SCALABLE SIMULATION TECHNOLOGY - APPROACH TO HIGH-FIDELITY SIMULATOR TRAINING AT LOWER COST

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ABSTRACT

Scalable simulation technology is the approach which uses an open-architecture system to produce high-fidelity simulators with options to meet a broad range of customer requirements. The customer objective for high-fidelity simulator training at lower life-cycle costs is addressed with the use of highly reliable, commercial off-the-shelf technologies and leveraging existing software investments. Depending upon acquisition and life-cycle support budgets, customers can choose from many options, such as visual systems, databases, and networking, to provide the best simulator capabilities to meet their training requirements. By using today's open architecture computer systems with extensive expansion capacity, scalable simulation also allows customers to add options, expand capabilities, and install upgrades at a future time without making costly modifications to the simulator. The scalable simulation approach and technology were used on the U.S. Air Force Unit Training Device (UTD) program, which provides high-fidelity flight and weapon system training at lower cost. Examples from the unit-level UTD program are cited to illustrate scalable simulation technologies and benefits.

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INTRODUCTION

Background

There are numerous types of military flight training courses, such as single-seat fighter aircraft, multi-crew aircraft, and helicopter courses. The courses are based upon proven training methods and provide important career flight training to the pilots, aircrew, and operators of the aircraft and helicopters.

Various ground-based media are used to support the career flight training, including classroom materials and simulators. The acquisition and life-cycle support costs of these media are significant. The 1990s are witness to reduced defense spending budgets. As a result, there is considerable effort aimed at reducing the costs of the media.

A traditional high-cost area is the flight simulator. Simulators are used in the flight training courses to provide "hands-on" and interactive training experiences to the end-user. During initial training, the simulators support upgrade and mission qualification courses. Then, simulators provide refresher and continuation training throughout a user's career.

Because flight training requires extensive hands-on experiences, the simulators have become less expensive alternatives to conducting hands-on training in the aircraft (Spears & Isley, 1986). Years of simulator training effectiveness studies show that end-users trained in simulators perform as well,
With stimulation, aircraft software (i.e., operational flight program) is used to update the avionics in the aircraft as well as the

when transferred to the aircraft, as those crew members who received all of their training in the actual aircraft (Ciavarelli, 1994).

Consequently, simulators have been used to replace and/or augment aircraft training. The design paradigm has been to produce a high level of similarity from the simulator to the aircraft. High similarity between the learning situation (i.e., simulator training) and the application situation (i.e., aircraft training) leads to increased learning (Gagne, 1954). The closer the similarity - the fidelity between the simulator and the aircraft - the more effective the instruction, which is a good reason why money is spent on high-fidelity simulators to begin with.

Problem

The high-fidelity simulators used in flight training are burdened with a number of high-cost areas. Many of the simulators are stand-alone proprietary systems with multiple functions such as sensors, weapons, visual systems, and databases. These advanced simulators use special-purpose hardware, such as many high-speed computers, to execute extensive software functions - all at great cost to acquire and support (NTSA Training 2000, 1994).

Another high-cost area is the cost of maintaining the concurrency of the simulator avionics to the same configuration as the aircraft avionics. There have been two basic methods to concurrency: stimulation and simulation.
aircraft avionics hardware used in the simulator. Because high-cost aircraft hardware is used, stimulation is expensive. With

simulation, design documentation is the basis for modeling simulator-unique software to functionally represent the aircraft avionics system. Unfortunately, simulation has considerable creation and debugging time which is expensive and often results in the simulator's avionics configuration "lagging" the aircraft configuration.

Today, because of diminishing budgets, the customer demand for high-cost proprietary simulators has also diminished. On the other hand, requirements persist for high-fidelity simulators to support the numerous military flight training courses. In fact, if flying hour erosion continues and other constraints to flying get worse (e.g., environmental restrictions), the expanded use of simulators seems imminent (Andrews, Carroll, & Bell, 1994). Clearly, new approaches are needed to provide pilots, aircrew, and operators as much high-fidelity simulator training within the constraints of diminished budgets.

