Accreditation Policy and Practice for Immersive Warfighter Simulators

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ABSTRACT

Immersive simulators are needed for substantive joint warfighter training, yet the policies and practices which can help ascertain the accuracy and credibility of these complex systems are not well developed. This paper uses an ongoing effort by Air Combat Command to modify its simulator accreditation process for fighter, bomber, and C2ISR simulators as an example of the challenges in developing appropriate validation and accreditation policies for warfighter training. The paper will review current verification, validation, and accreditation (VV&A) policies and practices in the academic, Department of Defense, and Federal Aviation Agency domains as well as the Air Force simulation certification program. While necessary, these policies and practices are not sufficient for judging the credibility of flight simulators when the purpose of the simulator training is expanded to mission-level knowledge and skills. By focusing on the purpose of DMO simulators as expressed in the concepts of immersiveness, instructional integration, and interoperability, we can collect more evidence for accreditation decisions. The paper concludes with recommendations on areas of further research and policy refinements.

ABOUT THE AUTHOR

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INTRODUCTION

About ten years ago a major automotive corporation consulted an academic modeling and simulation expert. The corporate representatives asked him to construct a simulation for a production facility that worked "just like the real assembly line." His response was that if you want something "just like the real thing," then you need to build the real thing, not a simulation. (Personal communication, 1998) This began the dialogue to establish the purpose and identify the users of the proposed assembly line simulation. The anecdote illustrates three facets of simulation that are familiar to modeling and simulation professionals.

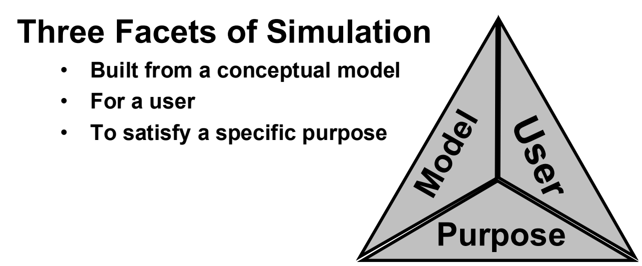

Figure 1
"Purpose" is the foundation of a simulation and is the primary concern in judging simulation credibility.

The first is that a simulation does not duplicate reality. A simulation is a computational implementation of a conceptual model. It is not genuine or authentic, but an artifice which will lack most of the detail and behavior of its real counterpart. It contains only what the modeler believed to be relevant at its inception.

The second is that a simulation has a user. If it is a sophisticated simulation intended to be integrated into organizational activities, the definition of "user" may broaden to include not only those who "run" the simulation, but also those who use simulation results to make decisions. Accommodating the intended users can be one of the most critical and difficult aspects of simulation design, development, and deployment.

The third is that a simulation is designed for a purpose. There could be many reasons for developing an assembly line simulation: modeling the effects of changes to labor contracts; management of inventory; developing requirements for manufacturing equipment; etc. Each purpose may result in a different type of simulation. An assembly line simulation designed to support labor contract negotiations would not be suitable for inventory management unless both requirements were specified in the initial design.

Purpose

The introductory anecdote touches upon another important issue in the modeling and simulation profession: the expectation that simulation can provide solutions to important organizational problems. This attitude is prevalent in the military where complex simulation-based applications are coupled to the training and readiness activities of operational warfighters.

An example of such an application is the Air Force's Distributed Mission Operations (DMO) program. The DMO program is creating a warfighter training network by linking fighter, bomber, command and control simulators, and, to a lesser extent, real manned and unmanned systems into local and wide area networks. There are a number of challenges facing the Air Force with respect to composing and certifying warfighter training which is conducted using complex simulation environments.

The purpose of this paper is to explore an important issue in the modeling and simulation profession: how to judge the credibility of simulation-based applications. The paper addresses this topic from the perspective of verification, validation, and accreditation (VV&A) and other modeling and simulation concepts as they apply to flight simulators used by operational warfighters.

Overview

The techniques used to judge the credibility of flight simulators for the purpose of supporting formal training programs – providing initial knowledge and skill development – are well understood. These techniques are also appropriate for follow-on training where the purpose is to maintain or refine foundational knowledge and skills. These techniques, while necessary, are not sufficient for judging the credibility of flight simulators when the purpose expands to mission-level knowledge and skills. By focusing on the purpose of simulators as embodied in the DMO concepts of immersiveness, instructional integration, and interoperability, we can collect more evidence for accreditation decisions.

The paper begins with background information on the DMO program. This section lays out the inception and nature of the program and briefly outlines the issue of using simulators to develop and accredit experience. Mission competencies and performance-based training are also discussed.

The next major section discusses simulation utility and credibility and reviews basic modeling and simulation theory. The relationships among purpose, conceptual modeling, and validation are presented.

The following section covers VV&A policies and practices in academia and the Department of Defense. The Federal Aviation Agency simulator qualification program and the Air Force simulation certification program are also covered.

The last section discusses the results of a simulator survey conducted at Air Force. Survey metrics were developed by using the concepts of immersiveness, instructional integration, and interoperability. The paper closes with recommendations on areas needing further research and suggests refinements to VV&A policy.

DISTRIBUTED MISSION OPERATIONS PROGRAM

For the Air Force, training transformation began in 1997. In the summer of that year, the Air Force celebrated its 50th anniversary at Nellis AFB, Nevada. In a hangar on the flight line was a prototype Mission Training Center developed by researchers and engineers from the Air Force Research Lab in Mesa, Arizona.

