The Multi-Mission Maritime Aircraft Modeling and Simulation Environment

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The need to counter and defeat a new generation of asymmetric, agile threats has necessitated a transformation of today's U.S. military forces. The inherent complexity associated with emerging system-of-systems operational strategies introduces many new challenges for the DoD acquisition community. Modeling and simulation (M&S) shows great promise as a tool for meeting these challenges; however, inefficient use of such tools can increase program costs and introduce technical risk. An evolving concept called Simulation Based Acquisition (SBA) defines a set of fundamental goals and principles for improving the quality, military worth, and supportability of fielded systems. This article describes the technical implementation of SBA within the Multi-mission Maritime Aircraft (MMA) Program. A key component of the MMA M&S strategy is an architectural blueprint for implementing an integrated standards-based environment of M&S tools and databases that can be actively shared across government/contractor boundaries. In addition to satisfying program functional requirements, this common toolset provides an invaluable mechanism for facilitating collaboration and cooperation among all program participants across the acquisition life cycle.

INTRODUCTION

The core doctrine and warfighting strategies of U.S. military forces are currently in a period of rapid change. During the Cold War era, the military's primary objective was to deter aggression (particularly nuclear aggression) against the United States and its allies and, if deterrence failed, to use whatever military power was necessary to overwhelm the opponent and resolve the conflict in accordance with long-term U.S. interests. Many of the war-fighting concepts and associated systems of that era focused on weapons of mass destruction to deter potential foes, such as strategic bombers and land-/submarine-launched nuclear missiles. While such systems clearly achieved the desired effect, the end of the Cold War signaled the beginning of a massive transformation of U.S. military forces.

Transformation can be defined as a process that involves developing new operational concepts, experimenting to determine the relative utility of those concepts, and implementing the ones that best meet stated objectives (see the article by Osborne and Prindle, this issue). This process includes

- Changes in the way military forces are organized, trained, and equipped
- Changes in the doctrine, tactics, techniques, and procedures that determine how they are employed
- Changes in the way they are led
- Changes in the way they interact to produce effects in battles and campaigns[1]

The need and strategy for transformation have been well articulated in such documents as *Joint Vision 2010*, and more recently, *Joint Vision 2020*.[2] The overarching focus is "full-spectrum dominance," i.e., the ability of U.S. forces, operating unilaterally or in combination with multi-national and interagency partners, to defeat any adversary and control any situation across the full range of military operations (from strategic nuclear deterrence to lesser regional conflicts to humanitarian relief). Warfighting concepts that support this overall goal, such as network-centric warfare, effects-based operations, and rapid decisive operations, are currently under development in several Joint and service communities.[3]

The future implementation of full-spectrum dominance poses significant challenges for the DoD system acquisition community. One of the primary challenges is related to the accessibility of supporting technologies. Because potential adversaries have access to many of the same technologies as the U.S. military, rogue nations can develop sophisticated offensive weaponry that requires strong, effective countermeasures. The need for such countermeasures requires careful forward planning and, when new systems are needed, rapid system development and timely delivery to the warfighter. Conversely, as the U.S. military develops new weapon systems, our opponents can be expected to adapt to such systems with countermeasures of their own. This again requires careful analysis of warfighter requirements and quicker, more streamlined acquisition processes in order to maintain our military advantage. Additional challenges relate to the pace of technological advancement (i.e., fielding systems before they become obsolete) and being able to maintain or increase the overall quality of future weapons systems while simultaneously achieving aggressive cost containment goals.

WHY MODELING AND SIMULATION?

