

A Persistent LVC Simulation Environment for UAS Airspace Integration

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ABSTRACT

Unmanned Aircraft Systems (UAS) are a key component of the overarching systems-of-systems needed to engage an asymmetric, agile threat in both current and future military engagements. A UAS can itself be considered to be a system-of-systems, integrating advanced airframe, sensor, weapon, and communication technologies into a critical capability in modern operational strategies. To effectively procure such a complex system, advanced modeling and simulation (M&S) capabilities have become an inherent aspect of contemporary systems engineering practices. Live, virtual, and constructive (LVC) M&S resources are routinely applied across all acquisition program phases to reduce technical risk and lower lifecycle costs.

This paper reports on an M&S initiative to develop a persistent LVC simulation environment to support UAS Airspace Integration (AI) analysis, testing, and training¹. The Live, Virtual, Constructive Distributed Environment (LVC-DE) concept involves using a mature, reliable DoD networking infrastructure (Joint Mission Environment Test Capability) to link multiple government M&S facilities into a single unified environment for representing the external flight environment that a UAS must operate within. Such representations include actual commercial flight traffic patterns, a wide variety of target entities, and supporting military aircraft. By reusing this government-managed environment, UAS system developers can focus on the representation of their own systems as they evolve, and interface with the LVC-DE to investigate pertinent safety issues and associated system design issues associated with integration of their systems into the National Airspace System (NAS).

In FY09, the Navy's Broad Area Maritime Surveillance (BAMS) Program served as the LVC-DE pathfinder, providing the funding resources and analytic requirements needed to drive the baseline development. A series of design meetings and integration events were conducted throughout the year, culminating in a successful "Runs for Record" (RFR) in December 2009. This paper will describe these efforts, and also define ongoing LVC-DE development/employment efforts in FY10.

¹ This document was generated under the direction and funding of the Naval Air System's Command PMA-262 Persistent Maritime Unmanned Aircraft Systems. Contract Number N00019-08-C-0023 applies.

ABOUT THE AUTHORS

Robert Lutz is a principal staff scientist at The Johns Hopkins University Applied Physics Laboratory in Laurel MD. He has over 29 years of experience in the design, implementation, and evaluation of modeling and simulation (M&S) systems for military customers. Currently, he is serving as the Navy's Broad Area Maritime Surveillance (BAMS) Program M&S lead in the Airspace Integration (AI) area. In this role, Mr. Lutz leads several M&S initiatives, including the development and employment of the Live, Virtual, Constructive Distributed Environment (LVC-DE). Mr Lutz is also actively participating in the LVC Architecture Roadmap (LVCAR) Phase II effort, and leads several M&S standards activities within the Simulation Interoperability Standards Organization (SISO). He also serves as an Executive Committee (EXCOM) member within SISO, and is a regular guest lecturer in The Johns Hopkins University Whiting School of Engineering.

Dr. Kenneth G. LeSueur serves as the Chief Technologist in the Subsystems Test Division at the U.S. Army Test & Evaluation Command (ATEC) Redstone Test Center (RTC) and has over 23 years experience in Test & Evaluation. His work and research have been concentrated in the areas of Hardware-In-The Loop (HWIL) testing of missile systems and optical sensors, distributed testing, Modeling and Simulation (M&S), and high performance computing. Dr. LeSueur is a leader in the area of Joint distributed LVC testing, directing a highly qualified and experienced staff with an extensive distributed test infrastructure, and an array of M&S capabilities. He serves RTC as the technical coordinator for three System Integration Labs (SILs) supporting all major commodities tested in the center. These SILs provide a means to link and synchronize all RTC test resources within the center to other Army developmental and operational test centers, and to joint, interagency, and multinational environments.

Paul R. Fast is a Vice President, Business Development Manager for Science Applications International Corporation (SAIC), and is currently the Outreach Director on SAIC's contract at The Simulation Laboratories at NASA Ames Research Center in Silicon Valley, CA. Mr. Fast is also an Air Battle Manager in the U.S. Air Force Reserve, and is the Director of Operations of the 701st Combat Operations Squadron, March Air Reserve Base, CA. Mr. Fast has over 18 years of civil and military flight operations and leadership experience. Mr. Fast's modeling and simulation integration experience ranges from integrating dissimilar military flight and command and control platforms, to integrating civil aviation, air traffic control, and unmanned systems in virtual distributed environments. Mr. Fast has led projects and programs for the USAF (Combined Air & Space Operations Center – Nellis), OSD (Joint Fires Coordination Measures Joint Test & Evaluation), and NASA. Mr. Fast, as Outreach Director at NASA Ames, is responsible for bringing new users of real time human in the loop simulation to The Simulation Laboratories (SimLabs), which includes the Vertical Motion Simulator (VMS), multiple hexapod motion-base civil air transport simulators, an air traffic control radar simulation lab, and Future Flight Central, and virtual air traffic control tower.