Purpose

This paper describes the use of scalable simulation technology to support military flight training courses with high-fidelity simulator training at lower cost. Scalable simulation uses today's commercial off-the-shelf technologies, such as computers with adaptable open architectures, to reduce many high-cost areas that plague flight simulators in the field. In addition, scalable simulation technology allows customers the flexibility to choose initially or at a future time the simulator options that best meet their training and budget requirements.

Scalable simulation is used for the U.S. Air Force Unit Training Device (UTD) program to meet the new direction in flight training resulting from the 1993 U.S. Air Force review of simulator programs. The review sanctioned the unit level, or squadron-based, UTD program which provides low cost, high-fidelity flight and weapon systems training capabilities for pilots in their unit-level environments.

APPROACH TO SCALABLE SIMULATION TECHNOLOGY

Simulator Analysis and Definition

To produce a high-fidelity flight simulator at lower cost, there are important up-front analysis and definition activities to conduct. The approach to scalable simulation technology is based on a complete training requirements analysis, the decomposition of the requirements into simulator functional capabilities, and quantification of the designs to meet the training requirements within customer budgets.

First, to identify the training requirements for flight simulation, customer and end-user involvement is critical during the up-front analysis and definition activities. In fact, as end-user involvement with the training analysis process increases, so does the likelihood of greater acceptability of the delivered product.

Complete understanding of end-user training objectives and instructional approaches to the training is critical to the analysis and definition activities (Caro, Shelnutt, & Spears, 1981). Considering only high-level training activities are insufficient for determining simulator functional capabilities for training (AFMAN 36-2234, Instructional System Development, 1993). Without in-depth front-end analysis, precious budgets can be spent on "gold-plated" simulator designs with functionality unnecessary for the designated training tasks.

The process to decompose the training requirements into simulator functional capabilities can be supported with a prototype scalable simulator. As illustrated in Figure 1, Process for Simulator Analysis and Definition, a prototype simulator can be used to try out instructional approaches to support pilots' learning as they proceed from part tasks to mission integration training (Golas & Bills, 1993). This front-end analysis activity was accomplished on the UTD program, and helped determine the UTD functional capabilities necessary to support the designated training requirements.

A prototype simulator can also be used to help balance the simulator's design between fidelity level and cost. In theory, appropriate levels of fidelity should be assigned to media components