Four state-of-the-art F-16C simulators with wrap-around visual systems were networked with two A-10 simulators, a C-130 flight simulator, and an AWACS weapons controller console. The eight simulators could fly together against computer-generated air and ground threats in a virtual reproduction of the Nevada ranges. Operational pilots and controllers flew a complex mission that combined close air support, air escort, and tactical airdrop into a single integrated training scenario. Audiences watched the mission unfold on large video monitors that showed several types of real-time views, including individual cockpit displays, aerial maneuvering, ground movements, and weapons delivery.

Figure 2
The Air Force 50th Anniversary Celebration showcased advanced networked simulators

To many of those who witnessed the event, the networked simulators were a revolutionary training technology. It was, in fact, a revolution that had been gestating for years. Within the military training and research community, there had been over a decade of effort by industry and the Air Force to develop networked simulators useful for training aerial combat tasks. (Bell and Waag, 1998) There was also recognition by senior leaders like General Hawley, the commander of Air Combat Command (ACC) that networked simulators were essential for the future. In December 1996, well before the 50th celebration, he had committed the Air Force to this path in a directive to the ACC headquarters staff.

(I) would like a simulator training initiative ready to put forward in the next budget cycle that would implement linked, mission level simulation for the command. The end state would be a four-ship of high fidelity visual sims at each base for each aircraft,

linked to the AWACS, JSTARS, and other C4ISR sims; to a dedicated set of adversary work stations that could present a manned threat and to the C2 Battle Lab. (We) need to flesh out a vision for where we want to go with sim training in the future, and then sponsor an initiative in the next POM update. (ACC, 1996)

By late 1997, a contract was in place for the first set of F-15C Mission Training Centers. AWACS and F-16C contracts soon followed, along with a contract to establish a wide area training network. Work soon began in planning for the inclusion of existing simulators by modifying them to be DMO-capable. The working definition of a DMO capable simulator was established as:

- Immersive high fidelity cockpits and visual systems
- Integrated brief/debrief system
- Interoperable in local and wide networks

In 2002, the Air Forces Chief of Staff, General John Jumper, christened the program with a new name, Distributed Mission Operations (DMO), and extended the program to the rest of the Air Force. The compelling concept of simulated war in a synthetic battlespace invigorated other significant activities. The Air Force Research Laboratory used the DMO test-bed at Mesa to help ACC develop warfighter training concepts and transition simulator technologies. The Theater Air Command and Control Simulation Facility at Kirtland AFB, NM became the Distributed Mission Operations Center and sponsored quarterly exercises linking simulators, simulations, and live ranges.

Senior Air Force leaders consistently emphasize two themes in advocating the program. The first is that a significant portion of combat training for new weapons and combat systems, such as the F-22A, can only be accomplished in high-fidelity simulators. The second is that contemporary warfighting requires training of the entire "kill chain."

Can Simulators Provide Warfighters with Experience?

Within ACC, the new simulator technology was readily accepted. Not as well embraced were other efforts by General Hawley that directed his staff to develop a plan to use these new, networked simulators to "experience" pilots. (ACC, 1998) What he was asking for was beyond the framework of established training policies and simulator use. It was a challenge that is now being solved by moving to a performance-based training system as discussed in a later section.

Prior to the fielding of DMO-capable systems, simulators did not contribute significantly to operational fighter squadrons' mission training. Figure 3 depicts simulator requirements for a typical fighter pilot as he or she progresses through formal training and into an operational fighter. In initial training, about half of the training sorties are accomplished in a simulator. Once the pilot reaches an operational fighter squadron, however, the yearly requirement for inexperienced pilots is 12 simulator sorties per year. The requirement falls to 8 per year for experienced pilots. In both cases the simulator sorties are oriented to single-ship procedural tasks.

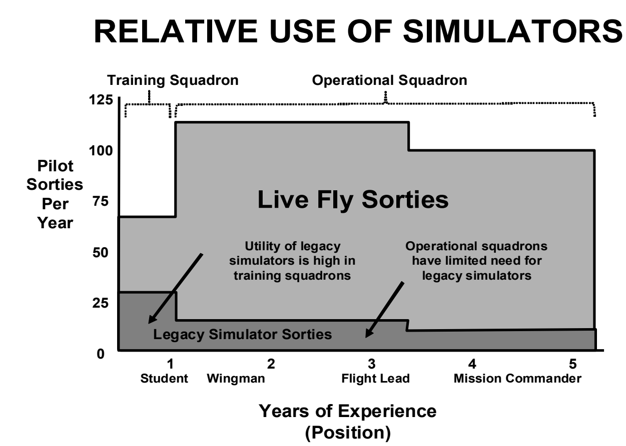

Figure 3

In the Combat Air Forces, "experience" is an official designation. A fighter pilot is "experienced" when he or she has 500 hours of flying time in a primary weapons system. The "experience" definition and the ratio between "experienced" and "non-experienced" pilots in an operational unit is an important benchmark used in a number of ways: reporting combat readiness, personnel assignments, funding the flying hour budget, and selecting pilots for leadership positions.

For several decades, 500 hours has been a useful yardstick. However, because of combat operations, the time-tested relationship between flying time and mission proficiency is becoming skewed in the wrong direction. Paradoxically, combat operations produce pilots who fly more but accumulate less expertise.

Training missions are designed to maximize exposure to the most crucial mission skills. Only about 15 minutes of a wartime mission is complex and intensive. That critical 15 minute period – releasing weapons close to friendly forces, attacking a time critical target, engaging an unknown air contact – while usually done once on an operational mission, is practiced several times during a training sortie.