Richard Graeff is the Infrastructure Branch Chief at the Simulation & Analysis Facility (SIMAF) at Wright-Patterson Air Force Base in Dayton, Ohio. He has over 25 years experience in conducting USAF acquisition and analysis support to the B-2, Global Hawk (GH), Reaper, J-UCAS, and Broad Area Maritime Surveillance (BAMS) Programs, as well as several joint & coalition initiatives. He currently is the technical manager for all UAS projects in the SIMAF, including M&S support to the OSD UAS Airspace Integration IPT and BAMS/GH Airspace Integration efforts, the Global Hawk Ground Station Re-Architecture, and is the Air Force M&S Lead for the Central Test & Evaluation Program (CTEIP) Joint UAS Mission Environment.

Anuradha Simlote has been working as Project Lead at IBST, NAVAIR for past several years. In this capacity she has led wide-ranging projects and has had the opportunity to work with distributed programs using DIS and TENA architectures, and is developing a UAS integration laboratory that supports testing of STANAG compliant UAS as well Directed Energy-related projects. Currently, she is serving as the P-8A (PMA-290) Government M&S lead. In this role, Ms. Simlote supports requirements traceability for M&S supported testing and verification of M&S. Ms. Simlote has a Master's Degree in Electrical Engineering from Drexel University in Philadelphia PA and a Master's Degree in Project and Organization from John Hopkins University in Baltimore MD.

John H Rutledge is a Senior Systems Architect with Trideum Corporation. Mr. Rutledge uses over 19 years of software and systems design, development and management experience in directly supporting the Joint Mission Environment Test Capability (JMETC) Program Office as an Event Support Lead. He served over 9 years in the United States Air Force (USAF) where he honed his skills in modeling and simulation development and design. Since leaving the USAF Mr. Rutledge has supported various projects from organizations including NASA, Missile Defense Agency, the US Army's Future Combat Systems (FCS) and now the Office of the Secretary of Defense.

Robert Mottl is the Northrop Grumman (NGC) Bethpage Cyber Warfare Integration Network (CWIN) Operations Manager responsible for the virtual, real-time modeling and simulation development activities. The NGC Cyber Warfare Integration Network is founded on physics based models, classified connectivity with multiple NGC, Government and Industry sites that supports Live, Virtual Constructive simulation in a classified, distributed Environment. Mr. Mottl brings over 25 years of Weapons System development, integration, and both Laboratory & Flight Testing to the modeling and simulation environment. He has lead the Bethpage integration effort to enable multiple Government and Industry simulation tools to become interoperable including JSAF, JCATS, EADSIM, MAPES, BAM and other DIS/HLA compliant applications. All of these tools have been utilized by the Bethpage team to support numerous Government Experiments and events, such as USAF ACE 08 & 09, Empire Challenge events at JFCOM, SIMEXs at MITRE, AGILE Fire from USAF SIMAF and the 2009 BAMS Airspace Integration LVC-DE experiment.

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BACKGROUND

Unmanned Aircraft Systems (UAS) represent new vehicle and operational concepts in civil aviation. With the emergence of these new concepts comes the desire for UAS to perform the “dull, dirty and dangerous” missions required by the nation’s science community (NASA, NOAA), emergency management (FEMA, DOA) and national security and defense organizations (DHS, DOD). Although this implies an urgent need for less restrictive access to the National Airspace System (NAS), there is a lack of common understanding of what is required to safely operate UAS in the NAS.

Currently, federal air regulations, procedures and technologies do not permit “routine UAS access to the NAS”. The lack of an on-board pilot, the ability of a single pilot/operator to control multiple aircraft, the strong reliance on command links, and wide performance variations are some of the unique attributes of UAS. The FAA has established a process where government agencies can request a Certificate of Authorization or Waiver (COA) to operate a UAS in the NAS. The COA process tends to be extremely resource intensive and lengthy, and COAs are restrictive and often lack the flexibility to meet the full mission needs. UAS operational restrictions are imposed due to the immaturity in standards and capabilities required to maintain safe separation from other aircraft, and to mitigate risk to personnel on the

ground. The resulting issues include impacts on system performance/safety due to communications/link latencies, flight rules (how do you operate in a mixed environment?), and operator certification (what tasks must the operator perform?).

As the demand for government and industry access to the NAS by UAS increases, the importance of addressing these challenges grows exponentially. The central question is how does government and industry gather sufficient data to make credible, informed decisions? In order to gather that data, a highly credible, verifiable data source must be utilized to experiment with existing and emerging technologies and procedures. With this new data, new processes, procedures, and ultimately, policies can be addressed, allowing access to the NAS by UAS to be truly “routine.” Figure 1 depicts an operational view (OV) of how UAS may be integrated into the NAS in today’s air traffic management environment.

