DESIGNING FOR CHANGE: A MODELING AND SIMULATION SYSTEM APPROACH

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ABSRACT

Training simulation systems for the 21st century are growing increasingly more complex. They are characterized by being multi-role, i.e., "what do I want to train today", rather than a point design aimed at solving a specific training need. In addition, these systems are no longer viewed as being a final design at Initial Operating Capability (IOC). Instead, they must continue to evolve and adapt to changing requirements over an extended period of time. This paradigm changes the approach to effective system design. This paper discusses an approach to developing a flight simulation system intended to meet a changing training environment.

Changes that drive the evolution of a simulation system design originate from changes in:

- Mission
- Requirements
- Technology

An approach to addressing changing missions is through the mapping of the mission to a Concept of Operations (CONOPS) that describes how all of the components work together to achieve the training objectives. This approach provides a broader perspective of mission needs that highlights the interaction and correlation between components.

An approach to addressing changing requirements is through the mapping of system requirements to the system design. This approach supports a flexible modular design. In the past, networking of flight simulation devices was a simple linking of integrated devices. In the future, systems components which are normally integral to a training device, such as electronic combat environment (ECE), natural environment, instructor operator station (IOS), are broken into separate simulation system components that can be flexibly configured to "build" the simulation system to support any training mission need. The end result is a totally modular and distributed simulation architecture in which every component is equivalent to a system in itself. This architecture places greater emphasis on understanding and facilitating the integration, interaction and correlation of the simulation system components.

An approach to addressing changing technology is by mapping of technology to the system architecture and performance requirements. This approach provides the visualization necessary to develop effective long-term technology incorporation by identifying optimum targets of opportunity to maintain concurrency, circumvent obsolescence, enhance training effectiveness and/or cost effectiveness.

AUTHOR BIOGRAPHIES

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INTRODUCTION

Training simulation systems for the 21st century are growing increasingly more complex. They are characterized by being multi-role, i.e., "what do I want to train today", rather than a point design aimed at solving a specific training need. In addition, these systems are no longer viewed as being a final design at Initial Operating Capability (IOC). Instead, they must continue to evolve and adapt to changing training requirements over an extended period of time. This paradigm shift to long-term evolving development changes the approach to effective system design. This paper discusses an approach to developing a flight simulation system intended to meet a changing training environment.

Changes that drive the evolution of a simulation system design baseline originate from changes in:

- Mission
- Requirements
- Technology

UNDERSTANDING THE MISSION

In the past, most training devices focused on a limited set of operational missions. In newer simulation systems, it is common to have an initial capability that focuses on a subset of missions with the objective to grow the capability to encompass all missions of the target aircraft as technology and funding permits. “In today’s training environment, Pentagon spending can no longer afford to support standalone systems with limited point solutions, but must be targeted with full interoperability mission training from the beginning” (Vesely, 1999). As a result, the training system must be developed to accommodate the final system objectives, not just the initial capabilities.

The first step in the process is to develop a complete understanding of the target system mission. This includes not only the training simulation device, but also the target aircraft. The basic principles embodied in the Defense Modeling and Simulation Office’s (DMSO) Conceptual Model of the Mission Space (CMMS) process provides effective guidance in developing a comprehensive mission analysis. It is not sufficient to simply analyze the current mission profiles for the target aircraft. An effective mission analysis for new systems requires analysis of changing doctrine and changing deployment strategies, e.g., Aerospace Expeditionary Force, to determine the aircraft’s future mission profiles and how it will be used in conjunction with other aircraft and ground resources to accomplish its mission. Analysis of recent actual deployments can give additional insight about the total mission space that the training simulation device might be required to support. The key to designing for change is to understand both the current and potential future mission space that must be accommodated by the training simulation system.

The CMMS and Mission Analysis activities (see Figure 1) use the Mission Tasks derived from the training requirements and the system objectives derived from the Operational Requirements Document (ORD) and the user’s Concept of Operations (CONOPS) to define the total set of synthetic environment requirements for the training device. These synthetic environment requirements, when combined with the requirements for other system components, define the detailed training system requirements for the simulation device. Through the integration of the detailed training system requirements with engineering requirements, the two driving documents for the system design can be developed; the System Specification and the system CONOPS, sometimes referred to as he Operational Concept Description (see Figure 1).