Training sorties are fairly short, usually 75-90 minutes. Depending on a number of factors, it takes 2-3 years of operational flying to produce an "experienced" pilot, 3-4 years if formal training is counted. (Figure 3) Combat sorties are 3-6 times longer than training missions. Most of the added flight time is spent getting to and from the target area, an important but mundane activity. Nevertheless, these hours count towards the 500 hour "experience" metric.

Furthermore, in some mission skills, deployed pilots lose proficiency. Operational units must be proficient in several types of missions, as determined by the needs of each theater. Skills needed for Iraq are different than those needed to support Pacific requirements. However, units deployed to support the war in Southwest Asia only perform missions in support of operations there. They do not fly training missions and may therefore incur deficiencies in critical mission skills needed for other theaters.

Because of these factors, pilots are receiving less relevant "experience" per flying hour. Leaders of operational units report that pilots reaching the 500 hour standard are often not exhibiting the level of knowledge and skill needed for leadership positions as flight leaders, instructor pilots, and mission commanders.

Mission Essential Competencies

In March 2006, the Air Force decided that approximately 20% of its F-15C live-fly training requirement will be done in a DMO-capable simulator. These MTC sorties will count towards the 500 hour "experience" metric. (ACC, 2006) The decision to move 20% of the live fly sorties is additive to the legacy simulator requirement depicted in Figure 3 which, incidentally, did not count towards "experience."

Two factors were important in this decision. One was the result of a simulator survey conducted a few months previously. (This survey will be discussed later.) The other factor was an ongoing effort to develop a new training approach for warfighters. Because of the experience issue and other factors, ACC is moving from an event-based to a performance-based training policy for operational units. (Training units will continue to use formal training methodologies.) The predominant policy, for which simulator training is a part, is focused on weapons system operation or events, rather than combat proficiency. (Bennett & Crane, 2002) Performance-based training will be based on Mission Essential Competencies (MECs). (Colegrove & Alliger, 2002, Colegrove, 2006).

Detailed decomposition of system operation tasks, such as that used for a Training Task List (TTL), is a common methodology. This approach focuses on discrete actions – air refueling for example – and lists the tasks need to be trained in order to perform the action. TTLs can be very useful for initial training of pilots. Generally speaking, TTLs address weapons system operations and discount the external environment. Therefore, they lose some of their utility for operational training where squadrons must consider various theaters, war plans, geography, potential adversaries, and rules of engagement.

Another training perspective is found in the Mission Essential Task Lists (METLs) delineated in joint and Service publications. (Air Force, 1998) Whereas the TTLs are very detailed, METLs are defined at such a high level that they are unsuitable for defining the knowledge and skills required of operational aircrews.

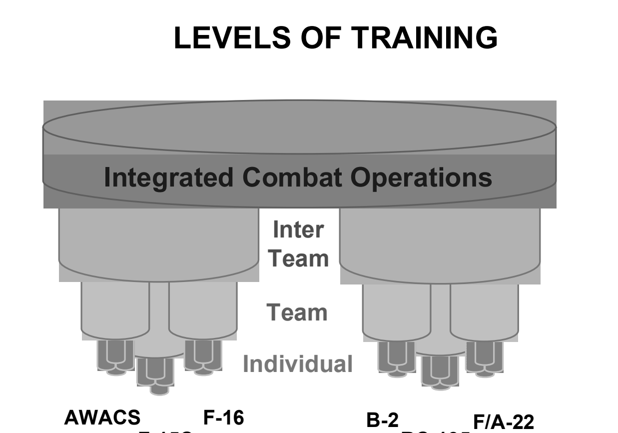

Figure 4

For example, there are only 2 primary METLs for an F-15C wing, both one-sentence statements. And like TTLs, METLs are static in the sense that it is very difficult to demonstrate how tasks are accomplished over time and integrated into larger events, such as a campaign or joint force mission statement.

MECS bridge the detail of TTLs with the mission orientation of METLs. But, more importantly, they capture the dynamic aspects of combat performance, something that neither TTLs nor METLs do. The heart of MEC development process is defining, from a warfighter view, the knowledge and skills that are needed each phase of the "kill chain"; how and when one moves between phases of a mission; and the critical interactions within and among combat teams during each phase. Figure 4 depicts the current view of MECs in showing the relationship among different levels of training. By linking MECs among sensor-shooter teams, MECs can accommodate contemporary warfighting concepts such as network-centric operations and information-based warfare.

When MECs are implemented into training policies, one consideration is determining what type of scenario provides competency development. This aspect of MECs is closely related to current training research areas, such as situation awareness, recognition-primed decision making, and naturalistic decision making. (Denning, 2004, and Chapman, 2004) The common theme is that the environment and context of the situation are critical to developing expert-level competency.

SIMULATION UTILITY AND CREDIBILITY

Simulation is valuable because it can be a useful surrogate for other, more direct types of knowledge or skill acquisition. (Modeling and simulation may also be an entertaining or artful activity but these uses are not discussed in this paper.) While both knowledge and skill acquisition are cognitive activities, knowledge is more often associated with system observation and skill with system manipulation – an internal versus external viewpoint.

Most textbooks on modeling and simulation explain the utility of simulation. (Shannon, 1975; Fishwick, 1995; Law & Kelton, 1991; Zeigler, 2000) The authors categorize the explanation in different ways but these explanations contain common themes. The rationale that computational simulation is preferred to theoretical or physical alternatives is based on one or more of the following:

- Understanding - Some problems are too complex to solve through logic, formalisms, or theory.
- Practicality – The authentic systems may be too expensive, dangerous, or otherwise unsuitable for experimentation or training.
- Contingency – The authentic system or the environment may not exist.