The need for rapid, highly coordinated responses to an asymmetric, agile threat places special demands on future military systems. Besides the need to be technologically superior to corresponding threat systems and adaptable to the full range of 21st century contingencies, these systems must also be highly interoperable in order to support evolving system-of-systems operational strategies. An example is the Army's Future Combat Systems (FCS), designed as an assemblage of manned and unmanned ground and air platforms that share information and operate collectively as a single integrated multimission system.[4]

Although highly effective, modern system-of-systems approaches are quite complex. While each component in the overall system architecture (e.g., sensors, weapons, communications equipment) has a well-defined role, there are likely to be many temporal and spatial dependencies that must be satisfied for the system to be effective as an integrated whole. Interfaces between components must be semantically and syntactically correct, and individual component failures must not cause the whole system to fail. From an acquisition perspective, such complexity increases both technological and cost risk across all major functional disciplines (e.g., systems engineering, logistics, test, training, manufacturing).

Although there have been many actions in the last several years to improve the way the DoD will acquire new military systems in the future,[5] a recognized need still exists for new tools and methodologies to help control the exploding complexity inherent to modern weapons systems. Computer modeling and simulation (M&S) has long been recognized within the acquisition community as an extremely effective means of addressing complex issues and thus reducing program risk. A model is an abstraction of a real-world system developed for the purpose of understanding the behavior or performance of the real system. A simulation provides an external stimulus to a model (in some desired operational context) in order to study system performance over time. Through the use of M&S, aspects of the actual system that are relevant to the immediate issue under investigation can be abstracted to whatever level of detail is needed, and aspects of the system that are not relevant to the problem can be excluded entirely. In the hands of a user who understands the simplifying assumptions inherent to the model, the model/simulation can provide the technical insight necessary to answer key questions about the real system.

Note that the use of M&S in acquisition is hardly new. Because the scope of potential applications of M&S for acquisition is extremely broad, a correspondingly wide variety of different types of models and simulations are in active use today. These are generally characterized according to their class (constructive, virtual, or live) and to the level of granularity they support (campaign, mission, engagement, engineering). The primary reason that M&S is so prevalent in acquisition is because M&S tools continue to provide the most effective means (and sometimes the only means) of understanding and predicting system behavior. With the complexity of future systems continuing to rise, a corresponding increase in the use of M&S in acquisition is all but certain. Ongoing DoD M&S initiatives to reduce the costs of acquisition (such as increasing the use of simulation to supplement some live system testing) are expected to feed this trend.

SIMULATION-BASED ACQUISITION

Although M&S has already become an integral part of DoD acquisition programs, many well-documented problems are associated with how M&S is used to support acquisition. For example, models and simulations built to support different functional disciplines tend not to interoperate, hampering the ability for multi-functional Integrated Product Teams to collaborate throughout the life cycle of a given product. The sharing and reuse of M&S tools and supporting databases are generally very limited, which can result in unnecessary costs and schedule delays in acquisition programs. There are also significant gaps in the standards that are needed to facilitate efficient product development processes. In addition, procedures for verification, validation, and accreditation (VV&A) are frequently inadequate, causing credibility problems or an unjustified acceptance of or reliance on potentially inaccurate simulation output data.[6]

In 1994, the Director of Defense Research and Engineering established the Acquisition Task Force on Modeling and Simulation to examine how M&S could be used more effectively. The report produced by this group introduced some of the earliest concepts upon which Simulation Based Acquisition (SBA) is based.[7] Between 1995 and 1997, several additional studies were published that helped to further elucidate the SBA concept.[8–11]

In 1998, the Acquisition Council of the DoD Executive Council for Modeling and Simulation chartered a Joint task force to develop a technology and investment roadmap for SBA implementation. The final report produced by the task force described a future architecture for SBA from operational, systems, and technical perspectives.[12] In delineating this architecture, many technical, process, and cultural challenges were identified. Several DoD acquisition programs are currently experimenting with concepts from the SBA roadmap to address these challenges and to validate that products can indeed be produced "better, faster, cheaper" by using M&S more effectively. Examples of such programs include the Joint Strike Fighter (JSF) Program,[13,14] the U.S. Army FCS Program,[15] and the Navy's DD(X) Program.

