9.0 Modeling And Simulation

9.1 Computer Modeling and Simulation Technology

Computer modeling and simulation provides parallel-world capabilities for the full spectrum of Air Force activities, from research and development through analysis, acquisition, test, evaluation, production and logistics to education, training, and operations.

Computer modeling and simulation has been evolving its broad range of Air Force capabilities since the first use of computers for ballistics applications in the 1940's. As a result, the current Air Force inventory of independently-developed computer models and simulations has formidable interoperability and compatibility problems. These have been overcome in some limited domains (e.g., flight dynamics models) and in some medium-scale training-oriented distributed interactive simulations such as Simnet. They have also been overcome in point-solution demonstrations and exercises linking wide varieties of models, simulations, real equipment, and operators. However, significant broad, regular-use operational issues of simulation such as interoperability, rapid configuration, and verification, validation, and accreditation (VV&A) are just beginning to be addressed.

By 2005, with a significant level of Air Force effort, basic large-scale interoperability support (consistent data definitions and fixed interaction protocols) will be available for critical-mass configurations. By 2015, this will extend to include dynamic interaction and interoperability agents. By 2005, simple user languages enabling rapid composition of models and simulations will be available. By 2015, these will extend to support automatic configuration of models and simulations to address given decisions (e.g., choice of airlift capabilities).

By 2000, the Defense Simulation Internet will provide broadband support of point-solution "Louisiana Maneuvers" scale simulation. By 2010, it will be operationally robust and able to support regular exercises at this scale. Currently, VV&A technology consists of basic test suites and simple assertion checking (e.g., of conservation of energy, resources, etc.). By 2005, with Air Force investment, this can expand to simple mission-domain model checking and built-in-tests. By 2015, this VV&A technology can expand to domain model checking using automated agents and dynamic built-in-test, achieving much higher levels of credibility.

By 2015, the resulting modeling and simulation capabilities will enable combat operations options to be credibly simulated before and during combat, greatly increasing combat effectiveness. The same capabilities will enable continuous two-sided exercise of information warfare capabilities, honing Air Force pre-eminence in this critical area. With appropriate attention to acquisition restructuring (e.g., virtual competition groundrules), it will enable virtual system acquisition, or flexible migration from virtual to actual combat systems, with complementary closed-loop combat system exercise and improvement across the system's life cycle.

9.2 Computer Modeling and Simulation (M&S) Rationale

In a warfare situation, the force which has the opportunity to explore the most options prior to combat has a significant advantage. The phenomenal growth of computer, communications, and software technology has enabled the Air Force to achieve such advantages via improved computer M&S.

Computer M&S enables the combat commander, mobility commander, or acquisition manager to open up numerous parallel “virtual worlds” in which many possible scenarios can be played out, and their likely outcomes assessed prior to commitment to a course of action. Current computer, communications, and software technology have enabled these virtual worlds to become sufficiently realistic to support credible virtual combat involving hundreds of human operators. This has enabled these distributed interactive simulations to serve as extremely cost-effective exercise areas for combat training, as well as for combat systems evaluation.

Computer, communications, and software technology advances described in the other chapters of this volume will continue to magnify the power provided to Air Force personnel by M&S capabilities. Not only will individual M&S’s become faster and more realistic, but improving M&S interoperability technology will make composition of multiple M&S’s a routine rather than a special-effort activity. Downstream, even greater advantages will result from embedding M&S’s into a closed-loop learning and improvement process for both the M&S’s and the systems they are emulating. This ability will be particularly important for information warfare, strengthening both information defense and offense capabilities via “information wargaming.”

M&S capabilities increasingly empower all sectors of the Air Force. Computational fluid dynamics models, materials phenomenology models, and knowledge models empower Air Force research and development. Combat M&S’s, weapons effects models, and cost models enable better force structure management, and better requirements determination for new Air Force combat systems. Engineering models, planning and scheduling models, and manufacturing models enable more rapid, predictable, and controllable system acquisition and upgrade. Test and evaluation is improved via hybrid human-in-the-loop and hardware-in-the-loop simulations, simulator/stimulator testbeds, and post-test analysis capabilities. Education, training, and operations are improved via human-in-the-loop distributed interactive simulation, re-creation of historic battles, and assessment of simulated course of action outcomes.