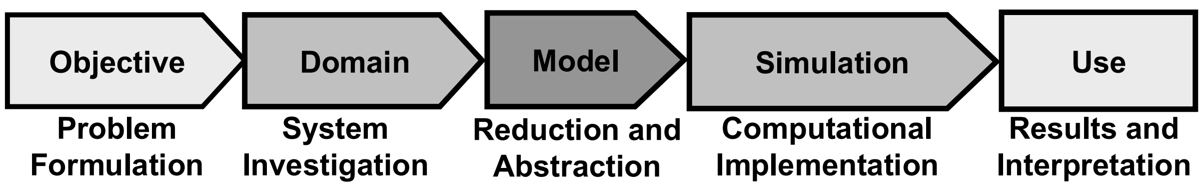

Figure 5

While these observations about utility of simulation may be generally true, those who use simulations for analysis, design, or training demand a more precise judgment about the specific capability of a simulation. Since simulation is a surrogate for an authentic system, the judgment should be made on measurements comparing the fictive to the genuine.

This introduces the two dilemmas. First, how does a simulation modeler investigate an authentic system which may be too complicated to intuitively grasp, not amenable to detailed observation, or lacking the theoretical structure needed to create simplifying assumptions? The second dilemma is closely related to the problem of initial system investigation. How does one ascertain if using a simulation provides genuine knowledge or develops the appropriate skill? The dual challenges of system investigation and system credibility can be addressed with a common reference, a conceptual model.

Simulation Design and Conceptual Model

A simulation is not a replication of a real world system, but a restricted representation of selected aspects of the real system. Creating a simulation or federation requires a simulation professional to engage in an iterative series of activities whose purpose is to assure that the final application is appropriate for the intended use. The activities begin with problem formulation, followed by investigation of the system of interest, reduction of the problem and system into a model, creating a computational implementation of the model, and finally executing the simulation. Figure 5 is a simple depiction of the progression from objective to use with respect to a modeling and simulation activity.

Although not rigorously defined, "conceptual modeling" is generally accepted as the early, implementation-independent foundation of the process. It distills the original system into features and behaviors of interest and describes how these factors will be approximated in the simulation application.

This underscores the underlying nature of simulation. Simulations are artificial systems and inherit the attributes of such a classification. Herbert Simon provides the definitive exposition between artificial and natural systems. (Simon, 1998) The most defining characteristic of artificial systems, according to Simon, is that they are artifacts of human activity created for a purpose. Emphasizing the purposeful nature of artificial systems can aid a simulation judgment activity in several ways. It sets the boundaries of the conceptual model and it provides context for judging simulation credibility when observations about the authentic system are not available for comparative testing.

Conceptual Model, Validation, and Purpose

Most of the recent research in conceptual modeling has been supported by the Defense Modeling and Simulation Office (DMSO) and is oriented to the use of a conceptual model as a tool in a simulation development effort. (Pace, 1999, DMSO, 2002) DMSO references define the conceptual model as:

A statement of the content and internal representations which are the user's and developer's combined concept of the model. It includes logic and algorithms and explicitly recognizes assumptions and limitations.

In addition, conceptual modeling is also part of Step 2 in the Federation and Development and Execution Process (FEDEP). There is also a product development group in the Simulation Interoperability Standards Organization creating a VV&A overlay to the FEDEP as a proposed standard. In the FEDEP, however, a conceptual model is used not for simulation development but as the basis for composing a federation of several simulations or other systems (often real). Closely related to the problem of composition, is validation.

Recommended practices for verification, validation, and accreditation include the need to design validation around the conceptual model. Using the conceptual model for validation is different from attempting to validate a simulation (or federation) directly against the authentic system, as is done in the case of FAA simulator qualification and discussed later in the next section.

VV&A POLICIES AND PRACTICES

Because purpose is the foundation of a simulation, it should be a critical element in the process to judge a simulation's credibility, commonly referred to as verification, validation, and accreditation (VV&A). The U.S. Department of Defense requires that all simulations be validated and accredited. Below is a definition of validation from the policy instruction on VV&A. (DODI 5000.61, 20003)

...the process of determining the degree to which a model and its associated data are an accurate representation of the real world from the perspective of the intended uses of the model.

The Defense Modeling and Simulation Office (DMSO) describes the need for VV&A of simulations as follows:

*"To determine whether a model or simulation or federation should be used in a given situation, its **credibility** should be established by evaluating **fitness** for the intended use. In simplest terms, verification, validation, and accreditation (VV&A) are three interrelated but distinct processes that gather and evaluate evidence to determine, based on the simulation's intended use, the simulation's capabilities, limitations, and performance relative to the real-world objects it simulates."* (DMSO, 2002)

These references provide an opportunity to emphasize precision in communicating M&S concepts. In the defense and academic M&S literature, "use," and "intended use" are synonyms for "purpose." There is a colloquial tendency, especially outside the M&S profession, to ascribe equivalency between "use" and "user." Hopefully, this paper will encourage M&S professionals to treat "use" and "user" as distinct concepts.

DMSO is engaged in a number of efforts to advance the practice of VV&A within the defense M&S community. DMSO efforts, while focused on the needs of the defense M&S community, base their recommended practices on the perspectives of academic M&S experts. Both the defense and academic M&S practitioners agree that there should be a distinct validation process integrated into a simulation-based activity. This process should result in a judgment about the accuracy and credibility of the simulation.