The user often generates a CONOPS to define the basic system requirements. It describes what the user wants the system to achieve and the context in which the system will be utilized. The system developer needs to expand upon the user CONOPS to generate a system CONOPS. The CONOPS for the delivered system defines how the system will actually be used and provides insight into the total system solution for both short-

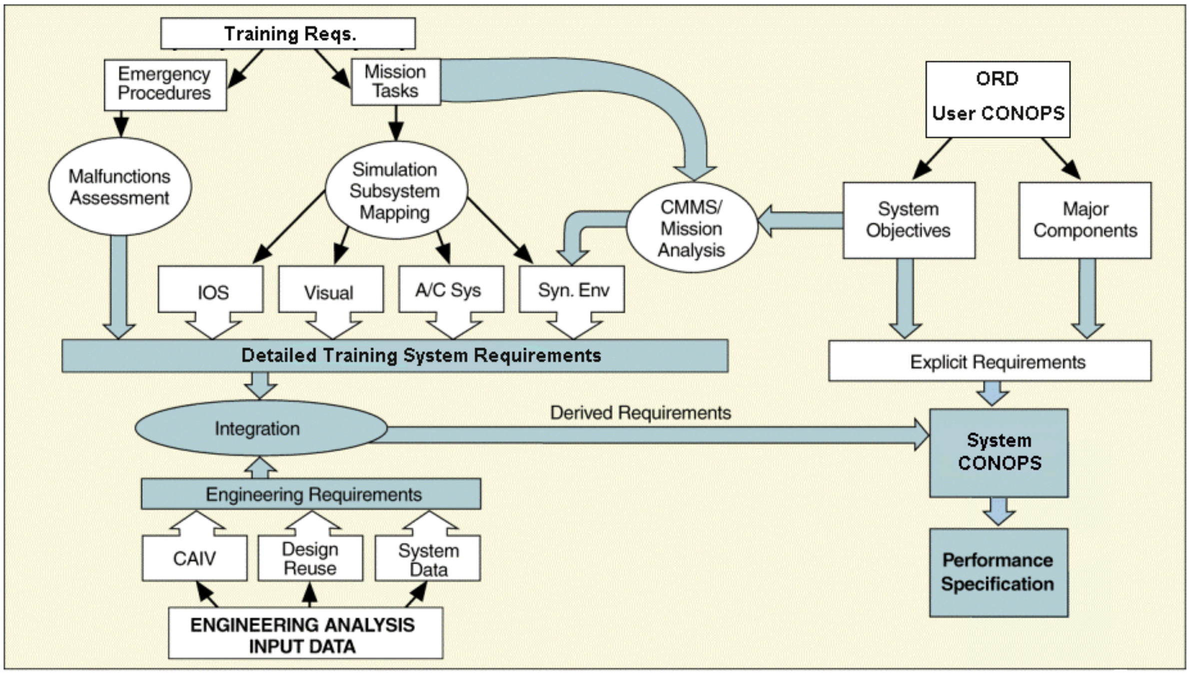

Figure 1. The requirements definition process.

term and long-term requirements for the training system. As such, the system CONOPS drives the design implementation and evolution.

What Is A CONOPS and How Is It Used?

An approach to addressing changing missions is through the mapping of the mission space to a system CONOPS that describes how all of the components work together to achieve the training objectives. This approach provides a broader perspective of mission needs that highlights the interaction and correlation between components, and also the personnel activities.

A CONOPS is a narrative discussion of how a training simulation system is intended to operate. It is written from a user's perspective and captures all aspects of the system operation. It must capture both short-term and long-term goals and objectives. A successful system CONOPS is one that can be used to quickly provide an individual with a comprehensive overview of all system goals and operational concepts.

In the past, systems were designed and developed to implement a constrained, prescribed system specification. As a result, they represented a point design valid only for IOC. Incorporating the potential for growth and change were not essential criteria.

Procurement requirements for recent training systems demand that a training system not only meet initial requirements, but also provide the capability to be expanded as the system and target aircraft evolve in capability and mission. The initial system specification is no longer the only source of information driving the design. The system CONOPS becomes a critical driver that outlines what the system must eventually become and is a key input to the design process (see Figure 2). Hence, the system CONOPS must look beyond the short-term goals and crystal ball the user's long-term goals and desires in order to avoid point solutions that do not support changing requirements.