While the nation’s science, emergency management, and national security communities work with the regulatory agencies and industry to address the concerns of integrating UAS into the NAS today, many of the same communities are addressing the air traffic management (ATM) system of tomorrow, known as the Next Generation (NextGen) ATM system. NextGen will be less centralized, and will be more automated, as depicted below in Figure 2.



Figure 1 – UAS Integration into the NAS

Unmanned systems will represent a larger share of the airborne fleet mix in 2025 than we currently see today. As the NextGen ATM concept matures, there will be many new issues related to the integration of UAS into the NAS. This requirement to operate safely in the NAS has implications for many UAS acquisition programs. On-board subsystems like collision avoidance sensors and low-latency, highly-reliable communication datalinks may be required to achieve defined levels of safety. Verification that these requirements are being met requires highly sophisticated evaluation techniques to account for the inherent complexity of UAS operations within the

NAS. The underlying method generally associated with such techniques is modeling and simulation (M&S), as closed-form techniques and other purely mathematical approaches imply a level of abstraction that will be unacceptable for most practical uses. M&S, however, can be tailored to represent complex systems at whatever level of resolution is appropriate for the problem at hand. Acquisition programs routinely take advantage of this, as low-resolution models that support early program phases (e.g., requirements development, concept evaluation) are replaced or modified as appropriate with more detailed representations of the system and its operating environment to satisfy the needs of stakeholders later in the process (e.g., testers, trainers). In fact, M&S has become the "lifblood" of modern acquisition systems, as many core acquisition functions are extremely reliant on M&S.

While M&S has critical importance to acquisition programs, there are some significant problems with the practical application of M&S. The most noteworthy problem is cost. The resources required to design, develop, and test a model or simulation can be quite high, depending on the nature of the problem to be addressed and the level of fidelity required. Many acquisition programs also make heavy use of *distributed simulation*, which links many simulation

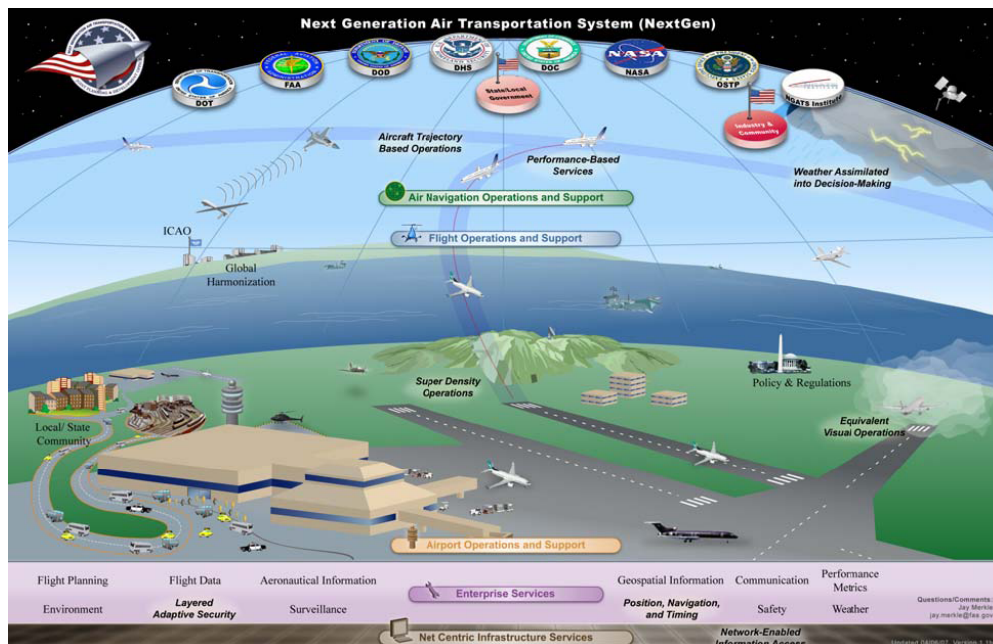


Figure 2 – NextGen ATM System

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assets into one single (potentially very powerful) simulation environment. As one would expect, the costs associated with developing and employing a distributed simulation environment are much higher than standalone simulations, as the syntactic and semantic differences among the participating simulations can be rather difficult and time consuming to resolve. Still, there are many significant benefits of distributed simulation (i.e., efficient reuse of existing assets, linkages to hardware or humans in-the-loop), and despite the costs, functional disciplines like testing and training depend on this approach.

