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SIMULATION FOR DESIGN, TEST AND EVALUATION, AND TRAINING: RECONCILING THE DIFFERENCES

Ronald G. Hughes

Combat Simulation and Systems Integration
McDonnell Douglas Helicopter Company
5000 East McDowell Road, Bldg. 531/C240
Mesa, Arizona 85205

ABSTRACT

A concept is presented which describes the role of simulation (more properly, real-time man-in-the-loop simulation) across the entire life cycle of a weapon system. Novel aspects of the concept include the potential for the selective use of the developer's "engineering" simulator during operational test and evaluation (OT&E) as well as the merits of a tightly coupled approach to the design of the engineering simulator and that of related training devices/simulators. Lest the role of the engineering simulator be overstated with respect to its role in systems integration, a clear distinction is made between the role of the engineering simulator and that of a "systems integration facility" (SIF). Parallels between the prime's use of such a concept and the use of such a concept to achieve integration among different Government laboratories is discussed. Lastly, the issue of "fidelity" is discussed with respect to current simulation technology limitations and their known effects upon performance outcomes.

1. INTRODUCTION

Simulation, both real-time man-in-the-loop and non-real-time computer (analytic) simulation, represents an important tool in the development and test of advanced weapon system concepts. Manned simulation, in addition to becoming an increasingly important design tool for the developer, has, in the past ten years, taken on a level of importance for training far beyond that associated with early procedural trainers and "simulators." Advances in a number of different simulation technology areas promise to revolutionize the manner in which manned simulation is used for both engineering design and test as well as training; in particular, advances in low-cost computer image generation systems, distributed microprocessor architectures, higher-order programming languages, modular system design, and the ability through local and long-haul networking to allow large numbers of heterogeneous systems to operate in a real-time "common operating environment."

Rapid advances in computer system hardware are creating opportunities which are increasingly making the distinction between "real-time" and "non-real-time" less meaningful. We are, in fact, seeing many organizations either physically merging their manned simulation and operations research functions or, at a minimum, imposing more deliberate management oversight over the long-range research and development activities of each. We are also seeing "simulation" being given the status of a "strategic" corporate technology in such large aerospace corporations as McDonnell Douglas.

In the present paper, I want to deal with three separate but related issues that are important to this expanding view of simulation. First, I want to address engineering simulation and its potential application across the life cycle of a weapon system. I want to discuss, in particular, the model which is emerging at the helicopter component of McDonnell Douglas and its relationship to some advanced thinking on the part of the Army in terms of a preliminary (Army) "master plan" for simulation. As a part of that discussion, I want to draw some parallels between the approach as implemented by the "prime" and the approach as it might be implemented between different Government laboratories (a la the draft Army Simulation Master Plan). Secondly, I want to focus on a particular aspect of this application, namely the simulation of the operational mission environment and where that responsibility might best lie.

Lastly I want to address certain concerns that all these applications have in common regardless of whether for design support, for test and evaluation, or for training – those being the effects of fidelity constraints and limitations on engagement/mission outcomes and the problem of "correlation" between outcomes generated under analytic, manned simulation, and/or actual range conditions.

2. ENGINEERING SIMULATION: A LIFE CYCLE APPROACH

Internally at the McDonnell Douglas Helicopter Company (MDHC), we are continuing to give a great deal of thought to the application of manned simulation across the entire life cycle of a weapon system. This approach is being developed and modified in the dynamic context of ongoing work on the Army LH and Apache Longbow programs.

2.1 Continuous Emphasis on Mission Effectiveness

A key aspect of this overall process for the use of manned simulation is being able to design, develop, test, and train, under conditions representing the actual mission environment. In the context of "concurrent engineering," it represents an attempt to pull the operational mission environment as far "to the left" in the engineering design process as possible. The role of manned simulation in this process is both very mission-oriented and man-centered while at the same time being very engineering-oriented in terms of the actual weapon system design itself. It is an approach which gives high priority to the human component of system design and to the contribution of the human component to overall system effectiveness.

2.2 Modular Development

The concept shown in Figure 1 depicts that of a highly modular system with the engineering simulator at the core. The simulator is represented in the figure by the icon of a dome. Superimposed on the dome is the notion that the engineering "simulator" apart from its cockpit, visual system, etc., is, in its earliest stage, a functional representation of the aircraft bus architecture and basic "modules."