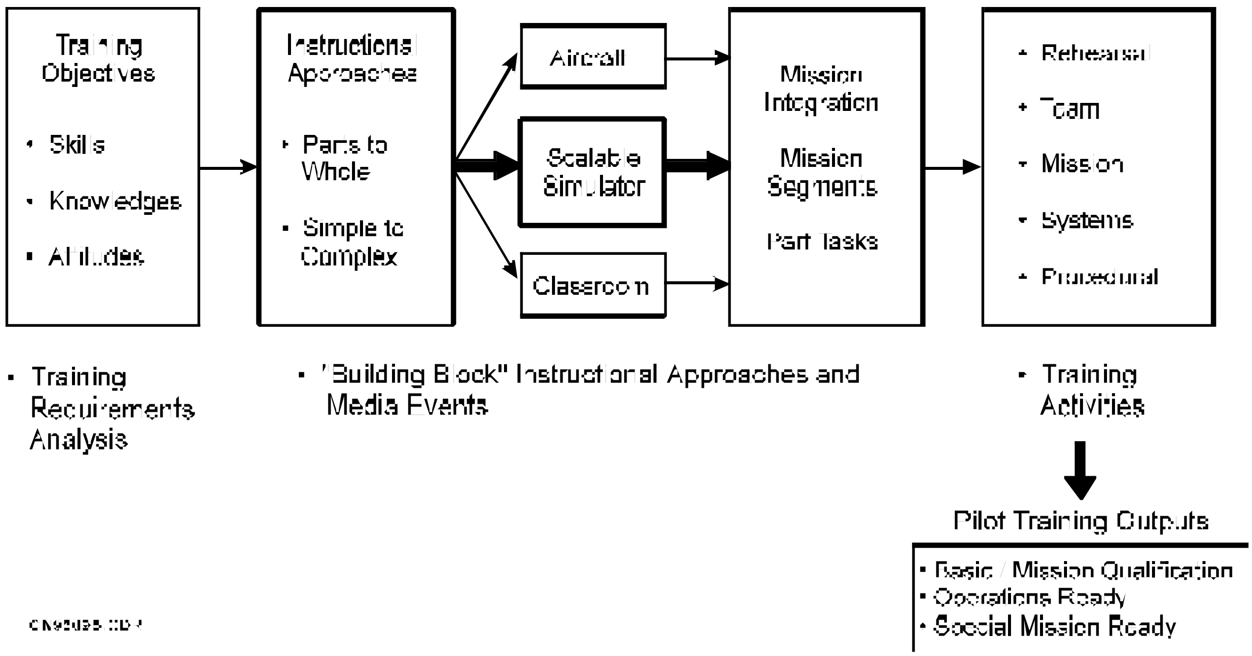

Figure 1 Process for Simulator Analysis and Definition

based on the training situation and the learning level of the trainee (Alessi, 1988). To determine UTD's fidelity, surrogate trainees used a prototype simulator and conducted numerous trade studies to quantify fidelity levels versus cost for UTD design decisions.

The analysis and definition activities help determine the simulator's capabilities to meet the customer's training and budget requirements. The modern commercial off-the-shelf technologies and approaches to produce flight simulators with high-fidelity capability at much lower cost are described next.

Scalable Simulation Technology - High Fidelity at Lower Cost

A scalable simulator addresses customer requirements for high-fidelity simulator training at lower cost by using today's commercial technologies and leveraging existing simulator software investments. The basis for high fidelity and lower cost is the simulator's common functions, which are illustrated in the top box of Figure 2, Scalable Simulator.

First and foremost, a powerful commercial computer system and executive combine many of the simulator's software functions (e.g., aircraft systems, sensors, databases, image generators, instructional features, etc.) to produce excellent performance. For example, the single computer approach facilitates correlation of the simulator software functions, and at the same time, reduces system throughput/latency. The result is high-fidelity training realism.

The high costs associated with proprietary, special-purpose hardware are reduced by using commercial off-the-shelf (COTS) computer systems now available. These modern computers are highly-reliable and have minimum need for repair and spare parts. Here the result is lower life-cycle costs. The computers are also readily available in the commercial market and have preplanned product improvement milestones, so future simulator capability upgrades can be inserted at the same time the computer system is enhanced.

The top box in Figure 2 also contains "core" simulator software functions from other simulator programs, such as aircraft systems, dynamics, and propulsion. The UTD avoids the high costs of developing proprietary, special-purpose software by rehosting high-fidelity, government-validated software from the F-16 Weapon System Trainer

Common High Fidelity Functions				
• Aircraft Dynamics and Propulsion	• Aircraft Systems and Avionics	• Basic Instructional Features	• Commercial Computer System and Executive	• Software Development and Debug Environment
• AirFields	• Nav Aids	• Malfunctions		

Scalable Environment	Scalable Packaging	Scalable Instructional System
• Sensors (Rdr, IR, EO)	• Cockpit and Hardware	• Single Monitor for Instructor Control
• Stores Management and Weapons	• Motion / G Cueing	• Single Monitor for Trainee Control
• Visual / Threat / EW Databases	• Control Loading	• Multiple Monitors for Mission Operator
• Image Generators	• Facility Power and Cooling	• Mission Director Position
• Display Systems	• Software Support	• Mission Planning
• Network	• Mobile / Deployable	• Mission Debrief

Figure 2 Scalable Simulator

(WST), B-2, and Simulated Aircraft Maintenance Trainer (SAMT) programs. Reuse of this core software saved the customer money by leveraging previously-made capital investments.