Another key issue with respect to M&S is *credibility*. There have been many examples in the past of studies and analyses that have come to false conclusions based on erroneous M&S results. When these studies/analyses are done in support of acquisition programs, bad design decisions can result, leading to significant rework later in the process once it is discovered that requirements are not being met. This is an even stronger issue in the case of UAS safety analysis, as inaccurate M&S results can lead to false conclusions on operational safety, which could potentially lead to injury or even death. While the costs of M&S verification and validation (V&V) can be significant, the consequences of unreliable M&S software and supporting databases are such that the necessary expenditures can be easily justified. Still, programs historically tend to underfund these types of activities, due to the need to channel limited program assets to what is perceived to be higher priority needs.

In recognition of the high reliance on credible M&S for resolving UAS airspace integration (AI) issues in future UAS programs, but weary of the costs to these programs, the UAS AI Joint Integrated Product Team (JIPT) developed a concept in the fall of 2008 to establish a persistent government-owned simulation environment dedicated to UAS AI analysis. The idea was to leverage existing assets to the maximum extent possible, but link them together in such a way as to provide a unified and credible representation of the flight environment that a UAS system would need to operate within. The name given to this environment was the *Live, Virtual, Constructive Distributed Environment (LVC-DE)*.

A key benefit of this concept was that once this infrastructure was established, any UAS program from any of the services could reuse it. Thus, UAS contractors could focus their simulation efforts on their own systems and simply link into the LVC-DE as the representation of the external flight environment that their UAS must operate within for system testing and

training purposes. This avoids having the services fund the development and V&V testing of a new external flight environment representation for every new UAS program, thus reducing M&S costs and improving M&S quality for future UAS programs.

In December 2008, the Navy's Broad Area Maritime Surveillance (BAMS) Program agreed to serve as the LVC-DE "pathfinder", providing the funding necessary to establish the infrastructure needed to support Airborne Sense and Avoid (ABSAA) related studies and safety case analysis in the FY10-13 timeframe. Although LVC-DE development was initially driven by BAMS requirements, the environment was built with reuse in mind, and thus this initial instantiation of the LVC-DE could be easily extended to address new requirements from subsequent user programs in the future.

The following sections will discuss the efforts to develop the LVC-DE in FY09. Subsequent sections will discuss the planned employment of the LVC-DE in FY10, as well as longer-term plans for LVC-DE evolution.

LVC-DE OVERVIEW

The LVC-DE consists of four government M&S facilities interconnected with a single contractor site through a high-speed secure network called the Joint Mission Environment Test Capability (JMETC). Three of the locations were Department of Defense (DoD) facilities, including the Air Combat Environment Test and Evaluation Facility (ACETEF) located at the US Navy Patuxent River Naval Air Station (Lexington Park, MD), the Simulation and Analysis Facility (SIMAF) located at the US Air Force Wright-Patterson Air Force Base (Dayton, OH), and the Distributed Test Control Center (DTCC) located at the US Army Redstone Test Center at Redstone Arsenal (Huntsville, AL). The only non-DoD government laboratory to participate in the LVC-DE was the National Aeronautics & Space Administration (NASA) Ames Research Center (Mountain View, CA). The one participating contractor site was the Northrop Grumman Corporation (NGC) BAMS Laboratory (Bethpage, NY). Each of these locations was selected based on their unique infrastructure and personnel needed to execute a defined role in the overall environment.

The interfaces of the LVC-DE participants spanned multiple simulation architectures, including the Test and Training Enabling Architecture (TENA), High

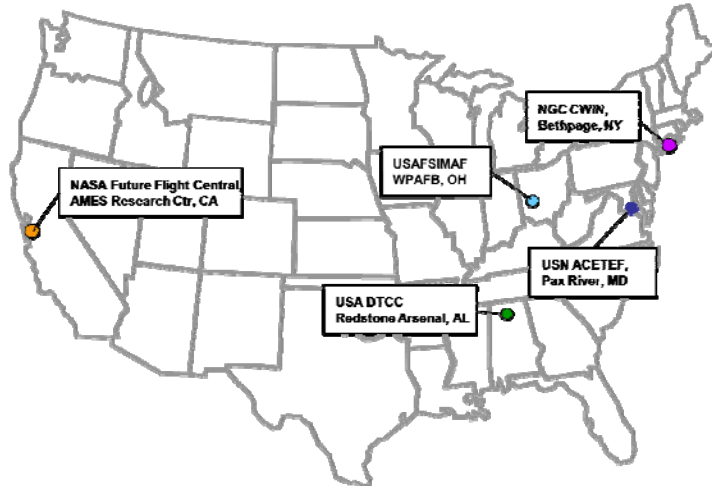


Figure 3. LVC-DE Participating Organizations

Level Architecture (HLA), and Distributed Interactive Simulation (DIS). This use of multiple architectures was required in order to link the multiple simulations and systems operating in their native format. All Wide Area Network (WAN) simulation and data collection traffic was exchanged using the TENA protocols, and gateways were used to convert the TENA traffic to and from HLA and DIS as needed.