The fundamental goals of SBA are to (1) substantially reduce the time, resources, and risk associated with the entire acquisition process, (2) increase the quality, military worth, and supportability of fielded systems while reducing total ownership costs throughout the acquisition life cycle, and (3) enable integrated product and process development across the entire acquisition life cycle. The basic SBA principles that support these goals are as follows (from a presentation by Randy C. Zittel, "SMART and DoD Acquisition Issues," Simulation and Modeling for Acquisition, Requirements, and Training Conf., Orlando, FL, Apr 2001):

- Early optimization of system performance compared to total ownership costs
- Advanced information technology applications
- Comprehensive cross-functional assessments (achieving reduced risk and more informed decisions)
- Total ownership cost minimization through standards-based reuse of information and software
- Enduring collaborative environments with reusable, interoperable tools and supporting resources
- Automated near–real-time sharing of relevant information among all program participants through a common technical architecture and community-accepted data interchange standards

SIMULATION-BASED ACQUISITION IN MMA

The goal of the Multi-mission Maritime Aircraft (MMA) Program is to develop the next-generation Navy Maritime Patrol and Reconnaissance aircraft. The P-3C aircraft currently gives the Navy strategic blue water and littoral undersea warfare capabilities and performs armed intelligence, surveillance, and reconnaissance functions. Introduced in the late 1960s, the P-3C fleet is fast approaching the end of its fatigue life. Recognizing that planned inventory sustainment efforts alone are inadequate to maintain the necessary P-3C force structure, the Navy established the MMA Program to improve aircraft capability, availability, and supportability while reducing total ownership costs.

As with other DoD acquisition programs, the need for M&S support in the MMA Program will be ubiquitous. For instance, the MMA Product Support Team will rely heavily on M&S for such activities as logistical analysis and crew training. The MMA Mission Systems Team will use M&S to investigate MMA system and subsystem design trade-off issues. The Offboard Systems Team will use M&S to study how MMA will interoperate with external systems within a larger system-of-systems context. The MMA Product Testing Team will use M&S for test planning and survivability analysis and to augment/drive hardware system testing. Other intended uses of M&S tools in the program include both force-level operations analysis and cost modeling.

The MMA Program is fully committed to implementing the SBA concept. From a technical perspective, the primary MMA initiative with respect to SBA is to establish an integrated, standards-based government/industry M&S environment that fully satisfies the functional requirements of the MMA teams. The general intent is to facilitate closer collaboration and more open communication across government functional teams and across government/industry boundaries through open sharing of reusable, interoperable M&S tools, databases, and supporting infrastructure.

The next section describes the structural characteristics of the MMA M&S environment. This blueprint defines the M&S architecture that will be implemented to support post–Milestone B program activities.

MMA M&S ARCHITECTURE

Figure 1 shows a top-level systems view of the MMA M&S architecture, which has four main components:

1. The representation of the MMA itself, along with all associated subsystems
2. The representation of all other forces in the synthetic environment
3. The representation of the natural environment in which all forces/entities operate
4. The interface to all external systems (ranges, C4I [command, control, communication, computers, and intelligence] devices, etc.)

The DoD High Level Architecture (HLA), identified as a mandated standard in the Joint Technical Architecture,[16] will provide the framework for communication among these four components. That is, when runtime simulation linkages among the four main components are required,

- The operation of the environment will be in accordance with the HLA rules.
- All data exchange among the components will be described in an HLA object model in accordance with the HLA Object Model Template.
- The interfaces between each component (or "federate" in HLA parlance) and the underlying runtime infrastructure (RTI) will be in accordance with the service specifications and associated Application Programmers Interface (API) described in the HLA Interface Specification.

The following sections describe each of these four main components in more detail.

