Table of Contents

I. EXECUTIVE SUMMARY

PURPOSE OF STUDY

In the current world political and economical environment, the Department of the Navy (DON) will be required to carry out a diversified list of missions with a smaller force and reduced budgets. The DON will have to find more efficient and less costly ways to train troops, refine new weapon system requirements, evaluate solutions, and acquire new or modified systems. Advances in Modeling and Simulation (M&S) capabilities and technologies offer significant opportunities for responding to these challenges.

OBSERVATIONS

Advances in the M&S world have been driven by the explosion in computer technology. Exponential growth in computer memory capacity, graphics display rates, network transmission rates, and computer power per dollar have made large simulations realistic and economically feasible. This report focuses on two emerging simulation technologies. Advanced Distributed Simulations (ADS) are the combinations of live simulations, virtual simulations, and constructive simulations; these combinations usually involve geographically distributed components that are connected through communication networks. Simulation Based Design/ Manufacturing (SBD/M) combines physical models with the common design database from computer-aided design, engineering, and manufacturing, and then adds the visualization of virtual prototypes.

While the DON has developed and used high quality physics-based models for many years, it is not a significant player in ADS. The Department of the Army has been the lead player in the ADS arena. The DON, in a partnership with the Advanced Research Projects Agency (ARPA), has only begun to participate in SBD/M activities through some of the ARPA programs; the leaders in SBD/M activities are in the commercial aircraft and automobile industries.

RECOMMENDATIONS

(1) Embrace Distributed Simulation Based Acquisition

The panel believes that the tools embedded in ADS and SBD/M provide a capability that can revolutionize the acquisition process. A new Distributed Simulation Based Acquisition (DSBA) process promotes end-to-end verification of requirements matched to design, manufacturing, and supportability, and it facilitates cost and performance trades for the complete life cycle, from pre-concept feasibility studies through development and training. The distribution of the common data base, and interactions with live and virtual simulations, is as valuable to training as it is to confirming operational requirements. DSBA also provides a mechanism to continually support user (operator/tester) involvement in needs, evaluation and training, and facilitates integrated product and process definition throughout the life cycle. If properly implemented we should be able to “try before buy,” using distributed interactive simulation to solve many of the problems that usually are first evidenced only after a hardware construct. Embracing DSBA requires an Executive Agent to provide leadership for all DON modeling and simulation programs.

(2) Technical Recommendations

The DON should leverage the investment ARPA and other services have made in ADS for air and ground combat, and should takes steps to ensure that systems developed for the DON are guaranteed to be interoperable with systems developed for the Army and Air Force. The DON must assume responsibility for DON-specific models. In particular, new models must be built and existing environmental models must be modified or extended, with particular attention to the unique problems emerging from interfaces between the air, the water surface, the subsurface, and the land. The DON should also actively participate in standards groups to ensure that evolving standards meet the Naval requirements.

Billions of dollars have been spent by users of SBD/M-like technology and by suppliers of SBD/M-like technology, producing a huge reservoir of software and expertise. Accordingly, DON investment in this area should be focused on leveraging existing technology, rather than attempting to recreate SBD/M technology inside Naval laboratories.

The Office of Naval Research (ONR) should invest in the development of new model-construction, evaluation, and comparison technology that supports reality-checking, validation, and verification. Techniques need to be available to evaluate the quality of the DON's models and other models connected to DON models.

(3) Pilot Programs

The DON should begin evolving DSBA with existing acquisition projects - the DSBA technology has been demonstrated and thus more demonstration programs are not needed. It was not possible for the Panel to consider all DON programs, and thus it cannot recommend the best candidates for pilot programs. However, we do suggest several good candidates that are part of existing acquisition programs. These include two near-term bounded projects that would provide results within a short period of time - the advanced short take-off vertical landing (ASTOVL) project and the unmanned aerial vehicle (UAV) landing deck design for the LPD-17. Other areas of DON acquisition that would provide good candidates for DSBA are mine countermeasures, sea-based theater ballistic missile defense (TBMD), and ship self defense. Certainly areas of ship and submarine design would also greatly benefit from developments of DSBA.