LVC-DE SIMULATION COMPONENTS

The following subsections describe each of the major simulation components that collectively define the LVC-DE.

BAMS UAS Representation

The representation of the BAMS platform and Mission Control Station (MCS) was provided via the Northrop Grumman CWIN facility. The Multiple Air Penetration Engagement Simulation (MAPES) was used to provide the BAMS Time Space, Position Information (TSPI) state data, and a notional operator workstation was developed to support early experimentation with human factors concepts. This workstation provided the means by which actual UAS operators controlled the BAMS aircraft during LVC-DE execution, and communicated with ATC operators.

UAS Flight Environment

The UAS flight environment leveraged existing capabilities at the NASA Ames Research Center's Simulation Laboratories (SimLabs) Crew Vehicle Systems Research Facility (CVSRF). This provided the representation of the civil airspace structure, civil

air traffic, and civil air traffic control (including civil pilot and controller subject matter expertise). During execution, the BAMS would "fly" in NASA's virtual airspace, effectively mixed-in with static and dynamic civil air traffic. Air traffic control (ATC) was provided by two actual ATC controllers operating NASA's ATC radar consoles.

External Entities

The representation of additional entities in the LVC-DE was provided by the Joint Integrated Mission Model (JIMM) resident at the Naval Air Systems Command (NAVAIR) ACETEF facility. JIMM is a language driven, discrete-event mission-level simulation that can model a wide variety of entities with sensors, tactics, and behaviors as determined by user requirements.

For the LVC-DE integration events, JIMM played the role of an environment generator/integrator as well as scenario support. In particular, JIMM provided the representation of a notional port area, shipping traffic moving in and out of the port area, targets mixed in with the background shipping traffic, and some additional air vehicles (e.g., military aircraft, non-cooperative aircraft²) to augment the commercial air traffic provided by NASA Ames. In addition, JIMM simulated the local air traffic in early integration events in support of initial LVC-DE testing (i.e., before the NASA Ames simulations were incorporated).

LVC-DE INFRASTRUCTURE COMPONENTS

The following subsections describe the infrastructure elements that collectively allowed the LVC-DE simulation components to operate together as a unified simulation environment.

Cross Domain Solution (CDS)

A significant technical risk for the LVC-DE effort was the integration of classified and unclassified networks and facilities. The DoD facilities and the NGC CWIN facility were all classified while the NASA Ames assets were unclassified. To facilitate the integration, a real-time Cross Domain Solution (CDS) was utilized to link the networks. The RTC SimShield™ CDS allows real-time bi-directional connection between classified

² Aircraft that do not have an electronic means of identification (i.e., a transponder) aboard or not operating such equipment due to malfunction or deliberate action.

and unclassified networks. Classified (high-side) LVC assets can only communicate to unclassified (low-side) assets through the CDS. The approval to pass data is based on a predetermined ruleset that governs what data is allowed to pass through the CDS.

After collecting data requirements and reviewing all security classification guides, the CDS ruleset was configured to bi-directionally pass TSPI, Air Transponder data, and TENA Engagement Messages, as is illustrated in Figure 4.

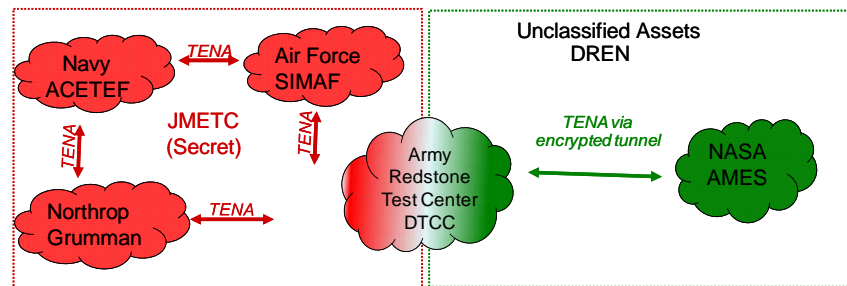


Figure 4. Distributed Network Architecture with CDS

The use of the real-time CDS allowed the integration of distributed LVC assets that otherwise would not be allowed to operate together.

JMETC

JMETC provides a dedicated network support center (called the SYSCON) that provides real-time support to distributed events using the JMETC classified network. This includes network monitoring to the site level, VoIP configuration, and support and troubleshooting down to the JMETC-provided network equipment located at each site.

The JMETC program was responsible for persistent networking connectivity between all participating LVC-DE sites. There were two primary goals in establishing the network infrastructure to support the LVC-DE. The first goal was to leverage existing connectivity to the greatest extent possible and the second goal was to provide a reusable capability to the government for future LVC-DE efforts.