MMA Federate

The MMA federate provides the MMA representation that can be exercised within the larger environment to study system and subsystem behaviors and performance. The specific implementation of the MMA federate depends on its intended use. For highly detailed engineering-level analysis of individual MMA subsystems, the federate will likely be implemented as a distributed system of simulators, stimulators, and actual hardware components. For less detailed engagement-level analysis, the federate could be implemented as a single simulation executing on a single host computer. In this case, the single simulation would provide a representation of the same basic MMA functions, but that representation would be at the system level rather than the subsystem level. For system-of-systems mission or campaign-level analysis, this component may not be implemented as a separate federate at all. Instead, an aggregate-level MMA platform could be represented within the Synthetic Forces federate (properly configured) as just another platform.

From a purely architectural perspective, there are many options for implementing the MMA federate structure shown in Fig. 2. For instance, in the most detailed case, the MMA federate could be implemented as a federation itself, where communication between components is provided by the RTI and the core MMA component provides an interface bridge to the other federates. Another option could be to implement the subcomponents as services, with the core MMA (client) component accessing the services via a defined API. The choice of which method of implementation makes the most sense for MMA will be driven by technological risk and cost implications as assessed by the joint government/industry team.

The core MMA component in Fig. 2 has two main functions. First, it provides the functionality for representing the MMA airframe. Thus, this component is responsible for modeling air vehicle performance and behavior, including navigational functions. Second, this component provides the means for integrating all mission systems functions with the airframe model to produce a complete representation of the MMA. The boxes in Fig. 2 represent different categories of mission systems. Each box can be further decomposed into component systems, where the representation of each individual mission system can be implemented as an independent application or as an object/module within a more aggregate simulation, depending on fidelity requirements. In fact, because of the wide range of potential uses of the MMA M&S environment, it is expected that multiple levels of fidelity will need to be supported not only for the MMA representation but also for other synthetic forces representations.

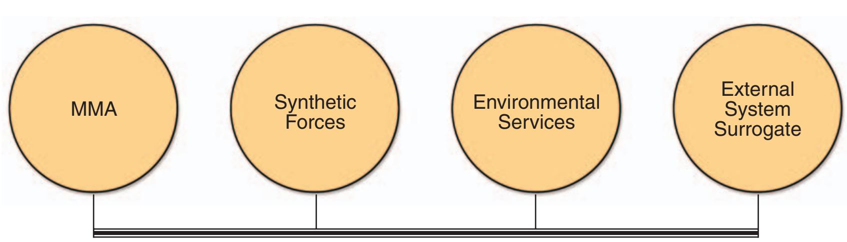

Figure 1. Top-level systems view of the MMA M&S architecture.

Synthetic Forces Federate

The Synthetic Forces (SF) federate is responsible for representing battlefield entities within the synthetic environment. As noted earlier, the MMA may or may not be

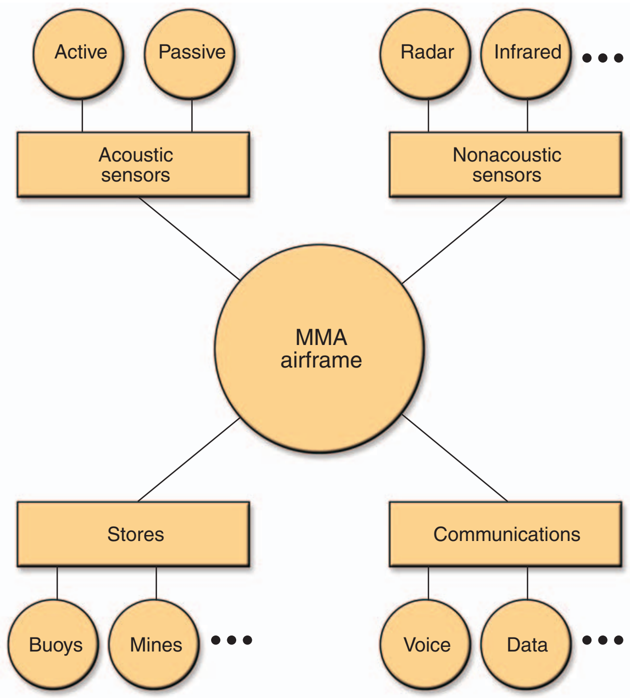

Figure 2. MMA federate structure.

included in the synthetic force representation, depending on intended use. In general, the SF federate is responsible for simulating platforms and systems in the combat environment within which the MMA must operate. Examples of the types of platforms and systems that could be supported by this federate include aircraft, satellites, surface ships, land vehicles, submarines, sensors, weapons, and C4I systems.