Balci, an academic authority on this subject, argues that "VV&T (testing) must be conducted throughout the life cycle of a simulation study." Balci uses the term "testing" rather than accreditation, presumably because he is focused on using a simulation as an analytical tool in a well defined activity, an analytical study. The term "testing" also implies a more rigorous level of judgment than an accreditation decision. Balci identifies four categories of verification, validation, and testing techniques. (Balci, 1998)

- Informal – relying on reason or observation without the use of mathematical formalism. Conducting a "Turing Test" is an example.
- Static – assessing the model design or simulation implementation without running the simulation. Interface analysis is an example.
- Dynamic – evaluating the behavior of the simulation based on executed behavior. Sensitivity analysis is an example.
- Formal – using mathematics or other formalisms to prove correctness. Lambda calculus is an example.

Law and Kelton present a similar perspective that is also oriented to simulation validity in the context of simulation support to analysis. Their characterization of the types of validity is very similar. (Law & Kelton, 1998)

- Face Validity – derived from sources such as system "experts," system observation, existing theory, similar simulations, experience and intuition.
- Empirical Validity – derived from sources such as tests of model assumption, input output comparisons of system and simulation, inspection of selected components, and statistical comparisons.

These viewpoints on validation are incorporated into the DMSO recommended practices and, in the case of supplemental technical references, Balci's recommendations, are included verbatim. The inclusion of academic expertise into DoD guidance is notable for two reasons. One, it lends credibility to VV&A guidance and practices. Secondly, it establishes the foundation of VV&A guidance on simulation used in support of analysis. Although a narrow foundation, DMSO has explicitly expanded its applicability beyond analysis to simulation development programs and federation development.

Presumably these VV&A practices can be tailored to large-scale applications such as warfighter flight simulators. These flight simulators are complex federations of physical and mathematical models. Cockpits and other fuselage components are normally included. Aerodynamic modeling in a simulator usually employs continuous simulation techniques. Discrete event simulation is often used for modeling normal and abnormal aircraft system behaviors. In addition, simulations are often attached that provide adversary behavior and interactions with a synthetic natural environment in different spectra, such as visual, radar, and infra-red.

Federal Aviation Administration Simulator Qualification Guidelines

The Federal Aviation Administration (FAA) regulates the activities of commercial air carriers including the licensing of their pilots. Airline pilots are required to hold an Air Transport Pilot (ATP) rating and be certified in the aircraft they operate. Acquiring and maintaining an ATP requires initial and recurrent training. Air carriers accomplish this training in simulators because aircraft diverted to training would not generate revenue. Because they rely so heavily on simulators, the FAA has a very strict program of simulator qualification, the National Simulator Program. (FAA, 1991)

The highest FAA simulator qualification is Level D. A Level D simulator requires a number of very specific components. For example, a simulator must have a motion base and other haptic stimuli to give the correct feel of the aircraft. The visual system must be a calligraphic system designed specifically to mimic airfield lighting during low-light ambient conditions, such as night and reduced visibility caused by weather. The aerodynamic models used in the simulator must include aeroelastic effects.

The FAA also requires that simulators be certified on a recurrent basis. With respect to the simulation validation categories just discussed, the FAA's requirement for judging aircraft simulator performance is a dynamic, empirical comparison between the simulation and the authentic system. The FAA requires that simulator performance be measured against an instrumented aircraft flown through a predetermined profile. The same profile is then flown in the simulator and the difference between the simulator and aircraft performance is recorded. If the error exceeds the FAA specification, then the simulator is not certified.

Because of the demonstrated utility of simulators in commercial aviation, the argument is sometimes made the military should do the same. The argument is usually expressed either as the desire to replace live-fly training with simulator training or to use FAA simulator guidelines for military simulators. The "military should train its pilots like the airlines" opinion is worth discussing because it illustrates how user, purpose, and modeling interact in establishing the utility and credibility of simulation.

Figure 6
Fighter simulators are not good candidates for motion platforms. Sense of movement is provided by 360 degree visual display systems.

Unlike the military, airlines do not hire potential pilots off the street and teach them to fly. They rely on a pool of already qualified applicants, many of whom are former military aviators. For an applicant to be considered by a major airline he or she must already possess an Airline Transport Pilot (ATP) rating and "jet" experience. An ATP rating is very stringent, requiring, among other things, at least 1500 hours of flying time. An airline pilot also flies more often than a military aviator, especially a fighter or bomber pilot. A typical airline pilot will fly 50 – 70 hours a month, while a USAF fighter pilot will fly about 15 hours per month.

Airline pilots fly in the national airspace system, a very structured environment dominated by regulation and procedure. There are strict rules on how pilots operate in this system, such as the criteria for beginning an instrument approach or the amount of extra fuel that must be carried. There are also procedures established by the aircraft manufacturer and the airlines which prescribe how the aircraft is to be operated, including the actions to be accomplished for abnormal situations. All air carriers operate with two pilots and the duties performed by the pilots differ. The purpose of the airline simulator training is to train crew coordination during the takeoff and landing phase, in bad weather, and with a serious aircraft malfunction.

The military services use flight simulator training for a similar purpose: procedural training to operate aircraft in regulated airspace. Warfighting aviators, however, have two additional environmental factors not relevant to FAA airline pilot training. The first is the mission environment. The most demanding phases of flight for airline pilots are takeoff/departure and approach/landing. For land-based fighter and bomber aviators, the most demanding tasks occur between landing and takeoff: formation flying, air refueling, engaging an enemy air defense system, delivering weapons close to ground forces, etc. This battlespace environment also includes another factor not relative to airline pilots, that of a dynamic interaction among other military actions and the adversary. Military pilots need to train as part of "kill chain." Airline pilots do not need to train as part of the airline's "revenue chain."