UNDERSTANDING CHANGING REQUIREMENTS

Simulation technology has matured rapidly in the last several years as user needs have changed from single-ship training devices to multi-ship full-mission training suites. Not so long ago the typical simulator consisted of an aircraft simulation, a visual simulation, a local mission environment, some sensor simulations and an instructor station.

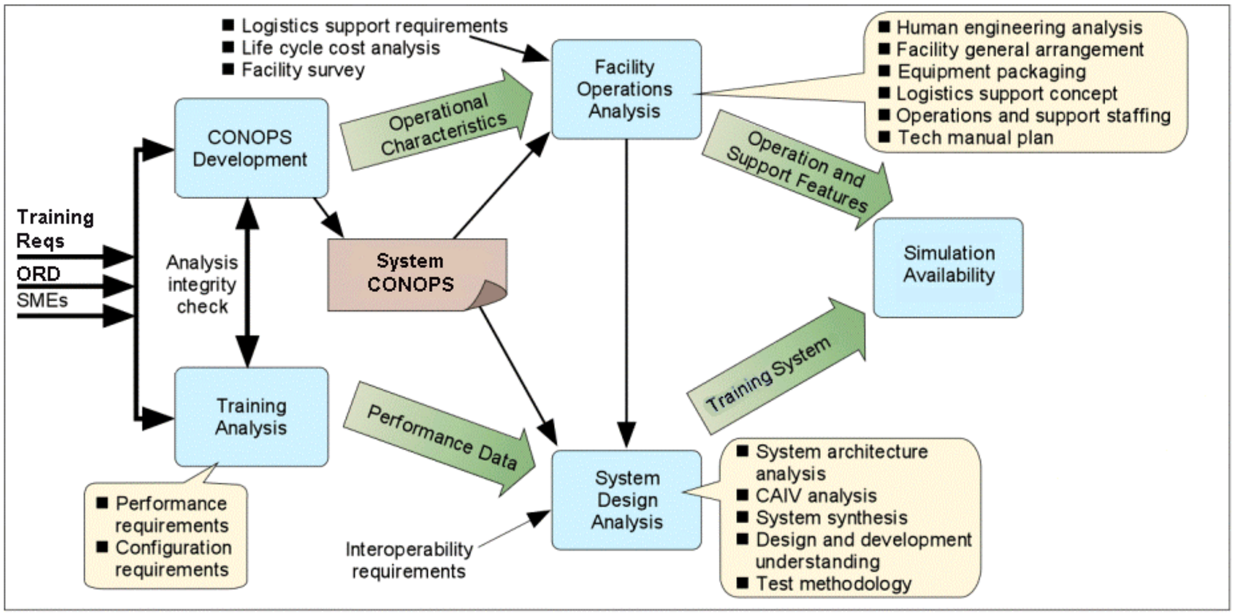

Figure 2. The CONOPS provides a direct input to the system design process.

Today's training needs require all these capabilities at a higher level of fidelity coupled with the ability to network multiple training devices together into a complex mission environment. In addition, the individual training components may be scattered via a long haul network around the world. This theme is undescored by Lt. Gen. David L. Vesely who stated recently that today's "models and simulations must be built the first time with interoperability in mind so that one can be used in multiple environments rather than building separate applications for each situation" (Vesely, 1999). Some of the reasons behind these changes include the affordability of sophisticated technologies leading to greater user expectations and changes in training requirements and the training environment: security concerns, airspace restrictions, inability to routinely marshal large forces for training, etc. This paradigm shift has caused industry to reexamine the fundamental design characteristics of the typical simulation training device so that full benefit can be taken of emerging and potential technologies to provide the user with an affordable and effective training solution. Today's full mission training devices must operate within an environment that includes almost all aspects of the modern battlefield, i.e. threats, other moving platforms, battle communications, and wide-area weather patterns.

Desired System Architecture Objectives

As a result of the new training initiatives, it is imperative that the next generation training device exhibit most, if not all, of the features shown in Table 1 if it is going to support long-term user requirements.