9.3 Computer M&S Definitions

We follow the definitions in DoDD 5000.59, “DoD Modeling and Simulation Management.” It defines a model as a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process. It defines simulation as twofold: a method for implementing a model over time; and a technique for testing, analyzing, or training in which real-world systems are used, or where real-world and conceptual systems are reproduced by a model.

As another perspective, the 1993 “Report of the DSB Task force on Simulation, Readiness, and Prototyping” says, “Everything is simulation except combat.”

This section of our panel report focuses on *computer* modeling and simulation. It thus excludes physical and mathematical models unless they are implemented as computer programs. It also excludes purely live simulations: exercises with live forces and real equipment in the field. It includes purely computational models such as computational fluid dynamics models, combat effectiveness models, logistics models, and cost models. It also includes hybrid computational and live simulations. These can be hardware-in-the-loop, as with sensor and missile test environment simulations; or human-in-the-loop, as with aircraft flight simulators and distributed interactive battle simulations such as Simnet.

For M&S applications, we use the hierarchical classification scheme from the excellent 1994 Defense Systems Management College (DSMC) guidebook, “Models and Simulations.” Engineering-level M&S’s address such issues as design, cost, manufacturing, and supportability. They provide measures of performance (MOP). Engagement-level M&S’s address evaluations of system effectiveness against enemy systems. They provide measures of effectiveness (MOE) at the system-on-system level. Mission/Battle-level M&S’s address evaluations of multiple platforms performing a specific mission. They provide MOE at the force-on-force level. Theater/Campaign-level M&S’s address outcomes of joint/combined forces in a theater/campaign level conflict. They provide measures of value added at the highest levels of conflict, sometimes called measures of outcome. The DSMC M&S guidebook provides further information on the usual levels of detail, time spans, outputs, and uses of M&S at each level.

9.4 Computer M&S Constituent Technologies

Gigabit communications technology enables high-fidelity, large-scale distributed interactive simulations. Combined with flexible networking technology, it enables such simulations to dynamically evolve their combinations of real and simulated systems. By the year 2000, the Defense Simulation Internet will provide near-gigabit communication and networking support of point-solution “Louisiana Maneuvers” scale simulation. By 2010, it will be an operationally robust multi-gigabit system able to support regular exercises at this scale.

The massively parallel computing capabilities enabled by hardware and architecture technology enable the Air Force to better solve its “Grand Challenge” computational problems, such as signal and image processing, computational fluid dynamics, and weather prediction. Possible biocomputing breakthroughs will initially provide orders-of-magnitude improvements only for niche problems, but more general capabilities are also possible. Continued exponential growth of individual processor speeds and memories will enable massive mainframe M&S’s to be exercised on individual desktops, with increasing fidelity and ability to explore multiple options.

Distributed software “middleware” capabilities will enable distributed simulations to be rapidly and reliably composed, including smooth adaptation to increasingly powerful commercial-off-the-shelf (COTS) software capabilities. The potential of massively parallel computing will be increasingly realized via improvements in parallel software: programming languages and compilers, operating systems and run-time services, and data management capabilities.

Increases in speed, flexibility, and scalability of Information Access Technology will strongly benefit large-scale M&S’s, which are prodigious consumers and generators of information. Particular M&S functions which will benefit are multi-database interoperability and interactive analysis of M&S outcome data.

Software development technology will provide stronger software architecture support of families of M&S’s, and the ability for M&S users to use very high level languages to compose and modify M&S’s. In general, advanced software environments will enable faster, cheaper, and better M&S development and modification. In particular, technology will provide much-needed improvements in the design and testing of distributed and parallel software and systems.