With respect to the issue of modeling, the FAA simulator qualification guidance is very extensive. Measuring simulator performance against equivalent data from an instrumented aircraft was previously noted but deserves more discussion. First, this validation technique can be automated. Many FAA qualified simulators have embedded tools that accomplish this measurement. The data can be recorded and transmitted physically or electronically to the certification authority – virtual validation! Second, in addition to motion and visuals, the FAA requires other hi-fidelity modeling to stimulate pilot perception. The force needed to manipulate cockpit controls must also match the instrumented aircraft, as well as specific sounds due to aircraft systems operation and ambient noise such as windshield wiper movement and precipitation. A Level D simulator must couple the motion system, visual system, and cockpit displays. The total coupled response must be within 150 milliseconds of actual aircraft response. (The goal for transport delay on the DMO wide area network is 100 milliseconds.)

There are limitations, however, in using instrumented aircraft for simulator models. It's expensive. ACC spent over $10M to instrument an aircraft to develop a training simulator. Another limitation is that instrumented aircraft data is most useful for collecting evidence to validate an aircraft model, not to create an original model. Other techniques are better for creating a simulator aircraft model. These techniques are used in aircraft design and engineering. Validation of training simulator models which use derivatives of engineering models can then be based on the pedigree of the engineering model. This approach is appropriate for fighter simulators when obtaining instrumented data for all possible weapons and external fuel tank combinations is impractical. (An airliner has one basic configuration, with flap and landing gear deviations for takeoff and landing.)

Recently, there has been a great deal of interest in using computer games for warfighter training and a corresponding belief that the success of computer gaming demonstrates that high fidelity simulators are not needed for substantive training. This is contrary to the direction of the FAA simulator qualification program. Advances in simulation technologies – visualization, computational fluid dynamics, eclectic motion platforms, acoustics – are adopted to raise, not reduce, simulator fidelity.

Comments on the value of FAA approach

The FAA simulator qualification framework is uniquely tailored to meet the needs of a very specific purpose, that of regulating the qualifications of pilots flying commercial airliners. To the extent that airliners are operated like military aircraft, the FAA approach to simulator-based training and simulator is valid. The area where they are most similar is in normal and abnormal crew procedural training and flight operations within the airfield environment during adverse environmental situations. One aspect of the FAA simulator qualification that might prove useful for warfighter simulations is the concept of automated or embedded validation tools.

Air Force Simulator Certification

With respect to aircraft simulators, the Air Force has two major categories and associated programs, one for the Mobility Air Forces (MAF) and the other for the Combat Air Forces (CAF). (The Air Force Special Operations Command (AFSOC) operates under Special Operations Command.)

Figure 7
The B-2 is a high fidelity simulator with a motion base.

Air Mobility Command (AMC) is the lead command for all MAF systems, primarily airlift and refueling aircraft. For the most part, AMC uses FAA simulator qualification requirements. AMC also relies on simulator training to the same extent as the airlines. For a new C-17 pilot, the first real sortie is the "check ride." All of the initial training leading up to the check ride takes place in the simulator. Over a decade ago, AMC used flying training funds to procure simulators meeting FAA specifications.

AMC has been very successful in reducing most live-fly training. Very few AMC sorties are "non-revenue."

However, AMC pilots, like airline pilots, fly a lot. The annual simulator requirement for a typical MAF pilot is 8 sorties (32 hours). In spite of the success in training the primary airlift mission, AMC does not rely on simulators to supplant tactical mobility mission training such as airdrop. Like CAF fighter and bomber crews, but to a lesser extent, the tactical mission environment limits the utility of MAF simulator-based training.

The CAF uses a program called SIMCERT (simulator certification) to judge the credibility of its simulators. The purpose and conduct of SIMCERT is outlined in several documents. (AFI 36-2248, 1998, and AFI 36-2251, 2003) The objectives of a SIMCERT are listed below.

- Determine at what level specific flight training events are creditable towards simulator-based training requirement
- Determine if the simulator is physically and functionally maintained to the designed configuration
- Compare the device with the weapons system to provide information to staff officers and training planning teams on simulator capabilities and limitations
- Identify operational and supportability issues

A SIMCERT is conducted on every CAF simulator on a rotating basis with a 12-24 month revisit rate. A SIMCERT usually takes 1-2 weeks but it is integrated into the unit's training schedule. The SIMCERT uses static and dynamic validation techniques. The static portion is primarily a documentation review and inspection covering the areas listed in the second and fourth bullet. The dynamic portion uses pilots and weapons systems to conduct a detailed subjective evaluation of the simulator. These subject matter experts rate the simulator's ability to train tasks using a Training Value Code (TVC) of 1, 2, 3, or 4, as explained below.

1. Fully simulates the weapons systems. Task can be fully trained.
2. Simulates the weapons system with limitations. Minimal additional training required. Task certified for formal training.
3. Marginal simulation of the weapons system. Significant training elements/components incorrect or missing.
4. Not certified. Unsatisfactory simulation of the weapons system. Negative training value or violates flight safety.

The primary referent for the SIMCERT is the TTL. (Training Task List was explained in the preceding section.) The TTL is a detailed decomposition of tasks associated with weapons system operation. A TTL reflects the type of hierarchical training taxonomies that are common in formal military training programs. TTLs are not currently used in ACC to develop training programs but they have continued to be created for simulator acquisition and evaluations. There are usually several hundred items in a TTL. (Table 1 is an excerpt from a recent SIMCERT showing the tasks associated with air refueling.)

The value of a SIMCERT is that it relies on user expertise and it reflects the users' opinions. The FAA does not rely on user opinions, preferring instead to base the judgment of credibility on measurable, not subjective, comparisons.

