three-dimensional (3D) virtual simulations.

BQ 21.1 was executed by USSOCOM in partnership with the JS J6 and NGA. BQ 21.1 occurred from 26 July to 13 August 2021, with the test control operating from the SOF Training Support Center (STSC) at Hurlburt Field, Florida, and participants networked in from:

- Air Force Special Operations Command (AFSOC) units at Hurlburt Field, FL and Cannon Air Force Base, NM
- JSOC at Fort Bragg, NC
- Marine Corps Forces Special Operations Command (MARSOC) at Stone Bay, NC
- Navy Special Operations Command (NAVSOC) at Coronado, CA
- U.S. Army Special Operations Command's 160<sup>th</sup> Special Operations Aviation Regiment (Airborne) (160<sup>th</sup> SOAR) at Fort Campbell, KY
- Air National Guard's (ANG) Distributed Training Operations Center (DTCO) at Des Moines, IA

- U.S. Air Forces Europe's Warrior Preparation Center (WPC) at Einsiedlerhof Air Station, Germany

BQ 21.1 execution was preceded by two integration and test events, which provided a baseline measurement of the general state of interoperability in distributed simulation.

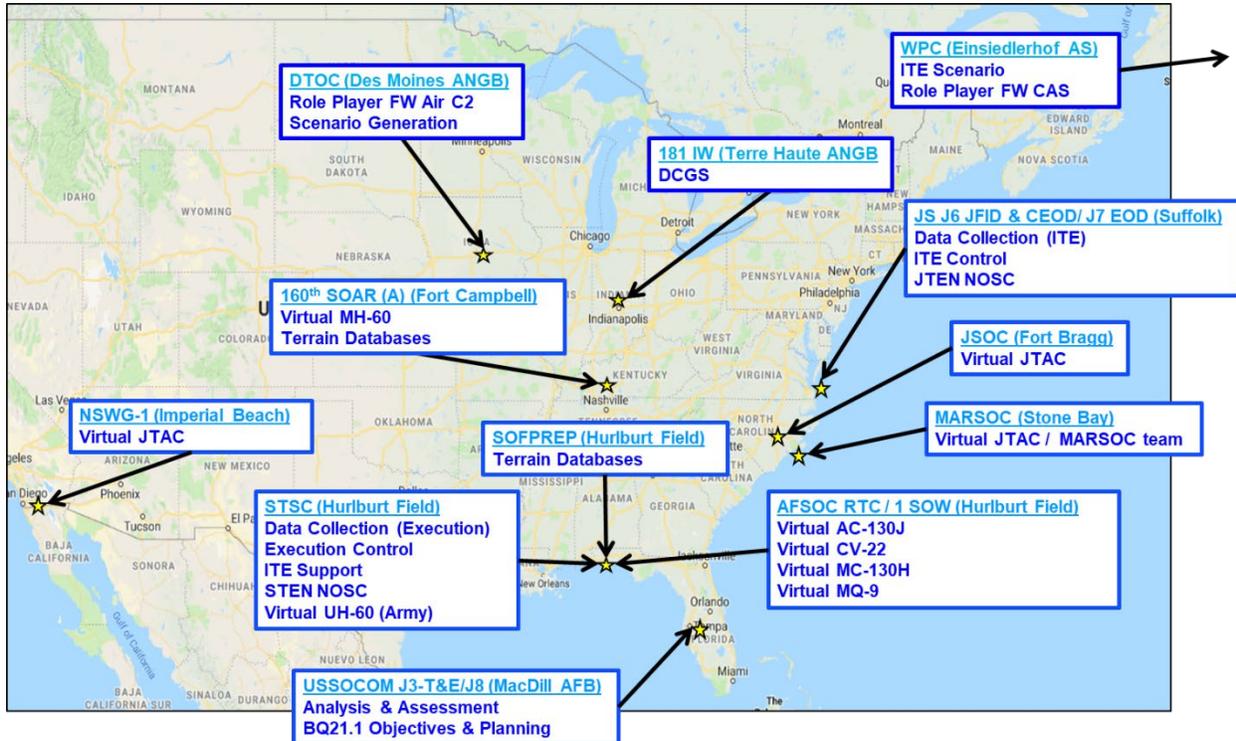


Figure 1. BQ 21.1 Sites, Units & Supporting Organizations

The team evaluated the improvements gained upon implementation of CDB, with a focus on holistically addressing simulation interoperability – attempting to use qualitative and quantitative analysis to assess technical and conceptual aspects of interoperability. However, the plan did not survive some of the unexpected interoperability challenges presented during the multi-month evaluation.