Study requirements will drive the breadth and depth of the synthetic force representation. For example, when examining relatively broad operational issues, the SF federate may be implemented as a federation of mission-level simulation tools or perhaps a single mission/campaign-level tool if one can be found that meets all study requirements. At the other extreme, when very narrowly focused engineering-level issues are examined, the SF federate could be implemented as a single high-fidelity threat signal simulator to stimulate an "in-the-loop" radar receiver. Also, while some MMA applications will require a constructive modeling environment, others (e.g., virtual prototyping) may require a virtual world representation, and still others may require the incorporation of live forces in the M&S environment. For this reason, the SF federate must be designed as a *composable* system of software modules/tools at various levels of fidelity that can be assembled in many different ways to address the needs of the user.

This basic principle is illustrated in Fig. 3, where libraries of composable software objects/modules exist at all modeling levels, along with well-defined interfaces

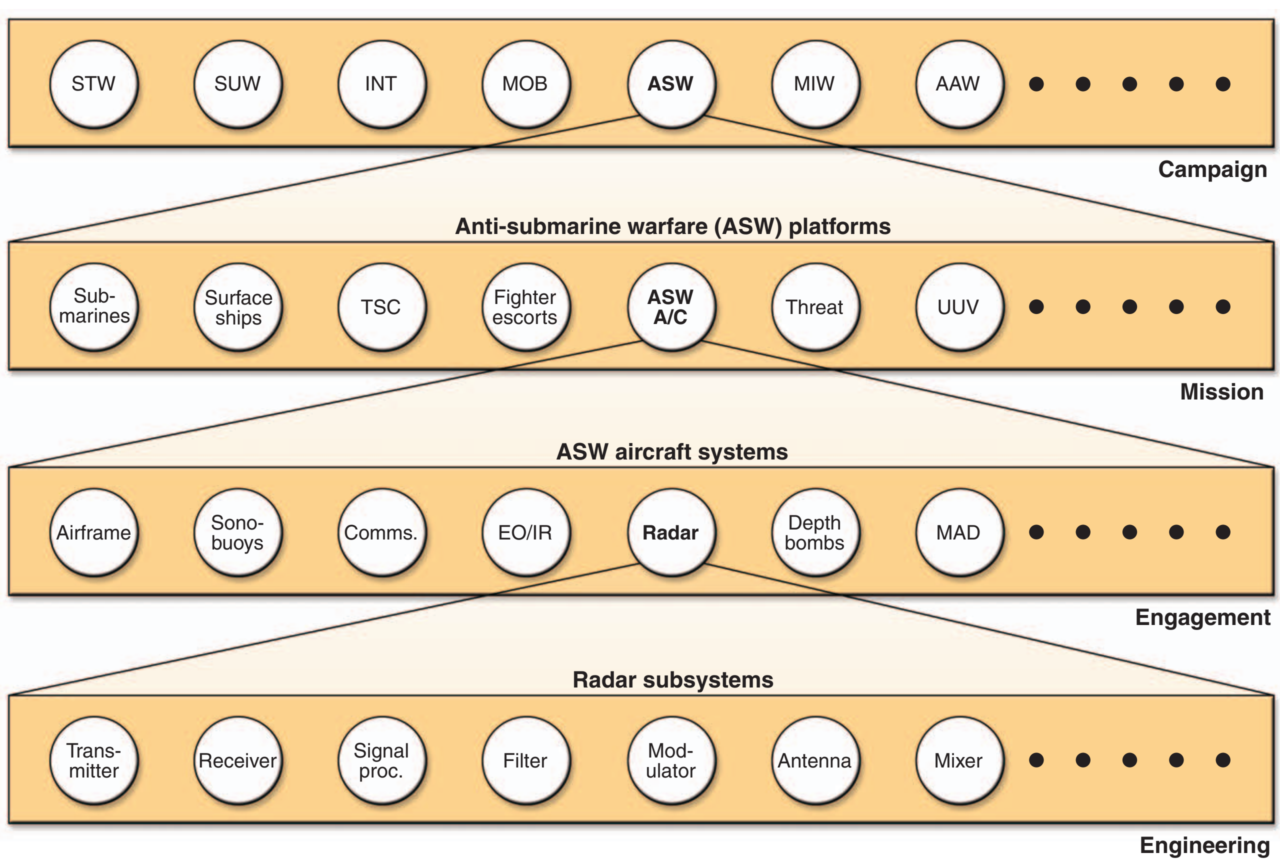

Figure 3. Comparability approach for the Synthetic Forces federate.

between each component class. For instance, at the mission level of modeling, users can choose a single tool to represent all required entities in the battlespace, integrate two or more mission-level tools that individually provide partial functionality, or potentially integrate tools and applications at lower levels when higher fidelity is needed for some critical function or functions (i.e., a software "zoom"[17]). This does not mean that every software component necessarily needs to seamlessly integrate with every other component, as mixed fidelity environments are difficult to validate and often simply do not make sense (e.g., a campaign-level tool with an engineering-level radar receiver representation). However, the MMA M&S environment will be populated (at each level) with whatever software models/tools are deemed most appropriate by the joint MMA government/industry team, and standard interfaces for both intra- and inter-model communication will be developed as users identify requirements for these interfaces.

Note that once the appropriate interfaces are defined, alternative models/tools can be substituted for existing components without a significant reintegration effort. Also there are many different possible integration strategies. In some situations, the runtime integration of all components into a single, logically unified M&S environment would be the best overall solution. In other cases, running low-level, high-resolution models to produce data tables for higher-level, more aggregate models (with appropriate analyst intervention) would be the best approach. In general, the specific strategy and technologies used for SF federate implementation will be based on perceived risk, facility availability, and the preferences of the development team.