The DTCC, ACETEF and SIMAF sites already existed on the JMETC network prior to the establishment of the LVC-DE. The LVC-DE required additional capabilities at the NGC and NASA Ames sites. In order to accomplish this, there were two different approaches used to bringing those new sites into the LVC-DE. NGC was brought in as another node on the JMETC network using JMETC's predefined new site

process while NASA Ames was brought in as a temporary site through the use of the CDS.

TENA version 5.2.2 was used as the over-the-wire protocol used in the LVC-DE. JMETC provided gateways that were used to convert HLA and DIS protocols to TENA v5.2.2, where necessary, in order for the data to be sent on the JMETC network. All of the LVC-DE gateways were developed using the Gateway Builder (GWB) tool.

The GWB-based TENA-DIS gateway is a mature product that was used in LVC-DE to allow the ACETEF and SIMAF facilities to communicate via TENA. The TENA-HLA gateway used for the LVC-DE was a new development as the HLA variant used at NASA Ames (Pitch 1516 RTI) had not been a previous requirement in any events using the JMETC network. The JMETC team worked closely with the GWB team to build the necessary capability into the GWB tool and ultimately auto-generate the required gateway to support the TENA-HLA interface. The process included mapping the NASA-provided Federation Object Model (FOM) to the appropriate TENA Object Model and writing the initial gateway interface by hand initially before moving the code over to the GWB tool.

Supporting Utilities

JMETC also provided a suite of tools to ensure that the network used for LVC-DE was configured properly and meeting level of performance objectives. One of these tools was an application called the SDREN Active Measurement Program (SAMP). The SAMP is used to gather overall network characteristics each night using customized scripts at each site. Additional tools used included nuttcp, ClearPath, mping, SIMDIS, and the Interface Verification Tool (IVT). Nuttcp was used to verify TCP/UDP throughput, latency and packet loss, while ClearPath and mping are used to verify multicast routing. SIMDIS was used for 2D and 3D visualization, and IVT was used to confirm TENA publish/subscribe capabilities at each site.

LVC-DE DEVELOPMENT

The LVC-DE development effort began with several planning meetings in February 2009. The disparity of the sites (classified and unclassified, government and industry) was a challenging integration task that

strongly suggested an incremental build strategy. Using the Distributed Simulation Engineering and Execution Process (IEEE P1730) as the overarching development framework, a series of three major integration events were planned, along with a final set of production runs referred to as the "Runs for Record" (RFR). The planning meeting also identified the roles and responsibilities of all participants and established a defined set of working groups (WG). The working groups, described below, enabled all sites to fully understand their roles and responsibilities and produce key products.

- **Analysis Working Group** (Air Force Lead): This group was responsible for translating high-level analytic objectives into a cohesive, executable Analysis Plan. The Analysis Plan defined key Measures of Performance and Effectiveness (MOP/MOE) and described processes and data collection requirements needed to successfully execute the RFR. This working group also specified requirements on the scenario to ensure the MOEs/MOPs of interest could be produced.
- **Architecture Working Group** (Army Lead): Based on the specific objectives of each incremental build, this group was responsible for defining the LVC-DE system architecture for each of the three development spirals. The resulting DoDAF views included all of the system components (e.g., simulations, viewers, loggers) and the associated interfaces.
- **Object Modeling/Federation Agreements Working Group** (Navy Lead): The initial responsibilities of this group was to develop a Federation Agreement Document (FAD) that established the data format, data rates, and interface standards facilitating runtime data exchange between various sites. Once the FAD (including the object model) were established, the focus of this group transitioned to identifying interface, communication, gateway, ports and protocols, and data input/output requirements for all sites.

LVC-DE Design Scenario

In support of the integration events, a design scenario was developed to provide a common basis for all testing activities. The scenario chosen was based in southern California (SoCal), and involved a BAMS operating offshore under ATC control that must suddenly transit through populated air traffic corridors to investigate a potential shipping threat entering a port area. To accurately represent the air traffic in that area, NASA initially explored the use of a specific day (July

13th, 2006) using recorded Enhanced Traffic Management System (ETMS) data, commonly used for JPDO-sponsored NextGen Air Traffic Management research. While there are advantages to using a commonly used dataset, the challenge with using that day's data for a real-time human-in-the-loop simulation is that the current navigation databases are different than they were in 2006, therefore the operators flying and controlling would either need old databases, or will need to adapt to new databases looking at an old adaptation. Subsequently, NASA was able to source current ETMS data from September 3rd, 2009, concentrating on a time window between 1700 and 1900 local, a window which sees relatively heavy trans-oceanic flight departures and arrivals to and from Hawaii, Asia, and Australia, with routings near the BAMS operating area. The ETMS data was translated into the NASA Ames Air Traffic Generator (ATG), which is done manually by manipulating a data file for use by the ATG. The manual nature of the data manipulation translated to longer timelines to prepare the scenario, and required significant SME involvement.