There are many definitions of interoperability, even within DoD. Joint Publication 102, *Department of Defense Dictionary of Military and Associated Terms*, offers two interpretations of interoperability. The first is a conceptual definition of interoperability as "the ability to act together coherently, effectively, and efficiently to achieve tactical, operational, and strategic objectives." The second definition focuses on technical interoperability: "the condition achieved among communications-electronics systems or of communications-electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users" (DoD, 2018). Discussions of interoperability in the wider Live, Virtual Constructive (LVC) domain address technical interoperability between systems. There is extensive literature on LVC technical interoperability, with the Levels of Conceptual Interoperability Model (LCIM) being perhaps the authoritative source (Tolk, 2003). The LCIM model describes seven layers of interoperability between systems, ranging from no interoperability to interoperability at an advanced conceptual level, where "[i]nteroperating systems are completely aware of each other's information, processes, contexts, and modeling assumptions" (Wang, Tolk & Wang, 2009).

In this case, we understood that the connected systems communicated technically – and the gaps of technical interoperability between the systems would, in some cases be seamless to users and, in other cases would cause critical negative training impacts. This understanding, focusing on end user impact and sheer technical differences, focused on the capacity of operators to gain situational awareness using synthetic environments generated by respective simulators and their ability to reference features in the environment to communicate with other elements (Figure 2).