Artificial intelligence technology will provide considerably stronger semiautomated force (SAFOR) capabilities for distributed interactive simulations. Speech and natural language technology will improve both human interfaces to M&S and the ability to analyze histories of human-in-the-loop simulations. Domain knowledge modeling technology will enable M&S's to be automatically or semiautomatically generated from statements of the decisions needing support (e.g., "I need to analyze the use of military vs. commercial aircraft for the following transportation scenarios. Configure the appropriate performance and cost models and provide me some comparison summaries on delivery time and cost").

Agent technology will facilitate M&S interoperability by use of agents to mediate inputs, outputs, control, and synchronization of multiple M&S's. Agents will also provide powerful information search capabilities for both configuring and operating M&S's. They will provide stronger assertion-checking capabilities for M&S verification, validation, and accreditation.

Assurance technology will also strengthen M&S verification, validation, and accreditation capabilities. In an information warfare context, it will provide stronger defenses against contamination of M&S software and results.

Improvements in human-computer interface and collaborative computing technology will dramatically enhance M&S capabilities for planning, development, testing, training, and operational support. Critical technology elements include high resolution displays, 3D displays, voice and speech recognition, speech generation, and tactile interfaces. For example, a helmet-mounted 360-degree 3D visual and audio system coupled with tactile input-output would enable pilots to "fly" simulated aircraft, instead of seeing just a narrow-field 2D display. It would allow the battle commander to move about a virtual battlefield and observe how well the virtual aircraft and other forces are performing. It would allow the system developer to enter the virtual environment and experiment with system parameters.

The most visible M&S technology needs involve improving the power and realism of Air Force M&S's by applying the constituent technologies discussed above. Particularly significant technologies in this regard are high performance computing and communications, software, human-computer interaction, and artificial intelligence.

However, it is also critical for the Air Force to address several less flashy but equally important M&S areas, which require a mix of technology advances and institutional emphasis. Primary among these are M&S interoperability; robust M&S; M&S verification, validation, and accreditation (VV&A); continuous instrumented exercise; and virtual system acquisition.

9.5 Modeling and Simulation Interoperability

There are many sources of M&S interoperability problems, involving incompatibilities in data definitions, control structures, timing, operating assumptions, and COTS componentry. These need institutional attention (e.g., via M&S adjuncts to Air Force Horizon interoperability initiatives) and new technical capabilities. The most significant technology areas are domain architectures for simulation and application domains; wrapper, mediator, and intelligent agent approaches for making M&S components interoperable; and M&S interoperability test and assurance technology.

9.6 Robust Modeling and Simulation

The more complex Air Force models and simulations tend to emphasize ad-hoc point solutions for demonstrations and individual exercises. Continuous two-sided M&S exercise requires significantly more robust M&S capabilities. The primary technology areas for M&S robustness are domain architectures and test and assurance technology. As much as anything, however, robustness needs institutional attention to the more rigorous applications of known software engineering techniques to M&S initiatives.

9.6.1 M&S Verification, Validation, and Accreditation

VV&A is critical to the credibility of M&S as a basis for making operational and acquisition decisions. An additional challenge is the VV&A of artificial intelligence techniques employed in M&S agents and semiautomated forces. Key technology opportunities include the development of more powerful and scaleable M&S validity assertion formalisms and checking techniques; and the use of intelligent agents for monitoring M&S validity conditions (although there is a bit of an agent-validity recursion issue here).

9.6.2 Continuing Instrumented Exercise and Virtual System Acquisition

Another approach for improving M&S interoperability, robustness, and VV&A involves continuing instrumented M&S exercise. Continuing exercise also strengthens M&S capabilities for training and decision support.

A particularly attractive application area for continuing instrumented M&S exercise involves virtual system acquisition. Providing capabilities for selectively mixing real and virtual system elements, and subjecting them to continuing exercise, can significantly improve the cycle time and effectiveness of traditional acquisition approaches. Critical success factors include domain architectures enabling modular mixing of real and virtual system elements; testbeds with instrumentation and analysis capabilities; revised acquisition process models and guidelines; and integration of technology M&S with life-cycle cost M&S.