Environmental Services Federate

The Environmental Services (ES) federate is responsible for providing a common, integrated natural environment representation to other components in the M&S architecture. The major reason for the architectural separation of the environmental representation from the models and simulations that use it is to ensure consistency of use. That is, although many models and simulations have some intrinsic means of modeling environmental phenomena, variations in the way the environment is represented can (and probably will) impact model results. For example, if two identical simulations are each modeling an identical tactical situation (i.e., identical scenario files) but have different environmental databases, it is unlikely that the results obtained from these two executions will be the same. If these two simulations are linked at runtime, "fair fight" issues will inevitably result. Having an independent component dedicated to providing environmental services to all client applications helps to provide the level playing field necessary for tool interoperability.

The environmental representation must also be integrated across environmental regimes. For instance, it makes little sense to have a snow-covered terrain surface if the air temperature is 80°F. Tools and techniques to ensure consistency across the full environmental spectrum (space, atmosphere, ocean, terrain), including environmental boundaries (e.g., shorelines), are critically important for predicting sensor performance and addressing other environmentally sensitive modeling issues.

The information necessary to model the natural environment is kept in this component of the overall architecture. The data can be distributed in either a pre-runtime or a runtime mode. Pre-runtime distribution is necessary when only a single application is using the data or for pre-execution configuration of a distributed application. In this latter case, the Synthetic Environment Data Representation and Interchange Specification (SEDRIS) provides standard formats and tools for pre-runtime initialization of the simulation environment.[18] Having all applications ingest the same SEDRIS transmittal helps to ensure the level playing field identified earlier, although the applications must still react to environmental factors in a consistent manner.