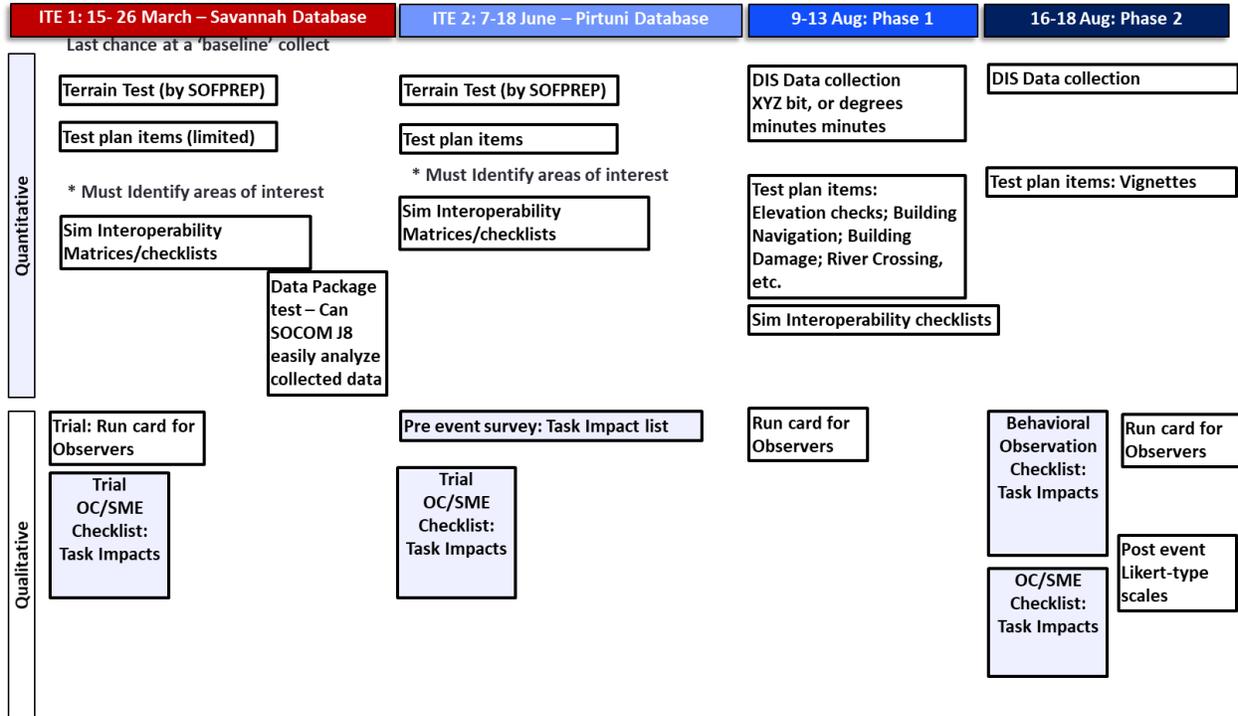


Figure 2. High level depiction of the assessment

Additionally, the team assessed the simulators' ability to render a timely common visual representation and outcomes once other simulators performed specific actions (i.e., movement, use of weapons, etc.). The timely ability of simulators to decode data incoming from other simulators is essential for coordinating entity positions in synthetic environments. Meaningful interoperation of simulators requires continuous alignment of entities represented in their respective environments (IEEE, 2010). This assessment includes calculations of the delta between entity positions across simulators. A similar approach was applied to evaluating impact on the target and the after effects of target engagement. Table 1 outlines these and other technically oriented test events used to assess how each simulator handled the terrain data at both a system and a user level.

Table 1. BQ 21.1 Integration Test Event (ITE) I, ITE II, and Execution Test Plan

Test	Name	Purpose	Detailed Description
1	Network Connectivity	Confirm network functionality for all participating sites (i.e., " <u>Is everything connected?</u> ")	1. Ensure the SOF Training Exercise Network, Joint Training Exercise Network, and the Air Reserve Component Network support the two-way flow of Transmission Control Protocol/Internet Protocol and Unit Deployment Program multicast traffic between all participating sites. 2. Ensure all participating simulators synchronize time.
2	Technical Integration	Confirm Distributed Interaction Simulation (DIS) technical interoperability between all participating sites (i.e., " <u>Does everything work as it should?</u> ")	1. Ensure DIS multicast traffic (data and voice) flows between all sites and simulators. 2. Ensure all sites are following the BQ21.1 guidance for simulator configuration (DIS data, DIS voice, and Full Motion Video (FMV)) 3. Ensure DIS enumerations follow the BQ21.1 DIS Enumerations List.
3	Operations Integration	Confirm operational interoperability between all participating sites (i.e.,	1. Confirm DIS entity model mapping and correct behavior of entities and weapons. 2. Confirm laser designators, smoke, and Infrared (IR).

		<u>"Does everything support training and mission rehearsal as it should?"</u>	<ol style="list-style-type: none"> <li>3. Confirm night vision capabilities.</li> <li>4. Confirm FMV send/receive from individual simulators.</li> <li>5. Determine any issues with terrain correlation between various terrain database formats of Pirtuni.</li> </ol>
4	Elevation Check	Determine if there are any entity elevation differences at a grid location between multiple different terrain databases.	<ol style="list-style-type: none"> <li>1. Sites take turns placing a virtual entity on the ground at Point A.</li> <li>2. Entity should be facing due north.</li> </ol>
5	Low Level Flight	Determine any differences in elevation, relative altitude and terrain features between multiple, different simulators.	<ol style="list-style-type: none"> <li>1. Sites take turns placing a vertical take-off-and landing capable aircraft on ground at Point A.</li> <li>2. Aircraft takes off and conducts vertical climb to 200 feet (ft) Above Ground Level (AGL) over Point A.</li> <li>3. Aircraft flies to Point B at 100 knots (kts) ground speed, hovers, and vertically lands at Point B.</li> <li>4. Entity produces DIS Entity State Protocol Data Units (PDU) throughout the test.</li> </ol>
6	Weapons Effects	Determine if there are any differences in weapons effectiveness between multiple, different terrain databases.	<ol style="list-style-type: none"> <li>1. Sites take turns employing onboard weapons at a ground vehicle target located at Point D.</li> <li>2. STSC will place the target vehicle, a "Technical" small pickup truck with a weapon in bed and one Insurgent w/AK-47 in the driver's seat.</li> </ol> <p>Note: Participants will maneuver in the optimum firing position for their particular weapon.</p>
7	Road Navigation	Determine if there are any differences in road networks between multiple, different terrain databases.	<ol style="list-style-type: none"> <li>1. Sites take turns driving a vehicle along a short section of roadway.</li> <li>2. Vehicle starts at Point E and drives along a road to Point F.</li> </ol>
8	Building Exteriors	Determine differences between high fidelity virtual building representation between multiple, different terrain databases.	<ol style="list-style-type: none"> <li>1. Sites take turns observing and reporting on characteristics of the high-fidelity building located at Point H.</li> <li>2. To make observations, site entity should be located at or near Point I for consistency.</li> <li>3. Characteristics of interest include number of floors, door types and location, window types and locations, roofing material and colors/textures.</li> </ol>