While some of these features may be found in most simulation devices available today, the complete set of features requires a considerable revamping of the traditional simulator architecture if all benefits are to be achieved.

Traditional Simulation Training Device

The comparison of desired features to the traditional training device provides the basis for understanding why it is necessary to establish some radical changes in the system architecture if the desired benefits are to be obtained. In the past, the design has included simulation fidelity compromises which were largely driven by the cost of hardware, which includes computational and visual system equipment. This resulted in simplifications to the simulation algorithms and the use of a minimum amount of computational equipment to render the simulation. These devices served their purpose very well and were an excellent supplement to the flight-training

Table 1

Features Of The Modern Training Device

Feature	Benefit
Interoperable training	Allows training devices, or specialized simulation components (federates), to form training groups (federations) with similar and dissimilar devices providing an enriched mission training environment. It should be possible to reconfigure any combination of mission assets to support the desired mission scenario on short notice of a few hours.
Capability substitution	Provides the ability to substitute more powerful or better-suited simulations for major components of the system, i.e., replace the local weapons simulation with a weapons server supporting all weapon users in the mission scenario. These components exhibit Plug ‘n Play features benefiting the mission flexibility objectives.
Encapsulation of simulation from federation	Allows dissimilar simulation components to be integrated under common standards to provide a rich mission environment. The simulation application within each component is shielded, or encapsulated, from the context of the mission environment and system architecture using a standard front-end architecture to achieve Plug ‘n Play qualities.
Expandable training	Allows enriched or upgraded simulations to provide greater training utility or ability to track aircraft concurrency upgrades without fundamental design impact to the component.
Affordable, reconfigurable architecture	Allows ease of design reuse for alternative simulations to be available within a user command (F-16 Block 30, 40, and 50), or between different user commands (F-22, B-2, F-18).
Ease of technology upgrade	Through the flexibility of the component and system architecture ensures the design can accommodate significant technology enhancements to achieve greatly improved training without design trauma.
Computational platform independence	The system design allows components to be independent of specific computational systems providing the freedom to migrate to differing platforms based on mission objectives, cost, performance, and user preferences.
High availability	Ensures the supplied equipment is available to meet desired scheduled training in the required configuration, with a low probability of failure, or long mission reconfiguration delays.

curriculum. In many cases, the training objectives were driven by the need to expose the pilot to a comprehensive understanding of mission capabilities followed up by a considerable amount of flight time to achieve the required tactical proficiency. Attempts to overcome some of these early simulator shortcomings were difficult and expensive to implement, such as 360-degree FOV visual systems, advanced sensor systems, sophisticated threat environments, and large-scale networking between multiple devices.

The architecture of many current generation training devices (see Figure 3) exhibit some but not all the essential features and capabilities essential for the next generation training device. Within this architecture the component architecture exhibits tight coupling and complex interfaces between many of simulation components. This makes future expansion to support new features, such as capability substitution and interoperability with other devices, more difficult. During networking for limited interoperability, the data transport between devices may be simple with little predictive filtering, or include more elaborate schemes using DIS based protocols. As we examine the characteristics of today’s simulator architecture we find that the desired features are only partially supported (see Table 2).

Needless to say, this current generation architecture provides excellent value and was designed to meet the training requirements from an earlier training procurement strategy for a fixed target price. The objectives of the next generation training capability may increase the unit price, but allows significantly increased flexibility in matching training to user requirements. This improved training utility can overcome many of the previously referenced limitations associated with the more traditional training environment.

Although it is technically possible to force today's current generation simulator to meet some of the future training objectives and support user expectations, it is most likely just a point design that will not support long term flexibility to adapt to the ever-changing mission training requirements.

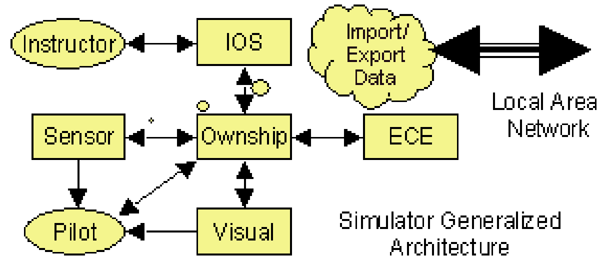

Figure 3. Conventional architecture.