The runtime mode of the ES federate is illustrated in Fig. 4. The ES federate has two main components and possibly a third, depending on the implementation approach. The first is the set of environmental databases themselves. The second required component is the Environmental Server, which supports both "push" and "pull" mechanisms for runtime data distribution. When using a data push mechanism, the Environmental Server simply publishes regular updates of environmental information at intervals defined in the HLA Federation Object Model. The data can either be ingested into the server prior to runtime or can be pulled from appropriate static or dynamic (e.g., near-real-time "live" weather) databases during execution. Users of this information subscribe to whatever portions of the data that are considered relevant, using either the Declaration Management or Data Distribution Management services offered by the HLA. Data pull mechanisms are required when other federates need to directly query the Environmental Server for environmental updates. In this case, the Environmental Server must be able to under-

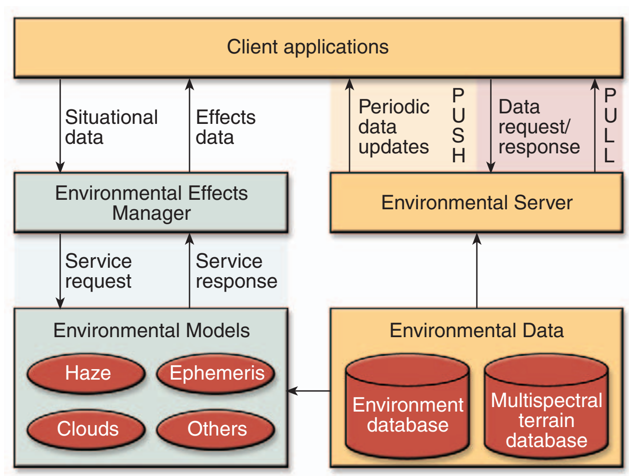

Figure 4. Runtime mode of the Environmental Services federate.

stand the semantics of the query, access the appropriate database (at runtime) for the appropriate information, and distribute an appropriate query response.

The third (optional) component is required if environmental service requests go beyond simple data queries. Although the models that use environmental data will normally be found in either the MMA or SF federate, it is also possible to include a standard suite of environmental effects models in the ES federate. This architectural approach addresses the "fair fight" issue by providing not only common environmental data but also common models for how the data are used. For instance, common models for such environmental phenomena as haze, clouds, and waves can be accessed and used by other federates (through an appropriate service request) rather than having each federate model such phenomena themselves (in potentially inconsistent ways). The Joint Synthetic Battlespace[19] and Joint Virtual Battlespace[20] programs both use this basic approach.

The purpose of this architectural component (called the Environmental Effects Manager, or EEM) is to manage this process. In particular, the EEM would receive service requests (as HLA interactions) and supporting situational data (as HLA interaction parameters), invoke the needed underlying environmental models to produce the necessary effects data (through an appropriate API), and prepare the appropriate response to the requesting federate. Although this general approach reduces the possibility of inconsistencies in the way the environment is treated, it can be complex and expensive to implement in practice. The decision as to whether to include an EEM component in the architecture or keep the environmental models resident in the MMA and SF federates reflects a trade-off between the amount of effort required for EEM development and associated client modifications and the effort required to reconcile differences in how multiple interconnected simulations model the environment.

External System Surrogate Federate

The External System Surrogate federate is responsible for linking external hardware systems to the MMA M&S environment. Examples of such systems include crew station mock-ups, sensor systems, and communications systems. The intent is to provide a stimulation capability within the M&S environment for training and test and evaluation purposes. For instance, the M&S system can produce realistic threat signal characteristics that could be used to stimulate a radar or infrared detector. Another example is the use of the M&S system to produce formatted messages that can stimulate a C4I workstation. Still another example is to insert live range data into a distributed training environment. Through the use of this federate, such external systems can operate seamlessly with simulated entities in the virtual environment.