Supporting the qualitative analysis were the following survey apparatuses. They were filled out by users at all assessment events, who were a mix of Subject Matter Experts (SME) and uniformed operators brought in to use the systems:

- Entity Visibility
- Elevation Check
- Low Level Flight
- Weapons Effects
- Road Navigation
- Building Exterior
- Demographics
- Impact of Visual Environment (Terrain, Landscape, Buildings, etc.) on Ground & Air Tasks
- Post Mission Feedback

## RESULTS FROM INTEGRATION AND TEST EVENTS

### ITE 1: 15-26 March 2021

In order to establish a baseline for measuring geospatial interoperability difference later in the test, ITE 1 was conducted using the Fort Stewart GA terrain database. This environment served as a benchmark, as it had been developed five years earlier, using multiple source data sets for different participating runtimes, to include Aechelon, Virtual Reality Scene Generator (VRSG), Vital, and Virtual Battle Space Three (VBS3). Six tests from Table 2 (items 1-6) established network connectivity, technical integration, and operational integration baselines. ITE 1 found both expected and unexpected results.

- Terrain databases sourced from different organizations and different source data do not provide well correlated representations of the real world between simulators. Many of the pre-determined points during the event could not be used due to simulator system-generated trees, power lines, and other 'cultural' data that did not match the actual site.
- Ground clamping in simulators settings does not change the height broadcast in the DIS entity state PDU. It did correct visual mismatches for the end user, but did not correct data mismatches.
- Weapons effects were primarily successful. Damage states did not show fine levels of degradation, settling either at 0 or 100%.
- Without a common terrain elevation height shared between the participating simulators, the data that interprets a platform's altitude can produce aircraft at unexpected heights above ground.

#### **ITE 2: 7-18 June 2021**

With a baseline of the current 'normal' way of operating collected in ITE 1, SOFPREP produced terrain databases for the 'Pirtuni' area of operations, drawn from the U.S. Army's Decisive Action Training Environment. Creating terrain from a CDB source, built on the lessons learned from the first test event, resulted in more accurate geodesic terrain measurements, and features across the range of participating systems.

The assessment team added the tests on building exteriors and road navigation to highlight how terrain modeling varied between simulations and how each system handled roads, buildings, and general structures (Table 1). ITE 2 found new challenges despite the improvements in functional correlation and end user task performance.

- Terrain database correlation can be improved by one organization using a common source data, such as CDB, and managing production of all other participating runtimes.
- Building and structure damage is extremely difficult to correlate in a distributed environment, due to how different simulators model cultural states (i.e., buildings and roads). Some systems treat roads and bridges as terrain, others as cultural states. For example, a bridge in one system might provide a stable surface for a user to drive a vehicle across; in another system, that same bridge might drop the user into the water to drive across the riverbed, under the water.

#### **Event Execution: 2-13 August 2021**

BQ21.1 execution included the test events from both of the previous ITEs, and added two mission rehearsal exercises in the Pirtuni database area. This event also added the Army's Cockpit Academic Procedural Tool – Enhanced Visual Control System (CAPT-EVCS) UH-60 simulator. Due to it being early in development, CAPT-EVCS could not meet cybersecurity requirements for network connection. It was transported to Hurlburt Field and set up in STSC for testing. This system was unique because it was the only participant using the Army's One World terrain format.

Execution began by testing OWT using the Army Game Studio Image Generator (AGS IG) and the U.S. Army's Cockpit Academic Procedural Tool–Enhanced Visual Control System's UH-60M Aircraft Avionics Procedural Software (AAPS). USSOCOM provided DIS entities and CDB on VBS3 for comparison. Discrepancies between terrain elevation and building features/textures were noted. However, there were also discrepancies among CDB database driven IGs, like IG implementations for entity models, damage states, responsive buildings, IR filtering, etc. The focus was primarily on the base terrain plus geo-specific building features/textures.