In order to present the concept in its simplest form, the figure shows the "simulator" as being a higher-order module in a system containing three other modules: a module for simulator control and performance

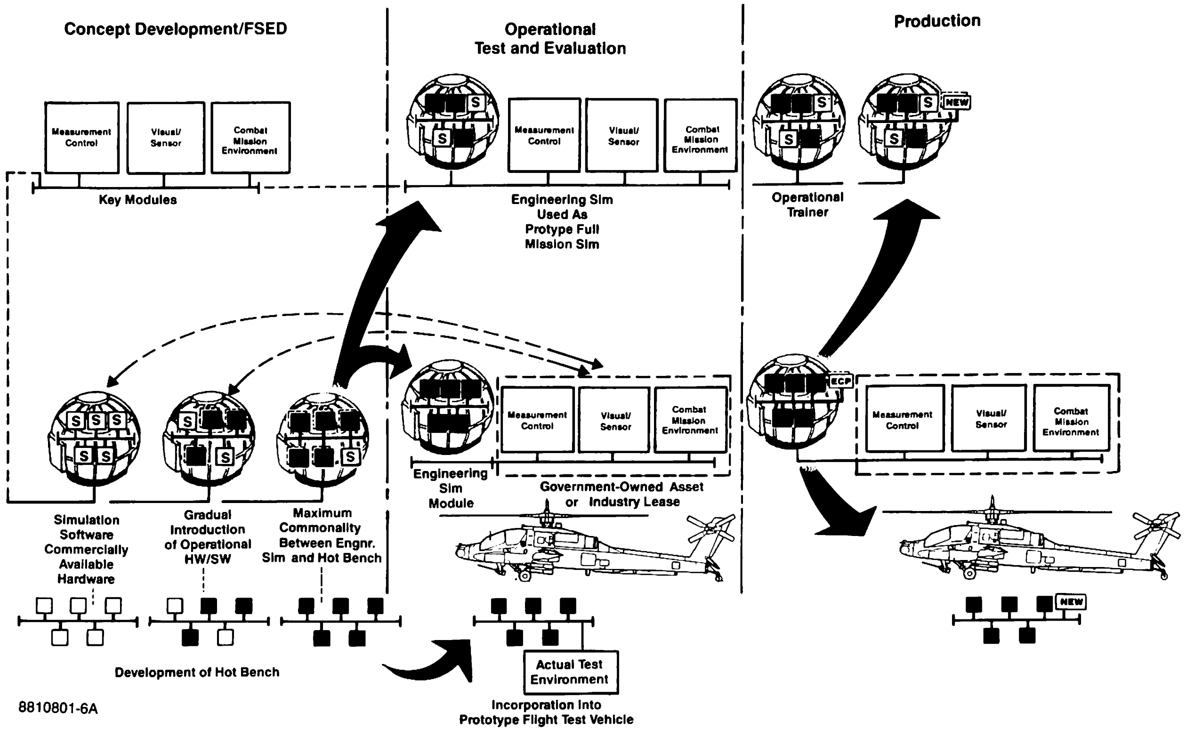

Figure 1. Representative Approach to a Concept for Life Cycle Manned Simulator Utilization

measurement; a module for visual and sensor simulation; and a module referred to as the "combat mission environment." These three higher-order modules provide the invariant elements of the context in which the engineering simulator matures from pure "simulation" (shown in Figure 1 as open boxes with an "S") to a configuration resembling, in part, the hardware/software type environment of the systems integration facility (filled boxes indicate use of actual flight hardware and software).

2.3 Role in Systems Integration

It is important to note that the engineering simulator is not intended to be a "systems integration facility" in the sense that all hardware/software integration would occur in the engineering simulator, per se. Aircraft hardware and operational flight software are integrated in environments that we refer to as the Software Integration Laboratory (SIL) and the Systems Integration Facility (SIF).

While the engineering simulator does not represent a critical path for all hardware/software integration prior to going to the aircraft, the engineering simulator is critical in those integration areas (e.g., controls and displays, etc.) where the pilot-vehicle interface is a key element of the system design. Thus while the actual aircraft display processor, multi-function displays, flight controls, helmet display, etc., would, for example, be expected to be an inherent part of the engineering simulator hardware environment, other hardware/software aspects of the actual aircraft (e.g., the full mission equipment package, or MEP) might not. When a pilot-in-the-loop requirement is critical to the hardware/software integration process, it is possible to physically interface the engineering simulator to the actual flight controls or avionics hot bench environments (e.g., the "SIF") in order to establish a fully integrated systems capability.