Attacking the high costs and inefficiencies of simulator concurrency were other primary targets for the UTD program. Because the customer identified concurrency cost reduction as a major concern, concurrency methods were examined rigorously.

Stimulation is highly effective if the aircraft is in the early years of its production, where the chance of frequent avionics configuration change is great. However, because high-cost aircraft hardware and software are used, stimulation is expensive. Due to the fact that many UTD simulators were planned, stimulation was not a cost effective approach because the recurring cost of aircraft hardware would have become prohibitive.

Simulation was not favored due to its "behind the aircraft" lag in implementing avionics configuration changes in simulators. In this case, the price to maintain concurrency is magnified by the threat of negative training when simulator functions are not concurrent with the aircraft.

A translation method to avionics concurrency emerged as the best approach to meet customer requirements at an affordable cost. A Hughes Aircraft-developed conversion kit translates aircraft software (i.e., the operational flight program) to simulator-suitable code (i.e., Jovial-to-Ada), so the software runs in the UTD's single, commercial computer. Without using expensive aircraft avionics hardware, the result is excellent concurrency through rapid conversion of aircraft software for use in the UTD.

Scalable Simulation Technology - Scale Options

The scalable simulation approach allows customers the flexibility to choose initially or at a future time the simulator options that best meet their training and budgets requirements. By using

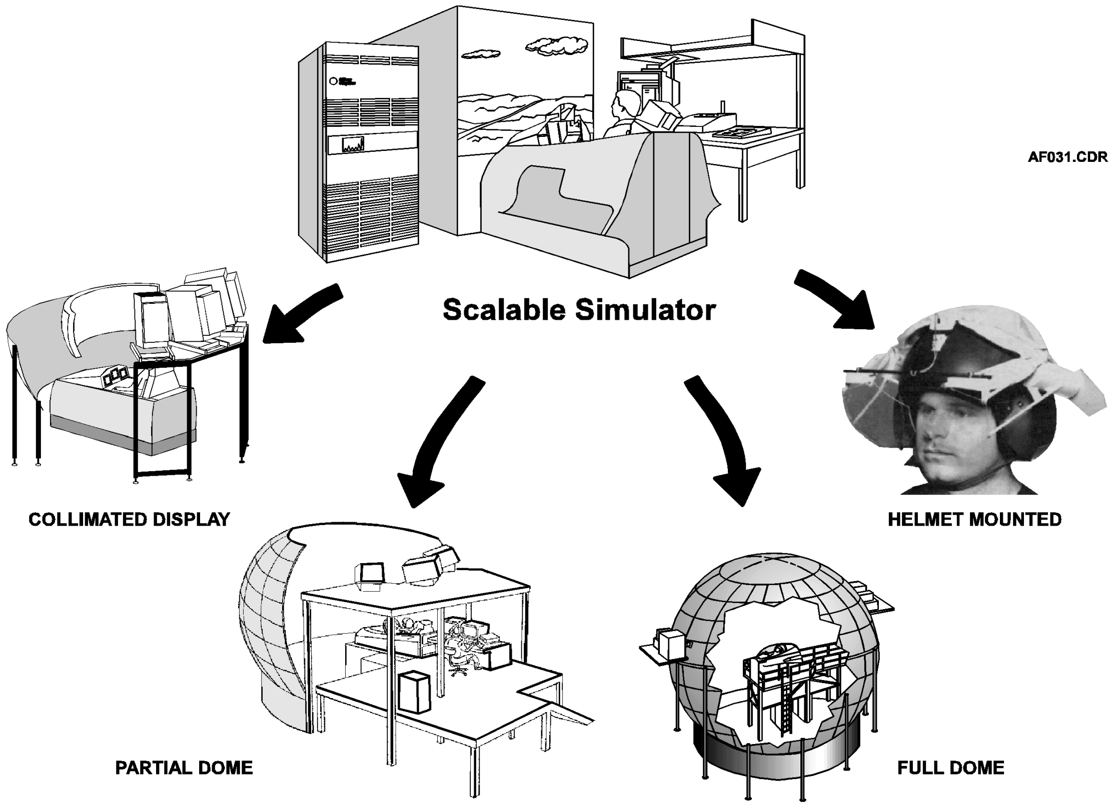

Figure 3 Visual Display Scale Options

powerful computer technology with open system architectures and extensive expansion capacity, scalable simulators can grow to support new and emerging training requirements.