Table 2

Current Generation Capability Compared To Desired Features

Feature	Benefit
Interoperable training	Generally, only possible with similar simulation.
Capability substitution	Typically, current generation devices tend to exhibit tight binding of major functions within the architecture that restricts easy substitution of improved capability from another source. Does not allow the existing ECE, or weather simulation, etc., to be easily replaced by another capability available within the simulation assets available to the user command.
Encapsulation of simulation from federation	Data transport between devices is generally tightly bound to an application and does not provide flexibility for adding additional functional components without major design change. Does not exhibit Plug 'n Play qualities.
Expandable training	Cannot easily add additional capabilities such as a common weapon server to support all weapon users within the training environement without major changes to sytem interfaces.
Affordable, reconfigurable architecture	Limited to the designs within the component.
Ease of technology upgrade	Modular architecture allows updates with the device. More widespread system additionsmay require significant changes to the system architecture to preserve the objectives for interoperability.
Computational platform independence	Majority of simulation designs are platform independent and can migrate to different platforms. Designs are generally visual vendor independent allowing user preferences to be satisfied.
High availability	Demonstrates good reliability promoting good traditional operational availablity. However, the ability to rapidly reconfigure to meet ever changing misison objectives is not possible.

Next Generation Training Device Architecture

The principle reason for requiring a change in the architecture of the training device is driven by the need to build in architectural flexibility. This means that the user will be able to obtain a diverse spectrum of training ranging from a simple single-ship, used for initial qualification training, to the rich, multi-ship, immersive training environment of a complex mission with diverse weapon platforms. This complex mission may well employ several types of virtual and constructive simulations associated with these different weapon platforms and environmental features for computer generated forces, weather, and weapons. In view of these training scenarios, what has to be done to establish an architecture that meets the user objectives and support the desired features of the next generation trainer?

This transformation into the next generation architecture requires several actions to occur. We must examine the features from the current simulation and integrate these with new features required by the users to establish the total list of required capabilities. We must standardize the number of models existing within any weapon platform simulation to allow greater flexibility in configuring systems for joint interoperable missions. Support for these assessment comes from the user statement of requirement, simulator supplier experience, an understanding of the CONOPS, and the objectives required for long-term supplier support. This list of major simulation features and capabilities must now be mapped into an architecture that supports the user training objectives identified within the CONOPS. As we perform this mapping into the architecture, we must be very conscious of the need for interoperability to allow mission training in a multi-platform environment with weapon platform simulations from several simulator providers. The architecture must address the issue of what system components are likely to have capability substitution from other sources, or provide additional control capabilities across the entire mission spectrum. The architecture should be flexible enough to handle any component or subcomponent changes that are required to make the system, as a whole, meet all training requirements. As we examine the architecture of today's simulator, we find there are several simulation capabilities/components that should be designed to support the larger mission capability with the flexibility for interoperable mission configuration and life cycle support. These simulation capabilities/components include:

- Ownship simulation, weapons, visual and sensors (OSVS)
- Electronic Combat Environment/Computer Generated Forces (ECE/CGF)
- Weather simulation/Natural Environment (WNE)
- Weapon Server (WS)
- Instructor Operator Station (IOS)
- Man-in-the-loop control stations/virtual simulations (MCS)
- Mission Observation Stations and data logging functions (MOS/DL)

The design decisions for this list of capabilities are largely based on the need for interoperable training with diverse mission structures. For example, there may be a training need requiring OSVS for F-16, F-18, B-1, and B-2 integrated missions with an ECE/CGF, WS and WNE from a government laboratory, multiple MCS from another site, IOS master mission control functions from one of the sites, and local MOS/DL for each site. This may be stretching the initial capability somewhat, but it represents the end game objective of distributed mission training. How does this diverse capability become integrated in a system design to provide a robust mission capability with design longevity?

The approach to the next generation architecture leverages off the principles and concepts established for the Joint Technical Architecture (JTA). The above list of simulation components now become federates in the architecture which integrates each component using principles established for Distributed Interactive Simulation (DIS) or High Level Architecture (HLA) protoco (see Figure 4). Ideally, these components exhibit Plug 'n Play featues allowing any mission scenario to be supported.