Because the engineering simulator does not represent the ideal environment for many aspects of hardware and software integration, many hardware and software functions may be simulated or emulated so that the engineering simulator can be used independently of its physical interface to the hot bench environment/s (e.g., for crew station, human factors, aircrew training, mission effectiveness studies, etc.).

2.4 Role in Test and Evaluation

Under the MDHC concept for manned simulation, test and evaluation are continuous functions through the life cycle and not restricted to formal customer-imposed requirements. The figure also suggests that the engineering simulator may have a critical role to play in the more formal aspects of test and evaluation. In a program such as LH, the effectiveness of the proposed FSD design must first be demonstrated (at the end of the demonstration/validation phase) in the engineering simulator under representative "mission" conditions. The use of the engineering simulator for this function has been referred to by some as a "sim-off" (as opposed to a fly-off of actual flight vehicle prototypes.). Later (during FSD), when an actual prototype vehicle exists, the engineering simulator will be used to train the aircrews who will participate in the formal developmental and operational tests (DTs and OTs).

These evaluations, conducted under simulated mission conditions, are important in obtaining estimates of mission effectiveness. A "correct" simulation of the mission environment is therefore of utmost importance, especially if outcomes are to be used as a basis for a "downselect" between competing development teams. Establishment of a "valid" mission environment (to include the activity of an opposing force) is critical regardless of whether that environment represents only a "slice" of the battle or a fullscale representation of the force-on-force conflict. The ability to link one's engineering simulator via a long-haul land line or satellite connection to a simulated, force-on-force environment represents one possibility for exercising alternative designs in a highly measurable and controlled environment without the expense of building actual prototype flight vehicles.

In the test and evaluation section of the concept, the suggestion is made of a Government owned and operated or leased "facility" (perhaps SIMNET). Such a capability would allow the Government or ultimate customer to reach into the actual system design early in the process. Such a capability gives the eventual user more of a concurrent role in the actual design of the system. That same ability on the part of the user to probe the developer's design in terms of its effectiveness also can work in the other direction to allow the developer to place his design in the ultimate OT&E environment early in the program. To the extent that real-time, manned simulation may represent a means for increasing the concurrent nature of design and evaluation functions, the developer is naturally concerned that the outcomes of such evaluations are not affected by artifacts of the simulation itself (such as might be the case in terms of performance effects due to simulator fidelity constraints). This concern will be addressed in a later section of the paper.

2.5 Coupled Design Approach to Training Devices

Under the MDHC approach to manned simulation, the engineering simulator is designed in such a way that its basic architecture and major modules can be transitioned directly to the aircrew training devices. Again, with respect to the notion of concurrent engineering, this represents an attempt to move key trainer design and production decisions as far to the left as is feasible.

This coupling of engineering simulator and training device design does not permit a total "flowdown" of flight hardware and software from the engineering simulator to the training devices. Remember that the engineering simulator is not a critical path for all aircraft hardware and software. The engineering simulator <u>will not</u> be a perfect replica of the actual aircraft hardware and operational flight software. This coupled approach does, however, have the advantage in a concurrent engineering sense of moving major trainer engineering issues (selection of image generator, display system, system architecture force cuing hardware and algorithms) significantly "to the left," increasing the likelihood of concurrent aircraft and training system availability. It also creates an effective instructional environment in which to insure that the human components of the system design are fully prepared (trained) prior to any full system evaluation.

2.6 Simulation During Production Phase

In the production phase shown in the right portion of the figure, the operational aircrew training devices are shown as a direct extension of the basic architecture of the engineering simulator. The systems integration facility (SIF) is shown in conjunction with its engineering simulator interface as being the basis for both the air vehicle and trainer post-development support facility. Engineering Change Proposals (ECPs) can be evaluated within both the actual air vehicle and within trainer system contexts before approval.

There is an additional application for simulation during the production phase. To the extent that simulation permits us to provide an effective operational environment around the design for both engineering design support and test/evaluation, that same capability can also provide an effective environment around the production air vehicle itself for production testing. In some instances, it should be possible to "fly" the equivalent of a combat mission before coming off the production line, significantly increasing the customer's confidence in the delivered product.