Customers can add simulator options, expand capabilities, and install upgrades without making major modifications or redesigning the simulator. Consequently, precious customer capital investments previously made in the initial simulator are not thrown away while growth and upgrade capabilities can be added for the lowest possible cost.

Customers may have many reasons for the choices they make about simulator options, such as mission training requirements, acquisition and life-cycle support budgets, available facility size, customer preference, and other factors. As a result, scalable simulators can have functional capabilities quite different from each other.

As illustrated in Figure 2, the three bottom boxes contain an extensive range of scale options which allow customers to make choices about simulator capability to meet their training requirements - today and tomorrow. There are three scale option areas: scalable environment, scalable packaging, and scalable instructional system.

Scalable Environment Customer choices for sensors, weapons, and synthetic environment databases are based on the extent and fidelity level required for training. For example, customers consider how large the "gaming area" database must be to support training. The customer also considers the fidelity level of options to meet training requirements, such as low-fidelity databases with simplified visual scene content, to very high-fidelity databases with complex photo-realistic scenes.

Customers have choices for visual display systems ranging from narrow to full Field-of-View (FOV) /Field of Regard (FOR) systems as shown in Figure 3, Visual Display Scale Options. Choices depend on various requirements and constraints.

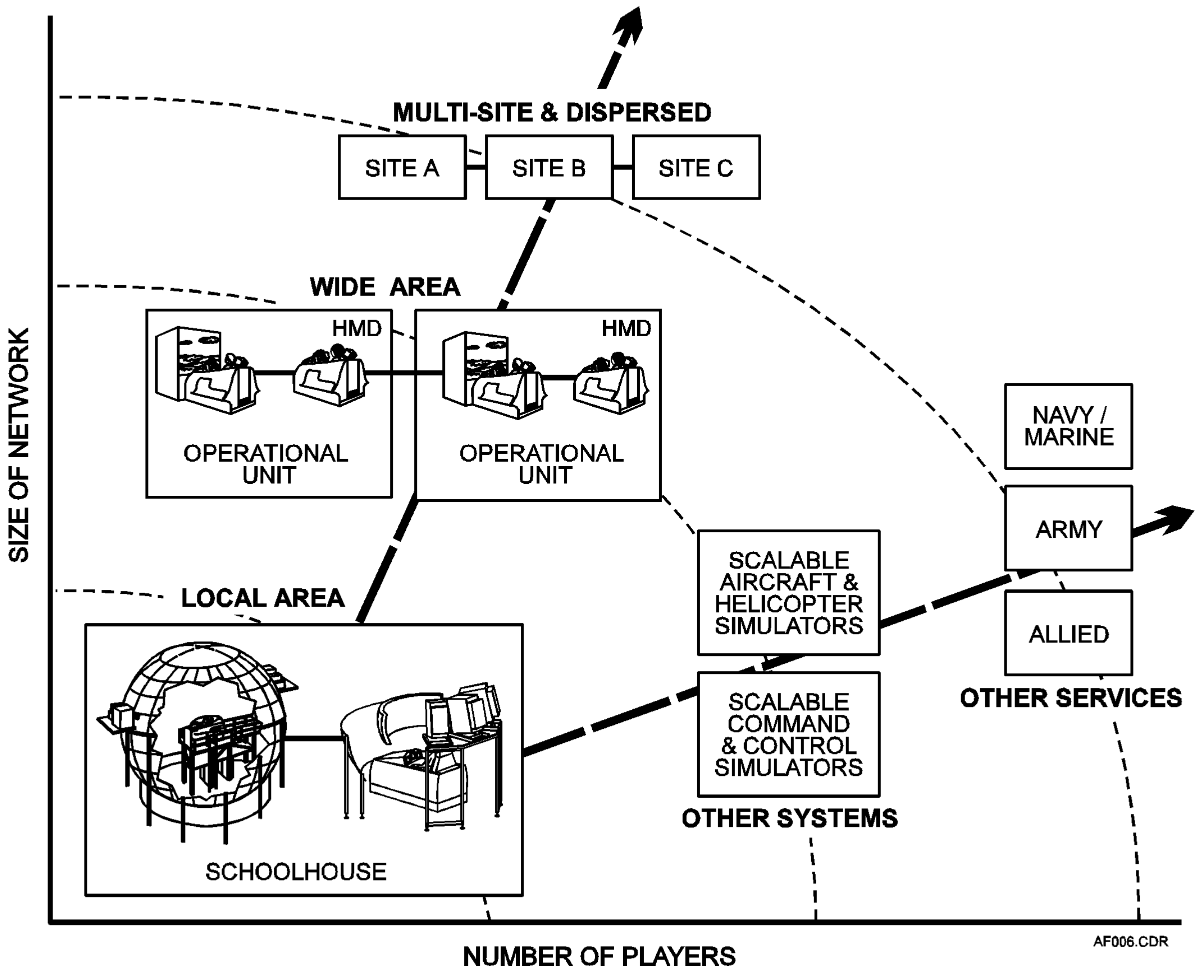

Figure 4 Network Scale Options

To meet training requirements, the customer considers how much simulated FOV is needed to accomplish the designated training tasks in the simulator. Generally speaking, FOV requirements are maneuver specific; that is, the trainee needs a simulated FOV to keep the object of interest (e.g., runway, flight leader, target, etc.) in sight during the maneuver or attack (Wiekhorst & Vaccaro, 1988).

Some training tasks, such as basic airfield approaches, are supported by narrow FOV displays. Other training tasks, such as formation maneuvering and visual threat avoidance, need a high-performance large FOV display (Thomas & Geltmacher, 1993).