In this diagram all the simulation components are shown as contributors to the hypothetical mission scenario. The OSVS, WNE, ECE/CGF and IOS are federates under HLA. There may be multiple instances of these components. Additional peripheral systems, such as MOS/DL and MCS functions can be supported using a Plug 'n Play subsystem approach. The specialized MCS functions enrich the mission environment by providing the essential human behaviors required for these critical mission capabilities. The elements shown in this illustration are representative and the quantities may vary for any site or they may be distributed over the Wide Area Network (WAN) at other sites.

The basic HLA protocol, or an equivalent protocol, provides the means to separate the federate functions from the mission by providing a common service layer for each federate. Figure 5 shows the partitioning of functions between the models in the federate and the common functions of HLA for each federate. It should be noted that the only communication path between any of these federates is over the network. There are no opportunities for back-channel data paths to corrupt the purity of the architecture, which have been epidemic in current day simulations, e.g., IOS initialization and record-replay functions. This rigor requires substantial effort to design the models in the federate and the common functions of HLA for each federate, the interface data structure and the message transactions or services required for this highly object-oriented architecture. The resulting architecture, however, offers the flexibility to

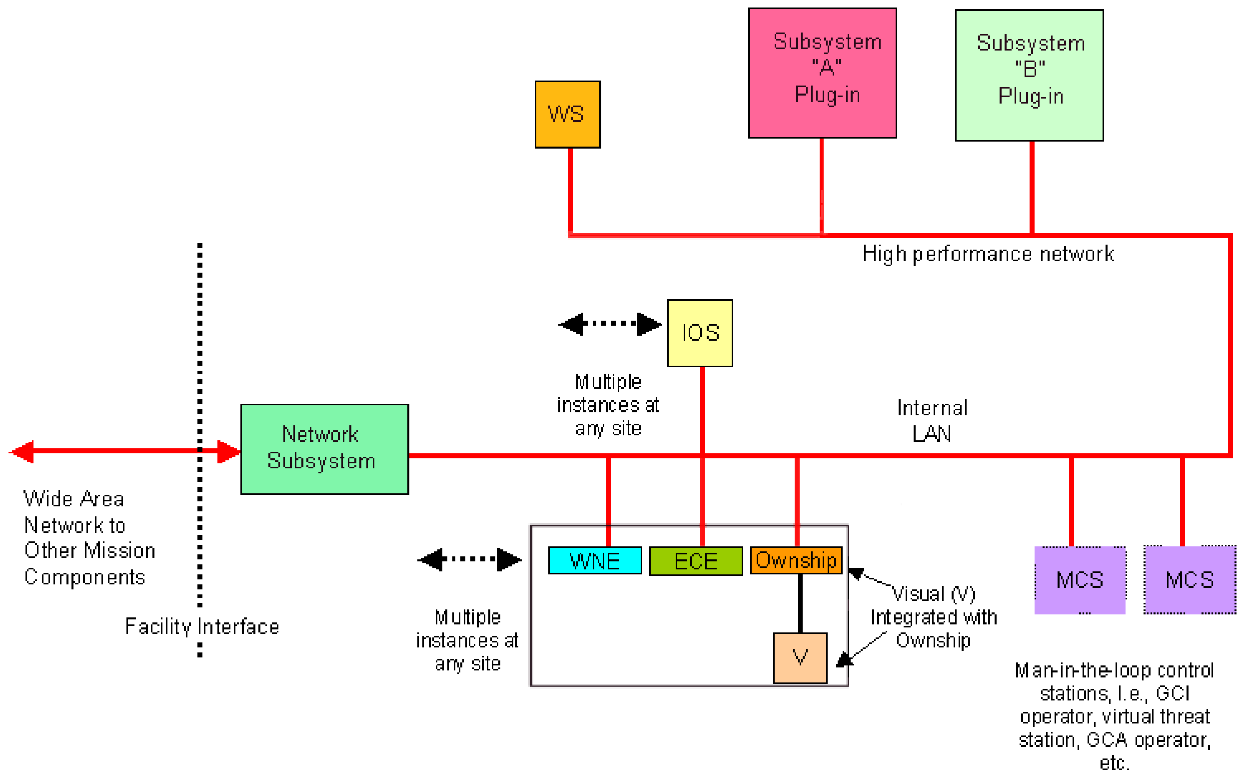

Figure 4. Next generation training device architecture.