The end result of the scenario development coding was approximately 200 aircraft over a two-hour period in the simulation airspace, on actual Instrumented Flight Rules (IFR) and Visual Flight Rules (VFR) routings (see Figure 5). All commercial aircraft were capable of being dynamically flown by pseudo-pilots, responding to ATC controller instruction. To optimize the use of the controllers and maximize the opportunities for the BAMS operator to interface with ATC, the scenario included only two TRACON (Terminal Radar Approach Control) sectors, although there are normally seven in the SoCal airspace. In addition, the warning areas off of the Los Angeles coast were not included. By eliminating the warning areas, the sector controllers had all traffic in the simulation airspace under their control.

LVC-DE Integration Events

A design review was conducted in April 2009 to provide the opportunity for the different working groups to share their progress to date, and define when their products would be available to support the various integration events. Each integration event was designed to build on the capabilities of the previous event, either connecting to additional sites or adding to the functionality of the LVC-DE infrastructure. All integration events were preceded by pre-integration events enabling sites to resolve connectivity issues before participating in the formal events.

The main findings of this second event included the following:

- The TENA ATG gateway continued to require further development and testing. In general, new gateways need a considerable amount of testing and developer support.
- Initial testing should be conducted with scenario subsets rather than the full scenario. Large number of entities add to the complexity of testing interfaces, gateways, and loggers.
- TENA Video needed experimentation with alternative settings to be visually appealing.

Integration Event III (16th-20th November 2009): The main focus of Integration Event III was to integrate the notional BAMS representation resident at Northrop Grumman into the LVC-DE. This required replacing the initial BAMS representation provided by JIMM in support of the first two integration events. This was accomplished by adding Northrop Grumman to the JMETC network on the high-side of the CDS.

The inclusion of Northrop Grumman into the LVC-DE allowed human-in-the-loop control of the notional BAMS platform for the first time via the MCS workstation. This was a significant improvement over the predefined flight paths flown in JIMM for Integration Events I and II. The mission could now be communicated to the BAMS operator who flew the aircraft through the scenario. This not only added to the realism of LVC-DE executions, but also provided the simulation environment needed to support RFR.

The main findings of this third event included the following:

- Configuration control is paramount to the success of any distributed event. Versioning errors can result in considerable time delays during testing.
- "Best effort" data delivery is sometimes not sufficient to achieve certain runtime data requirements.

The LVC-DE system architecture leading into the RFR is shown in Figure 6 (on the following page).

FY09 LVC-DE "RUNS FOR RECORD"

Although the focus of FY09 LVC-DE efforts was on the instantiation of the simulation environment, a "Runs For Record" (RFR) event was conducted on 7-11 Dec 2009. This involved the execution of a predefined Analysis Plan, based on the desire to get early

insight into some key BAMS AI issues. The flight environment used for this analysis was the scenario used in support of Integration Event III. Different scenario variations were explored on each day of the event, including the effect of lost communications with the BAMS aircraft and the impact of non-cooperative aircraft on the ability to maintain safe separation. Also, since the BAMS design was still in development at this time, only a notional, relatively low-fidelity representation of a BAMS aircraft and operator station was used to support this initial analysis.

Numerous encounters were analyzed during the RFR to visualize the aircraft maneuvers and record the Closest Point of Approach (CPA). The following observations and conclusions were drawn from the RFR:

- The encounter analysis demonstrated that in controlled airspace, Air Traffic Control (ATC) operators were able to vector traffic safely, and the BAMS UAS in particular, through realistic NAS traffic. Often these ATC-commanded maneuvers occurred well prior to the BAMS operator being able to detect the threat on their own on-board sensors. In general, ATC's demonstrated ability to maintain safety around the BAMS (especially with lost communications) is likely a result of the rigorous training and years of experience of the controllers.
- The ability for the BAMS system to operate safely in a "Due Regard"³ situation is still to be determined. However, as Sense And Avoid (SAA) sensors and interfaces are further developed in the BAMS program, the LVC-DE demonstrated the ability to provide the external environment required to verify system requirements prior to flight testing and operational employment.
- The LVC-DE environment successfully demonstrated the ability to put a BAMS aircraft and intruders in plausible but dangerous scenarios without real-world dangers consequences being experienced.

NEXT STEPS

The success of FY09 activities has allowed the focus for the FY10 LVC-DE effort to shift from development of the simulation environment to employment. In order to satisfy BAMS Due Regard and AI system

³ A phase of flight wherein a commander of an aircraft assumes responsibility to separate his or her aircraft from all other aircraft.