Besides training requirements, customers also consider facility size and budget constraints they have for visual display systems. Obviously, trade-offs may be necessary to reach a solution.

A full FOV dome display may provide the best overall system characteristics. The dome has a simulator visual view that is like the view from the actual aircraft to facilitate the trainee's performance of the training tasks. However, limited facility size prompts compromise decisions for the type and size of the display system to choose.

Another customer choice under scalable environment is the network option. As illustrated in Figure 4, Network Scale Options, the scalable simulator is used as the basic building block for the network. Depending on customer requirements for teamwork training, the size of the simulator network can be determined.

For example, scalable simulators with narrow and full FOV display systems are locally networked to support training requirements at the schoolhouse. The scalable simulators located at operational units - some with full FOR helmet-mounted displays (HMDs) - are also locally networked to provide multi-ship teamwork training for squadron pilots. Using long-haul network technology, wide area (i.e., two or more operational units) and multi-site and dispersed locations can be linked so many players can practice high-value teamwork training.

The size of the network and number of players can be expanded to include other weapon systems and services, as illustrated in Figure 4. Using scalable simulation technology as the baseline, other aircraft and helicopter players (e.g., F-15, F-16, B-1, C-130, AH-1, AH-64, etc.) and command and control players (e.g., E-3 AWACS, radar controllers, battle managers, etc.) can join the network of many scalable simulators for advanced team training and/or rehearsals for composite force missions.

Scalable Packaging Customer choice for cockpit hardware is an area where multiple relationships exist. For example, the relationships between concurrency approach, cockpit fidelity necessary to support training, and costs are analyzed.

As a result of the cost and benefits analysis, for the UTD program a spatially correct, simulated cockpit was the optimum approach. This is so because the UTD's translation concurrency method does not need aircraft hardware to function, as does the stimulation method, and low-cost simulated hardware provided proper levels of fidelity for pilots to accomplish their training. The selection of simulated hardware was also in keeping with UTD's high-fidelity at lower-cost approach.