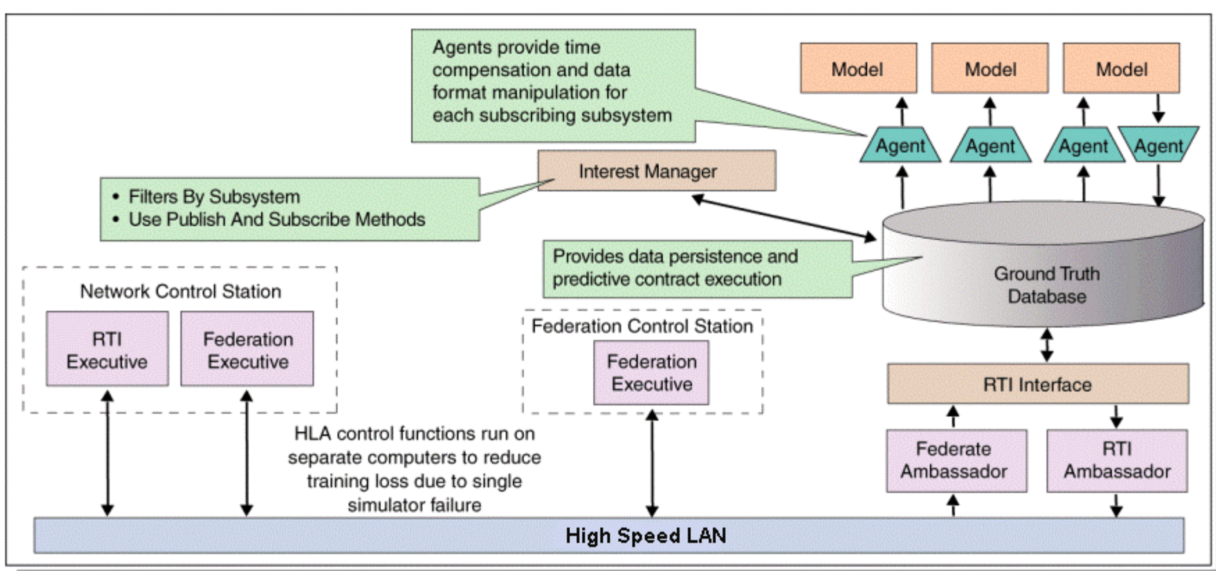

Figure 5. Federate partitioning.

support multiple configurations of the architecture needed for specific training objectives, and the ability to sustain changes in design over the program life cycle. Any design changes needed in any federate are shielded from the remainder of the federation and should be transparent in its mission implementation. New technologies may be added as modifications to each federate or by adding new federates depending on the nature of the application. Above all the architecture requires careful coordination in the preparation of the interoperability rules that define the methods in which the federates interact with each other.

An architecture, such as that described for the next generation training device, offers all the desired features identified earlier in this paper. The implementation characteristics for the features are summarized in Table 3.

Table 3

<u>Next Generation Capability Compared To Desired Features</u>

Feature	Benefit
Interoperable training	Multiple or different federates operating to a common set of architecture and interoperablity rules provide the flexibility to rapidly configure the training equipment to users immediate needs at very short notice with excellent long term growth objectives.
Capability substitution	Each federate such as ECE/CGF or WNE, etc., may be replaced by a substitute federate from another source to provide increased capabilities as long as the basic interoperability rules are still satisfied. This allows the “best of the best” from all available mission assets to be configured to support government demonstrations such as Road Runner, etc.
Encapsulation of simulation from federation	The application of HLA, or more advanced common architectures, to the choice of federates for the major mission functions and a common set of interoperability rules allows the application models to be hidden from the remainder of the mission or federation to preserve mission integrity. Plug ‘n Play capability is now achievable with the ability to rapidly reconfigure to any mission need.
Expandable training	The flexibility of the interoperable system architecture through the use of the network control station allows the architecture to expand or contract or be apportioned to provide integrated mission training or multiple instances of single-ship training, etc. In other words, the precise mission can be easily created from the assets available to the user command.
Affordable, reconfigurable architecture	The architecture within each federate is a complete simulation model to itself. Given common interoperability rules and independence of computational platform, a federate simulation from an one weapon system platform can operate within another weapon system platform, i.e., and F-16 simulation component can operate in a B-2 mission environment, without violating fundamental architectural boundaries.
Ease of technology upgrade	A highly object oriented architecture with optimized interfaces, services between federates, encapsulation of models, and computational platform independence provides the ability to accomodate significant technology upgrades without a major overhaul of the architecture.
Computational platform independence	Computational resources for each federate or cluster of federates is based on the performance requirements of the set of models, commonality requirements for hardware, and life-cycle cost objectives. Several different computational platforms can easily coexist due to the encapsulation of simulation.
High availability	The application of optimized high-reliability computational capacity reduces support costs. The flexibility to reconfigure the federation members from the available set of mission asets or federates allows specific mission requirements to be satisfied with minimum configuration delays.