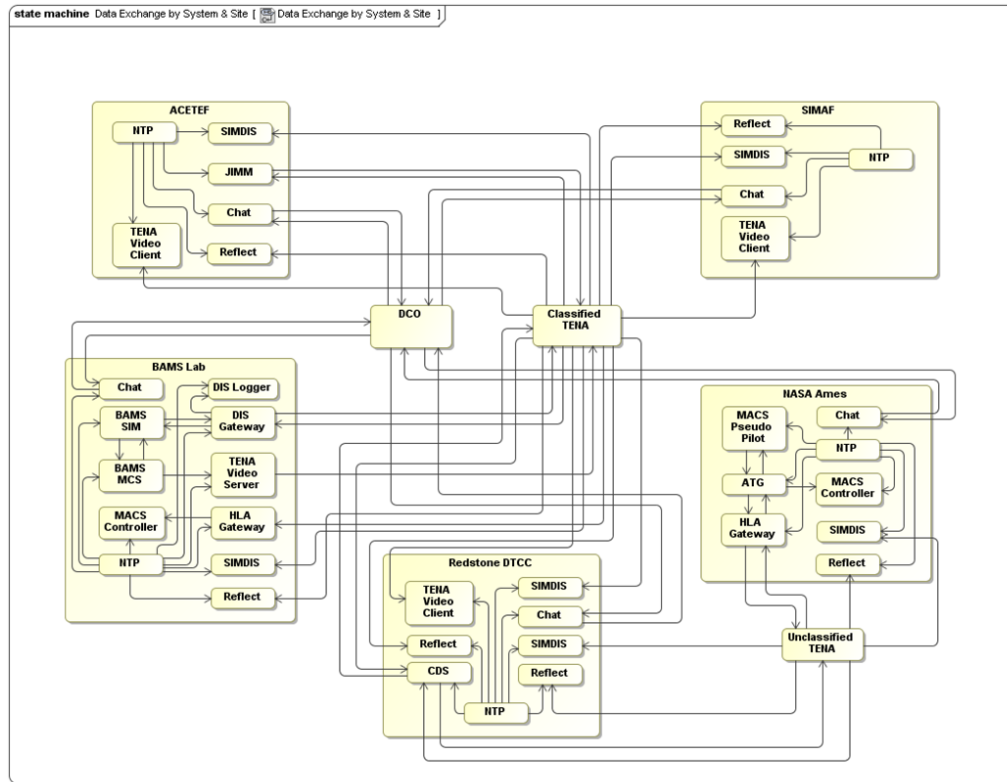


Figure 6. LVC-DE Architecture

specification requirements, NGC will use LVC-DE to perform independent analysis for the BAMS Program and support critical design reviews scheduled for 2010. Key analytic issues will be drawn from the BAMS Sense-And-Avoid (SAA) Analysis Plan, and Master Scenario Event Lists (MSEL) developed that will exercise the BAMS aircraft, operators, Air Traffic Controllers, and other scenario participants in defined areas of interest. The LVC-DE will then be executed, in a series of events, to produce the data needed to support the design reviews. While Verification, Validation, and Accreditation (VV&A) is still a critical concern, the focus of the VV&A effort will shift this year from basic testing of the environment itself (e.g., runtime data exchange, time synchronization) to results validation.

Also in FY10, the LVC-DE M&S Service Leads will actively engage in strategic planning with representatives of the Central Test & Evaluation Investment Program (CTEIP) Joint UAS Mission Environment (JUAS-ME) initiative. This project will produce a simulation environment to support UAS interactions with other DoD platforms as well as National Airspace systems. It will be of sufficient fidelity to stimulate actual UAS hardware in the test environment, and start conducting events in FY11

through FY14. The BAMS LVC-DE will be heavily leveraged in the initial instantiation of the JUAS-ME, and both efforts will share supporting software and databases as appropriate in the coming years to reflect their mutual interests.

An additional factor in BAMS LVC-DE planning this year is to ensure that the analysis questions to be answered in FY10 (and beyond) will encompass the scope of requirements to formulate and feed the upcoming BAMS safety case analysis. This analysis will be needed to obtain flight clearance approval for BAMS oceanic and CONUS operations. Although the FY10 efforts will support early assessments of safety concerns, the LVC-DE will play a critical role during FY11-12 in producing the necessary data to verify that BAMS safety requirements are being met.

ACKNOWLEDGEMENTS

The authors of this paper would first like to recognize Pat Lowien and Paul Frederick of NAVAIR for their vision and unwavering support to the goals of this project. We would also like to acknowledge the invaluable contributions of Dr. Yi-Liang Chen of Northrop Grumman and the other members of the

LVC-DE team. Although the full list of contributors is too lengthy to identify individually, the development and operation of the LVC-DE would not have been possible without our designers, developers, and performers in other related areas as VV&A and analysis. A sincere thanks to all!

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