Table 1

Air Refueling		
Training Task	**TVC**	**Comment**
Perform Rendezvous and Precontact Checklist	1	
Perform Point Parallel Rendezvous	2	Visual acuity is limited in range.
Perform Enroute Rendezvous	2	Visuals don't replicate acft.
Perform Electronic Rendezvous	NE	
Perform Precontact and Contact	1	
Perform Contact Checklist	2	Sim gives contact too far away
Perform Disconnect Checklist	1	
Perform Post-Air Refueling Checklist	1	
Perform Tanker Autopilot Off	NS	
Perform Night Air Refueling	2	Visuals don't replicate acft.
Perform Toboggan Procedures	NS	
Perform 3-Engine	2	Visuals don't replicate acft.
Perform O/R Override	2	Not modeled correctly.
Perform Overrun Procedures	1	
Perform Breakaway/Practice Separation	2	Visuals don't replicate acft.
Perform Boom Limits	2	Visual do not support full range.

CRITERIA FOR JUDGING DMO SIMULATORS

The decision to move 20% of F-15C training from live-fly to the simulator was described earlier but now requires further elaboration. The decision was made without reference to the F-15C SIMCERT or any empirical comparison of the F-15C DMO simulator performance to actual aircraft performance. It was nevertheless an informed decision based on an existing F-15C MEC analysis and a simulator survey conducted two months earlier.

As previously noted, ACC is changing the way it uses simulators for operational training. In January 2006, the ACC director of operations commissioned a survey of fighter, bomber, and C2 aircraft simulators in order to judge the degree to which they could provide mission training. Because the existing SIMCERT process did not address all the factors relevant to the underlying issues, the survey team developed a more comprehensive survey measure by expanding on the attributes of immersiveness, instructional integration, and interoperability in General Hawley's original vision. (DMT CONOPS, 1997) A simple rating scale of green, yellow, and red was used as explained below.

Immersiveness is the degree to which a simulator system is capable of providing a credible mission environment and weapons system representation. An immersive simulator system evokes adaptive behaviors by providing equivalent modes of human, machine, and environmental interactions that exist in a live context. Below are examples of system components or functions that can be examined in order to make a judgment about the immersiveness of a simulator system.

<u>Cockpit or Console</u> – the look and feel of the referent systems

- Green – all machine interfaces (switches, knobs, dials, displays, handles, controls, etc.) used in typical system operation are represented with visually and haptically equivalent substitutes.
- Yellow – a significant interface missing
- Red – most interfaces missing or interfaces do not adequately substitute the real interface

<u>Cueing</u> – psycho-physiological stimulation such as motion cueing that provide a sense of dynamic changes to system state.

- Green – At least two modes of a multi-mode rendition of dynamic changes (e,g., motion base and visual or visual and stick buffet)
- Yellow – One primary mode (e.g., full visual)
- Red – No significant mode available (partial visual) – any significant interface missing

<u>Sensor representation</u> – visual, radar, IR, etc.

- Green – All machine and human sensor channels related to system operation and mission performance are accommodated in highly realistic fashion (e.g., photo-realistic visual system)
- Yellow – any significant channels missing
- Red – numerous channels mission

<u>Ownship modeling</u> – system performance in natural environment such as aero and engine models

- Green – all primary systems dynamically modeled
- Yellow – all systems modeled but not high-fidelity
- Red – not all primary systems modeled

<u>Mission modeling</u> – modeling of battlespace elements and systems

- Green – threat, blue and gray system interactions dynamically modeled
- Yellow – all systems modeled but not high-fidelity
- Red – not all primary systems modeled

<u>Concurrency</u> – of those elements which are incorporated, to what extent does it compare to fielded system configuration

- Green – system equivalent to fielded system software or block upgrade
- Red – system significantly different from fielded system software or block upgrade

Instructional Integration is the degree to which the simulator system can be used to construct, conduct, and debrief training. Below are examples of system components or functions that can be examined in order to make a judgment about the instructional utility of a simulator system.

Instructor systems – the ability to prepare, run and intervene in training events

- Green – embedded tools to support creation of training scenarios and manage training mission training events
- Yellow – limited ability to create training scenarios or control mission training mission events, can only monitor training scenario
- Red – no ability to observe or monitor mission scenario or training events

Brief/debrief system – the ability to develop, record and analyze performance during a training event

- Green – ability to measure and record detailed mission performance
- Yellow – mission replay capability
- Red – no replay capability

Mission Interoperability is the degree to which the simulator system provides an equivalent training environment to all mission crew members (within an aircraft) among flight/cell members (fighter and attack) and linkage to primary kill chain partner(s) (if applicable). Below are examples of system components or functions that can be examined in order to make a judgment about the local and wide area mission interoperability features of a simulator system.

Crew (multi-place fighter, bomber and C2ISR aircraft)

- Green – all mission crew positions accommodated in integrated system
- Yellow – all mission positions accommodated but not integrated
- Red – some crew positions not accommodated

Flight / Cell (fighter and bomber) networking

- Green – locally networked, multi-ship formation
- Red – single ship only

Kill chain – wide area networking with other primary mission systems

- Green – persistent, wide area connectivity
- Yellow – non-persistent, periodic wide area connectivity
- Red – no connectivity

Survey Results and Implications

Table 2 is summary information from the survey showing clearly why the F-15C was selected as the first weapons system to credit simulator time for mission training and experience. (The numbers in parentheses represent the year in which the simulator was expected to reach a green status.) The information was obtained from a very limited number of operational pilots and simulation program managers. It is not a substitute for a comprehensive validation. The value of the survey is that it demonstrated other factors can be used in judging the credibility of a warfighter simulator in addition to task decomposition and comparison to instrumented aircraft data. In fact, the survey structure could accommodate empirical validation techniques in several areas. ACC intends to use the survey to improve the SIMCERT process.