3. AN INTEGRATED APPROACH TO ENGINEERING SIMULATION: PARALLELS IN INDUSTRY AND GOVERNMENT APPLICATIONS

Manned simulation at MDHC, in conjunction with analytic simulation, plays a key role in concept formulation and system design. At MDHC, manned and analytic (mission effectiveness) organizations have been physically integrated in order to provide a "common environment" for evaluating alternative concepts and system designs (refer to Figure 2).

The key aspect of this commonality between analytic and manned simulation lies in the definition of the mission environment and one's ability to interact with that environment without regard to the real-time or non-real-time nature of that interaction.

In addition to providing a common (mission) environment for evaluation purposes, manned simulation is important in providing a common (software) operating environment for use by developers in different areas (e.g., avionics, crew station, flight controls, etc.). On programs such as LH, Longbow Apache, and the like, developers represent either different functional organizations within the prime or different subcontractors and teammates. As we said earlier, although the engineering simulator (as well as the "correlated" use of non-real-time analytic simulation methods) is not the primary systems integration function, it does serve as the common ground for the early development and integration of capabilities from different sources.

The Government is like the prime in that different laboratories, usually at different locations, are responsible for different "pieces" of a program (AMES for flight controls and crew station, AVRADA for avionics, Rucker for operations/training, OTEA for test and evaluation, etc.). In order for manned simulation to provide the common operating environment for cooperative laboratory efforts, there must be agreement as to who shall have primary responsibility for establishing the simulator architecture and facility and what the rules shall be for different users/laboratories to interface with that facility. The use of engineering simulation as a common operating environment for the different systems engineering interests of different laboratory users was a chief systems engineering theme of the draft Army Master Simulation Plan [Haller 1989].

Implied in the draft Master Plan was also the notion that through the proper establishment of such a common environment, Industry as well as Government laboratories could participate. A review of the draft plan by the American Defense Preparedness Association (ADPA) pointed out that such an arrangement would take deliberate effort on the part of both the Government and Industry in that the promises of being able to network totally heterogeneous hardware/software systems as well as being able to do so via yet unproven long-haul technology was currently extremely optimistic. Nevertheless, to do so (at some time in the future) represents a direct extension of the approach being employed internally by MDHC and others. The concepts explored in the Army's Master Simulation Plan (and supported by Darpa's SIMNET initiative) suggest that we could be on the verge of "networking" independent Government laboratories and industry locations together in the same manner that we have come to find networking within the business office environment increasingly commonplace.

We must be cautious, however. Whereas our use of a common alphabet and number system permits us to function in a common operating environment for most alphanumeric and mathematical operations in the office place, the factors governing the creation of a simulated, common "mission" environment for tactical systems are more complicated.