The use of high-fidelity, simulated cockpit hardware in the UTD influenced other option areas under scalable packaging. Due to the simulated hardware, power and cooling requirements are greatly reduced so the UTD has a very low impact on facilities. The UTD's unit-level design means that it has a small "footprint" size with the capability for easy moving and set-up. As a result, the UTD is considered portable; that is, the UTD is very mobile which makes it suitable for rapid deployment.

Scalable Instructional System There are many instructional options to support the numerous flight simulation training requirements. A baseline instructor station has all the instructional functions for training and can be easily customized to support unique requirements. For unit-level training, a single monitor option mounted next to the cockpit provides "over-the-shoulder" instructor monitoring and/or control of the training by the trainee from the simulator's cockpit.

SUMMARY

Today's military flight training courses qualify pilots, aircrew, and operators for their demanding, multi-mission duties. Flight simulators have successfully supported the training courses for years. However, these simulators have been characterized by a number of high-cost areas, such as high cost proprietary hardware, approaches to avionics concurrency, and life cycle support. While the demand persists - and may increase - for the simulators to support the flight training courses, the budgets for these simulators are diminishing.

Now, the relationships between customer training requirements, the use of modern technologies, and cost effectiveness strategies are examined to provide high-fidelity simulation training at much lower costs. These important relationships are illustrated in Figure 5, Key Areas of the Scalable Simulation Approach.

Scalable simulation technology is used for the U.S. Air Force Unit Training Device (UTD) program. The UTD provides high-fidelity flight and weapon system training capability at lower cost. UTDs have a low-facility impact design to fit into office workspaces. Because UTDs are lower cost, customers may afford multiple UTDs for highly-available, on-demand training in the units. Using local and wide-area networking technology, multiple UTDs can be networked for team training. Scalable simulation is also the building block for large simulator networks. This capability allows the pilots, aircrew, and operators of many weapon systems to practice high-value team coordination training to the extent required.

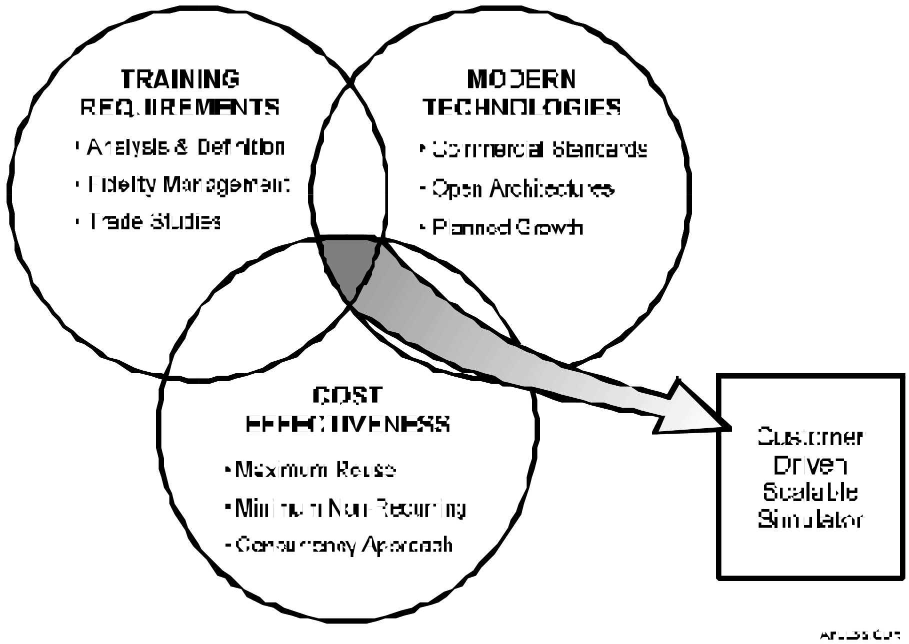

Figure 5 Key Areas of the Scalable Simuation Approach

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