The purpose of this federate is to provide the interface bridge between real and simulated entities. On the real-world side, this federate must be able to import and export information in the formats expected by the external system. On the simulation side, it must have an HLA interface that imports and exports information as described in the Federation Object Model. In between, the function of this federate is to translate information from the formats of the data producer to the expected formats of the data consumer. Figure 5 illustrates this concept.

The interface to real-world systems should adhere to whatever Joint Technical Architecture standards apply for that class of system. For external systems in which an appropriate interface standard does not exist, a custom interface may need to be developed. However, point solutions for interfaces to individual systems should be avoided whenever possible.

Other Architectural Considerations

In addition to the core architecture, a number of associated issues affect the overall operation of the MMA M&S environment. One such issue is verification and validation (V&V). The MMA Program understands that for a model or simulation to be considered credible to users, it is virtually impossible to evaluate the correctness of the software code without also considering the accuracy of the data that drive the underlying algorithms. This interdependence between simulations and their associated data sets necessitates the inclusion of data V&V activities as part of the overall M&S V&V process. The interplay of data V&V activities with the M&S V&V process is described in the *VV&A Recommended Practices Guide*.[21] The MMA Program

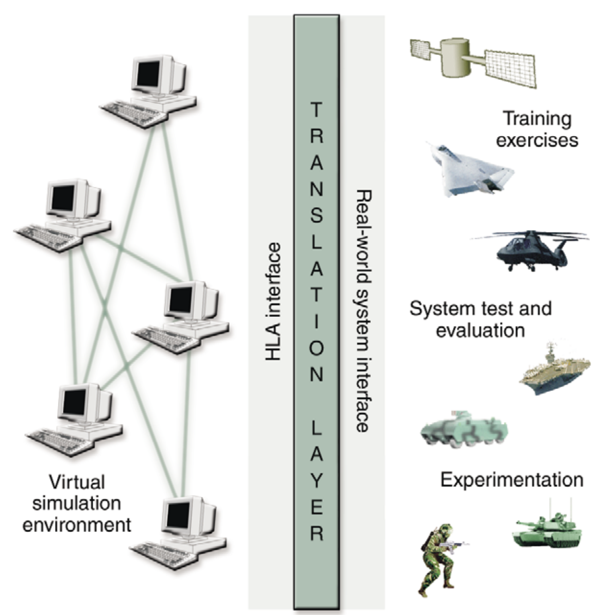

Figure 5. External System Surrogate federate.

intends to use that guide as its baseline reference for addressing both software and data V&V concerns.

In addition to the need for database credibility, there is also a need for database consistency within the MMA Program. Even if different government and/or industry teams are using the same tools, differences in the underlying tool databases will inevitably lead to inconsistent results. Adjudicating such inconsistencies requires both time and money and can increase program risk if not properly resolved. To avoid this problem, MMA will explicitly identify the appropriate set of authoritative data sources and catalog (as appropriate) the data sets produced by each source in a common government/contractor integrated data environment. The open access provided by the integrated data environment encourages data sharing and reuse, thus reducing program cost and the potential for database inconsistencies and/or incompatibilities.

SUMMARY

The MMA Program, in recognition of the need to address the inherent complexities of modern warfare, is committed to the extensive use of M&S tools throughout the program life cycle. Although program participants can simply select and apply such tools independently, the MMA Program understands the long-term cost savings achievable through a common, integrated environment of M&S tools and databases shared by both government and contractor teams. The M&S architecture described in this article defines the fundamental structure of this shared environment. This architecture will continue to evolve and will serve as the blueprint for the development of the M&S environment as the program progresses into system development and demonstration.

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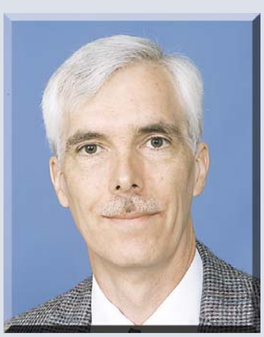

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