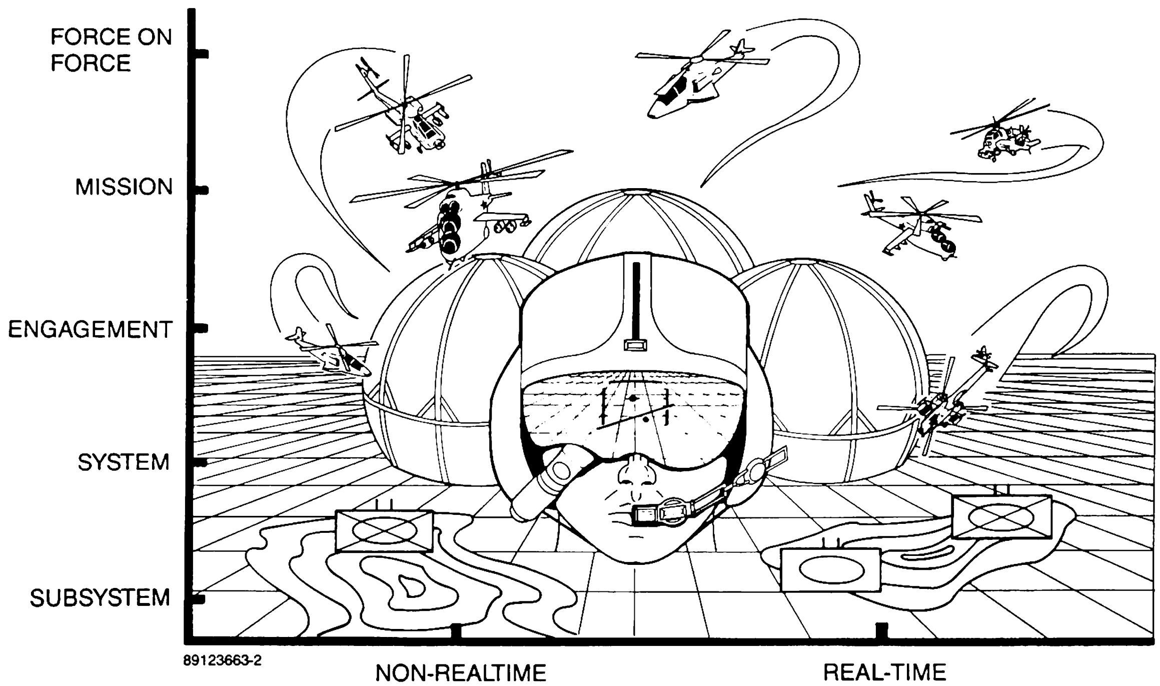

Figure 2. The Simulation Continuum

4. TACTICAL "OUTCOMES" AND THE EFFECTS OF SIMULATOR FIDELITY

Simulation is not just a "tool" but also a technology or set of technologies. In some instances - for example, in the area of visual simulation for man-in-the-loop operations - limitations and constraints of current technology can have a significant impact upon the effectiveness of simulation as a tool. If one is not aware of these limitations, the outcomes of manned simulation studies can differ significantly from outcomes generated analytically or derived from actual field conditions. In light of the current enthusiasm for low-cost, networked simulators for training and the possible extension of this use for test and evaluation, it is important to be aware of some of these limitations and their effects.

4.1 Practice In Simulators Influences Operational Outcomes

Until recently, real-time man-in-the-loop simulation was capable of supporting only "single ship" performances under limited engagement conditions [Hughes et al. 1982]. These early studies were, however, effective in showing that pilot training, even under such limited single-ship conditions, could significantly affect collective performances in operational environments such as RED FLAG. These studies were important, too, in showing that meaningful "correlations" could be established between the performance of pilots in simulators and the performances of these same pilots under operational conditions.

4.2 Effects of Constraints and Artificialities

These studies were instructive, too, in revealing the impacts of range "artificialities" on mission outcomes. Hughes found attrition data from the RED FLAG environment to differ markedly from that obtained in the simulator under similar, but not identical, conditions. Attrition data from the simulator were, in fact, found to agree better with computer simulation predictions than with actual operational range data.

The area of most significant artificiality was associated with simulation of the surface-to-air threat [see Killion 1986]. Just as Killion was able to demonstrate the effects of EW threat simulation fidelity on weapon system performance, other studies [Kerchner et al. 1983; Hughes and Brown 1985] were showing that simulator fidelity constraints (especially in the visual area) could result in significant alteration of mission outcomes. Kerchner's data, which dealt with variables affecting simulator air combat outcomes, showed that such constraints could, in fact, change the entire nature of the engagement itself, not simply the quantitative level of the outcome.

4.3 Do Operational Tests Sometimes Underestimate Effectiveness?

The Hughes data are also instructive from a different perspective. Although Hughes used "mission-ready" subjects in conjunction with a scheduled, unit RED FLAG training exercise, performances in the simulator were continuing to improve even when subjects returned to the simulator for additional practice following the two-week RED FLAG exercise. Even though the minimum simulator training prior to RED FLAG was able to improve RED

FLAG outcomes by 15-20 percent in terms of sorties survived, the fact that asymptotic performance was never achieved in the simulator suggests that most OT&E activities never observe system performance under conditions where the aircrew component is fully trained.

The sensitivity of outcomes to such "fidelity effects" is a problem for both analytic and real-time simulation. For traditional computer simulation approaches, fidelity effects are most often the result of lack of understanding of how to model essential variables; for real-time simulation, such effects are most often associated with technology constraints. . . particularly in the area of visual simulation for the human operator [Hughes 1989, 1990].

4.4 Simulators, SIMNET, and OT&E Support

There is a serious and growing interest in using manned simulation to augment conventional operational test and evaluation (OT&E) resources [Shipley et al. 1988; Hughes 1988]. Shipley et al. investigated the technical feasibility of such an approach in the context of the Army Scout-Attack mission. In particular, Shipley focused on how one might effectively augment use of the developer's high-fidelity engineering simulator with other low-cost "local" simulations/simulators in order to provide an effective battlefield context [see also Blizek 1988].