Of all the results comparing OWT and CDB sourced data, the most significant gap existed in geospecific / geotypical models (trees, buildings, towers, etc.). OWT received and included CDB-sourced geo-specific/geo-typical models in their data pull. However, what did not make it into the rendered output is the real world textures/graphics associated with those models. The AGS IG rendered view shows the correct model shape, size, and location but without the CDB textures/graphics/etc. The OWT models simply had whatever native terrain texture it had for those locations wrapped over the model. The end effect was that geo-specific models had OWT imagery overlay which looked similar to the buildings (metal roofs, concrete walls, blue shutters, etc.); however, geo-typical models simply had the base OWT terrain for that location, meaning that if in the real-world bare sand is at that location, OWT overlaid a brownish curtain over the model, say the shape of a water tower. However, as a first conversion, OWT's deviations were similar to those presented by other models in the quality of their building models.

**Table 2. Weapons Effects Test During BQ 21.1 Execution**

	Elevation	Impact	Effect
AGM 176 Griffon	10m	Splash Splash Splash	0% + Crater (cont) 0% + Crater (cont) 0% + Crater (cont) 100% Destroyed (AB 6')
AGM-114 Hellfire	10m	Splash Neg Impact	0% + Crater (AB 7')
PGM	10m	Splash	Destroyed
GBU-39	10m	Splash Splash Splash	0% Crater (cont) Destroyed (AB 14') Destroyed
30mm	10m	Within 1 ft'	Destroyed (HE)
105mm	10m	.5 Direct	Destroyed (HE) Destroyed (HE) Destroyed (Prex)

Particularly challenging for the main event was the mismatch of weapons effects. The weapons test was performed for each simulator with mixed results (Table 2). Each of the 0% effects was verified to have been correctly on target according to system data and self-declared coordinates, but did not register due to a mismatch of elevations between the systems, and how those systems represented center mass of a target. In a deeply involving scenario spanning multiple systems, assets and end users, this mismatch between distributed simulations could create negative training impacts.

**Table 3. Test 1-4: Example Elevation Check results**

System	ITE 1	Ft. Stewart Location	ITE 2	CDB Sourced Data
	Alt Delta	Ground Delta	Alt Delta	Ground Delta
AFSOC AC-130J w/ VITAL	-83.12	1.76		
AFSOC CV-22 ATD w/ Vital	-85.92	8334.04	-149.57	771.05
AFSOC MQ-9 MSAT w/ VRSG	-84.88	1.76		
MARSOC Marine VBS3	-86.46	1.76		
JTC-TRS			-152.31	2.79
MH-60			-149.71	20.30
MC-130H WST			-154.02	703.61

Poor terrain correlation was initially observed between OWT running on AGS IG and CDB running on VBS3 (on the order of 200+ feet). The team determined that some of the mismatch was due to the modeling mechanism within AGS IG. Essentially, current AGS IG implementation uses the Cesium 3D plugin for the Unreal Engine 4 based IG. The IG currently uses a flat-earth model, mapping OWT onto a flat-earth. This is a valuable technique for local (near-origin) troops on the ground simulation. The origin is essentially the point to which the IG clamps the database, and thus references all additional calculations.

The issue is that as the team moved farther away from the origin point, the earth's curvature was not considered, which provided additional deltas between the VBS3 WGS-84 ellipsoid, the AGS IG flat-Earth model, and the UH-60M flight model WGS-84 ellipsoid. Initially, the test team used two map loads with a unique origin point; however, neither was particularly close to the points of interest (POI). A patch was provided enabling the loading of the database with a unique origin very near each of the POIs. This eliminated the flat-earth versus WGS-84 ellipsoid discrepancies; however, elevation deltas of ~125 feet at specific POIs were still noted, though some were below 10 feet. Most terrain elevation mismatches post-patch appear to be within OWT and not the AGS IG implementation.

Three meter discrepancies are prevalent between different IGs for entity altitude correlation due to different entity models and their Cartesian reference (where on the model the point of origin is considered to be). See table 3 for the span of results that the team experienced across all systems during the testing events. Some IGs/models use the lowest point; others use a nominal center of gravity. Some use the lowest point for ground entities and a nominal center of gravity for air entities. The host simulations are likely using a different reference for the DIS entities they are broadcasting. It becomes an issue when determining precisely what is responsible for those more minor altitude mismatches. The DIS entity state PDU generator used has an input for altitude offset to help alleviate this when operating in a collective environment. For this test, the offset was set at 0 feet, to allow for measurement of an uncorrected state.