ANTICIPATING TECHNOLOGY

While the core technologies that support flight simulation devices have advanced significantly in recent years, they have not matured sufficiently to keep pace with increasing training demands and expectations. Increasing demands on fidelity, interoperability, and mission complexity and flexibility necessitate effective technology enhancement to continually improve training effectiveness. Mapping technology to the system architecture provides the visualization necessary to identifying optimum targets of opportunity to cost effectively enhance training capabilities (see Figure 6).

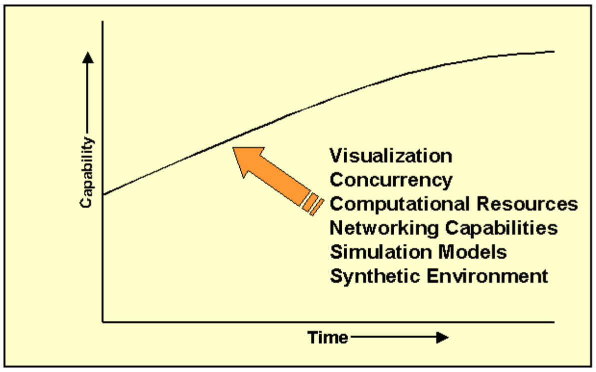

Figure 6. Effective technology insertion continually enhances training capability.

The critical design features to effectively accommodate changing technology are an open system architecture and loosely coupled interfaces that promote the substitution of alternative technologies. This approach facilitates the primary goal of better training, which can be achieved by:

- Making the training device life match the aircraft
- Increasing performance at lower cost
- Increasing training features

In the flight simulation area, potential technology enhancements are expected in a variety of domains including:

- Visualization of visual and sensor simulations,
- Simulated device concurrency upgrades,
- Computational systems,
- Networking capabilities including interoperability,
- Simulation models, and
- Synthetic environment enhancements.

Each of these technology domains provides a different training benefit. It is necessary to work closely with the user to prioritize and evaluate all technology enhancements. Technology upgrades must be undertaken because it benefits mission training objectives or provides significant cost savings that can be applied to other enhancements, not just because it can be done.

Technology enhancement to meet changing requirements becomes a non-traumatic event when the basic system architecture principles discussed earlier are followed:

1. Develop a well-defined system architecture with loosely coupled interfaces.
2. Design the system to be independent of any specific computational system.
3. Develop core simulation applications as federates that are shielded by the network protocol.
4. Facilitate technology upgrade by applying the concept of resource substitution.

CONCLUSION

Designing for change in flight simulation systems is a fundamental change in philosophy. Historically, flight training devices have been designed for a point IOC capability. Later changes required by evolving training requirements and aircraft changes have been accommodated through patches and fixes. New flight simulation systems are required to not only meet IOC requirements, but to also support changes and evolution of training requirements for extended periods of time. Maturing technology has provided the tools and resources to design flight simulation systems with accommodation of change as a driving requirement. The design to change approach outlined in this paper has focused on three key tasks: understanding the aircraft mission and its future trends, developing a system architecture that is specifically designed to facilitate change, and pursuing continuous improvement through effective technology enhancement.

REFERENCES

Vesely. D. L. (1999) Defense Modeling and Simulation Office (DMSO) industry day remarks, June 1999.