Shipley also addressed the option of providing a long-haul interface to SIMNET [see Thorpe 1988]. Such an approach would, in theory, permit the networking of either the developer's high-fidelity engineering simulator or the simulation of multiple platforms of lesser, but acceptable, fidelity into the SIMNET battlefield consisting of both manned adversaries and some degree of simulated opposing force (SIMOPFOR). The approach is attractive for systems where simulator technology constraints (especially visual) would not play a major role. However, the use of SIMNET for aviation elements with significant out-the-window visual requirements appears inconsistent with what we know about the effects of fidelity limitations (especially visual) on engagement outcomes [Hughes 1989, 1990].

The use of SIMNET for augmenting operational test and evaluation has several problems. These are more pragmatic than technical. First, a SIMNET exercise is difficult to manage logistically and is labor-intensive. Part of the inherent advantage of simulation is that it is readily "available" and, other than the O&M costs of the simulation facility, does not involve a significant requirement for operational equipment and/or personnel. A second issue concerns the "free play" nature of the SIMNET operation. The apparent fidelity of the large-scale force-on-force aspects of the engagement leads some to infer confidence in outcomes derived from a "sample of one." There can be a dangerous tendency to "come off freeze" and see what happens. . . rather than to utilize the simulation to increase the number of observations possible under a controlled set of conditions carefully derived from the requirements of specific test events or issues.

What would be helpful would be for the developer to remotely (by long haul) link into an approved SIMNET scenario utilizing the SIMOPFOR, where the performance (or general rules governing performance) of the SIMOPFOR was selectable depending upon the needs of the developer. Use of the SIMOPFOR would make possible a common operating (mission) environment for all developers on the program and would do so without the dependency associated with a real-time SIMNET exercise. Such an approach would do three things: first, it would serve to standardize the target and threat laydowns used by individual contractors; second, it would provide the Government with a degree of control over test and evaluation aspects of development; and third, it would free the contractor/developer of the cost of developing and maintaining his own "mission" environment.

5. SUMMARY OF KEY POINTS

a. Simulation, both manned and analytic, represents significant tools in the development and evaluation of advanced weapon system concepts and their associated mission effectiveness.

b. Advances in technology are making traditional distinctions between manned and analytic approaches in terms of "real time" less meaningful.

c. An effective "simulation" approach is one that fully integrates manned and analytic methods.

d. Engineering (manned) simulation can provide an effective "common operating environment" (COE) for the development, integration, and test of capabilities developed as individual stand-alone "modules."

e. A common operating environment, deliberately conceived and implemented, represents the central core of the Army's draft Master Simulation Plan.

f. A central apsect of the common operating environment is the simulation of the "mission" environment (target and threat laydowns, threat behavior, etc.). Responsibility for standardizing mission environment definition for different users is extremely important.

g. A force-on-force simulation environment, such as that being developed for SIMNET, represents a key requirement in the use of simulation to augment conventional operational test and evaluation (OT&E) resources.

h. The results of numerous visual simulation studies indicate that engagement outcomes can be significantly affected by image generation and display system constraints.

i. Low-cost simulation is generally associated with visual system constraints and limitations and should be considered suspect with respect to engagement fidelity.

6. CONCLUSION

Simulation, broadly defined, without respect to the traditional boundaries of real-time or non-real-time, provides us with the exciting potential of being able to clearly "see the future" to the extent that we are able to understand and correctly represent the physical relationships between natural events. Our simulations in the past have lacked the ability to model the most difficult of natural events, those involving the behavior of the human element in our systems. Our understanding of human performance, especially under complex conditions such as combat, increases slowly. However, manned simulation and especially recent advances in our ability to expand the manned simulation "battlefield" are now providing us an important ability to observe human behavior under conditions approaching those of actual combat. Through networking, not only can we permit independently developed "modules" to communicate in a "common environment" but perhaps in the near future we shall also be able to permit Government and Industry to participate within common environments for design, test, and evaluation.

The technology still has limitations. Simulation is still not "the real thing." As we move into situations where simulation represents the only means to explore the relationships between system performance (especially the human element of that performance) and key variables of interest, we cannot loose sight of the criterion problem. How much fidelity is enough?. . . enough for training, enough for engineering design, enough for test and evaluation? The same technology that permits us to advance to new levels continues to constrain us as well. We have mentioned one such technology here, that of visual simulation and its limitations in terms of its effects upon human operator performance. Simulation is a tool, a valuable tool indeed, but like any tool, it is valuable only when used with a full understanding of its limitations.

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