Between ITE-2 and the final execution, the deltas narrowed critically. All systems were able to generate the entity at an altitude within a proximity of 2.41 meters to target. Additionally, all systems participating in the event could locate within 2.78 meters of the given location. This mostly allowed the systems to operate within feet of each-other. Visually, all entities could be placed approximately on the ground with minimal model clipping into the ground.

Thanks to several team members, USSOCOM overcame some of the scenario obstacles with input from key stakeholders to create more realistic scenarios for the final execution of the two distributed scenario events. Using a standard military planning battle rhythm made training more realistic. Visual issues arose, and resetting the visual entity and ground clamping was done to resolve some of the issues. Some destroyed states failed to transfer on entities, but overall damage states were achieved. This "proof of concept" for networking simulators with different runtimes forced USSOCOM and the Services to come together and work with other simulation centers to discover pitfalls and solutions to support DMO execution.

## **LESSONS LEARNED**

While the Pirtuni database for this event was built from the same source terrain data, it was a reversal of the norm from basic good practices for database creation. Databases are usually built from a small geospecific location, (a target area) then built out to suit the air component or the ground component based on the mission set. In BQ 21.1, a large geographic area was initially built, and then once the targets were agreed upon, SOFPREP was asked to enhance two smaller target areas later during exercise development. In the future, targets should be identified first, and then surrounding terrain built out depending on the device and end user requirements.

Minimum hardware and software settings must be defined before starting simulation operations. One user on VRSG will not necessarily be the same as another VRSG user.

Due to the initial size of the database, load times were too long, and tweaks for each system were not possible without reducing the size of the target area/database for each participating simulation system/runtime. Multi-gigabyte data sets are still hard to transfer and often have to be loaded onto a hard drive and physically mailed. This is a long-term challenge to be solved. The distribution of modeling data for both physical and cultural terrain had to be frequently modified. 3D terrain packages are not plug and play. Several participants had to reach out to simulator SMEs within the commercial sector for assistance. Load times were as high as 7.5 hours from start to finish. This was a heavy burden for simulator operators, especially those working from the west coast of the U.S. or overseas. However, the use of distributed simulation technology eliminated the need for USSOCOM units to travel or rely on live fire ranges.

Cybersecurity remained the Achilles' heel of persistent distributed simulation during this assessment. It is on the "critical path" with complicated and long-lead times to accomplish. Despite this being a terrain assessment, the team still had to aggressively monitor sites to help them accomplish cybersecurity requirements and processes. This includes the Authority to Operate (ATO) and the Authority to Connect (ATC).

## **CONCLUSIONS**

Three years of planning were required to execute the OUSD(R&E) decision memo guidance to improve simulator interoperability. While the team encountered turbulence during execution (e.g., ATOs being approved at the last minute, connectivity challenges with cut lines and commercial outages, the COVID-19 pandemic), BQ21.1 was the first time all USSOCOM components and JSOC were able to participate in a distributed simulation event at the same time, on a correlated database, on a distributed network. The collection of systems participating also represented five

different simulation system runtimes, which was a challenge for any terrain production organization, even when drawing from a centralized data repository such as NGA's GRiD.

Second, this centralized DoD repository for correlated source data was beneficial for creating the terrain databases fused in this assessment. Due to the small number of participating CDB-compliant simulators, a definite conclusion on how much CDB used in its native format at runtime would further reduce interoperability issues is unknown; however, the findings from ITE-1 and ITE-2 clearly show that using the same correlated source data layers did reduce interoperability issues. NGA's current effort on building and maintaining a DoD centralized repository of CDB data that can be converted to 2D and 3D common formats has excellent potential for the M&S community and other uses such as mission planning.

Third, BQ21.1 was the first "test flight" of USSOCOM's new distributed simulation enterprise, connecting all its components, JSOC, and other Services in a common synthetic environment. However, as the saying goes, with great power comes great responsibility. Managing and maintaining this enterprise capability will require significant effort and investment in configuration management, systems integration, and periodic testing to ensure USSOCOM's simulation capability can meet its future requirements for distributed training and no notice/short notice mission rehearsals.

Finally, DoD should encourage a standard model and structure for storing and disseminating geospatial content for use in simulation systems, especially virtual 3D representations of the earth. DoD should also discourage other Services and Agencies from building their own. The interoperability of CDB and the Army's OWT outlined above highlight the pitfalls associated with multiple standards for representing geospatial data and will reduce overall DoD interoperability between Service M&S environments.

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