The survey also confirmed that sensor representation, especially for non-visual systems, is very important in some mission areas. Evaluation of the electronic warfare environment was once part of simulator evaluations called SIMVAL. The SIMVAL function was dropped several years ago because of manpower and funding reductions. ACC is currently investigating the value and methodologies for rejuvenating a SIMVAL-type function.

Table 2

	Immersive	Instructional	Interoperable
F-15C	Green	Green	Green
F-16(50)	Yellow (06)	Green	Yellow (06)
F-22A	Yellow	Yellow	Red (09)
A-10	Yellow (08)	Yellow (08)	Yellow (10)
B-2	Yellow	Red	Red (09)
F-117	Yellow	Red	Red
B-1	Yellow	Red	Red (06)
B-52	Red	Red	Red (08)
F-16(40)	Red (10)	Red (10)	Red (10)
F-15E	(07)	(07)	(07)
AWACS	Green	Green	Yellow
JSTARS	Green	Yellow	Green
EC-130	Yellow	Green	Red
RJ	Yellow	Red	Yellow

CONCLUDING COMMENTS

Simulators and simulations have been used in various types of training for many years. The use of these synthetic systems has been especially important to the United States' armed forces. In the past several decades, their use has expanded because of two reinforcing sets of factors. The first set is associated with the broader acceptance of synthetic systems by warfighters due to rapid, continuing improvements in a range of technologies: computer processing, visual displays, and local and wide area networking. The second set is the decreasing ability of live training venues to accommodate existing and emerging military systems and operating concepts.

Both the defense and academic M&S practitioners agree that there should be a rigorous process to judge the accuracy and credibility of the simulation. In making such judgments, however, we need to be aware of the kinds of errors we can make. Below is a list of 3 errors types. (A reinterpretation of that presented by Balci, (Balci 1998))

- Type I – the simulation provides valid results but they are not accepted/accredited.
- Type II – the simulation does not provide valid results but results are accepted.
- Type III – the simulation is not appropriately structured for the problem being investigated.

Summary

Maturation of the modeling and simulation profession and its technologies, especially computing and networking, has created the ability to investigate increasingly important problems using progressively more complicated synthetic simulation environments. With respect to computing, simulations are capable of processing very detailed digital models. Network technology provides the ability to link diverse simulations, simulators and operational equipment in local and wide area networks.

The Air Force will rely more heavily on complex immersive simulator systems for joint, theater-specific, operational mission training. While these systems are very valuable, the structure to collect evidence in order to judge their credibility is lacking. The techniques used for evaluating flight simulators for formal training and airline use are well understood and these techniques can be an important part of a validation effort but they are not sufficient. Other methods need to be included when the purpsoe of the simulator goes beyond weapon system operation and into mission-oriented knowledge and skills.

Applicability to Other Areas and Recommendations for Further Research and Policy Improvements

Most warfighters are not fighter or bomber pilots. However, the training methodology and technology gleaned from mission-oriented flight simulator training may be increasingly relevant to earth-bound warfighters. Increasingly, these other warfighters resemble fighter pilots in terms of system integration and fighting organization. We are equipping them with information processing systems, sensors, and providing them access to long range weapons. Like air operations, more land combat operations are relying on small teams to quickly accomplish missions that were once done by large units.

This trend suggests that a general conceptual modeling framework should be developed for synthetic warfighter training, one which is oriented to the operational mission environment and applicable to individual, small team, and "kill chain" levels of training. Such a framework could be derived from simulation engineering modeling practices and cognitive theories of human behavior and performance. This framework should be oriented to the cognitive mediation of perception and action in a battlespace environment. The cognitive perspective can be extended to provide a scalable framework describing interactions among warfighters. This framework then could be used to provide better policy guidance for judging the acceptability of simulators, especially when used in coupled or collective warfighter training.

The current foundation for DoD VV&A practices is derived primarily from experience in developing and using simulations for analysis. The recommended guidance has expanded to include other uses such as supporting simulation in a development program. The scope has also broadened to include development of simulation federations. More research, however, is needed to develop guidance that will assist in judging the credibility of existing simulations for new purposes. There is a similar lack of knowledge about how to evaluate the validity of simulations and federations for persistent use across a broad class of problems.

With respect to policy, the overall DoD perspective on modeling and simulation needs containment. In some segments of the defense-related M&S community, there is a desire to achieve certainty in simulation. This desire is a combination of several factors. Occupational pride and the quest to improve the tools and stature of the modeling and simulation profession is probably one. Another may be the gravity and immediacy of the national security problems that defense simulation is expected to "solve." One of the outcomes of this perspective is the proliferation of "holodeck" visions for M&S programs. "Predictive Battlespace Awareness" and other terms often accompany some of these depictions.

DoD M&S policy should be more explicit in recognizing that simulations are not all-purpose compressions of reality. They are artificial systems that lack most of the characteristics of the authentic system. Policy guidance should also emphasize that the VV&A process can produce a relative, not absolute, judgment about the fitness of a simulation for a specific use. This judgment is only valid for the conditions in which it was tested. Technical interoperability and re-use of simulations are appropriate goals but meaningless without a way to judge the credibility of their output. A narrow emphasis on technical interoperability standards and composability is likely to create numerous federations with significant Type III errors.

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