SUMMARY

The Panel believes that the DON has an opportunity to revolutionize its acquisition process through Distributed Simulation Based Acquisition. We have provided recommendations that would guide investments in areas unique to the DON and in areas that are not yet mature. First-hand experience with Distributed Simulation Based Acquisition should begin immediately through pilot programs within existing acquisition programs. "Seize this opportunity!"

II. PANEL MEMBERSHIP

CHAIRPERSON
Dr. Delores M. Etter
Electrical/Computer
Engineering Department
University of Colorado

VICE-CHAIRPERSON
Dr. Patrick Winston
Director, Artificial Intelligence
Laboratory
Massachusetts Institute of Technology

Mr. Thomas A. Brancati
President and CEO
Whitaker Corporation

Mr. Grover W. Coors
Consultant

Mr. John L. Gardner
Group Vice President and
General Manager, Orlando Group
Coleman Research Corporation

Dr. Daniel N. Held
Director, R&D and Advanced
Programs
Westinghouse Norden Systems

Dr. L. Raymond Hettche
Director, Applied Research
Laboratory
Pennsylvania State University

VADM Bernard M. Kauderer, USN (Ret.)
Consultant

Mr. Marvin Langston
Applied Physics Laboratory
Johns Hopkins University

Mr. Reginald G. Low
Vice President, Mission Planning
GDE Systems, Inc.

Mr. Stephen P. Otsuki
NTBIC Program Director
Martin Marietta

Mr. James M. Sinnett
Senior Vice President for New
Aircraft and Missile Products
McDonnell Douglas Aerospace

Dr. Albert L. Stevens
Vice President and
General Manager
Loral ADS

Dr. Thomas D. Taylor
Senior Fellow
Center for Naval Analyses Corporation

LtGen Duane A. Wills, USMC (Ret.)
Consultant

ASN(RD&A) SPONSOR
MajGen Carol Mutter, USMC
Commanding General
Marine Corps Systems Command

ASN(RD&A) SPONSOR
RADM William P. Houley, USN
Director, Test and Evaluation and
Technology Requirements (OPNAV N091)

EXECUTIVE SECRETARY
MAJ Gary R. Wentz, USMC
Marine Corps Combat Development
Command
Modeling and Simulation
Management Office

DOD EXECUTIVE LEADERSHIP
PROGRAM OBSERVER
Ms. Mahnaz A. Dean
Mechanical/CAD Processor Engineer
Naval Sea Systems Command

The Panel membership represented leadership from within academia, industry (both large and small companies), government, and the military (Navy and Marine Corps). The Panel members provided significant expertise within the enabling technologies which facilitate M&S in an Advanced Distributed Simulation environment. The technical expertise represented by the panel included:

- modeling and simulation
- simulation networking technologies
- visual systems
- digital signal processing
- communications
- artificial intelligence
- computer engineering
- system engineering

TERMS OF REFERENCE
SPECIFIC TASKING

1. Review Current Utilization of DON Modeling and Simulation
2. Evaluate the Strengths and Weaknesses of Modeling and Simulation Technologies
3. Recommend Specific Related Research Areas For DON Investments
4. Identify Key Areas that Would Benefit from an Investment in Modeling and Simulation
5. Identify Candidate Demonstration Projects

III. TERMS OF REFERENCE/ SPECIFIC TASKING

GENERAL OBJECTIVE

Assess the importance of high fidelity models and Advanced Distributed Simulation technologies to enhance the Department of the Navy test and evaluation and acquisition programs.

BACKGROUND

The current world political environment presents the DON with a series of new challenges. The DON will be required to carry out a diversified list of missions with a smaller force and reduced budgets. Reduced budgets will impact the methods for evaluating new systems and operational concepts. The DON will have to find more efficient and less costly ways to refine requirements, evaluate solutions, and refine system designs. Advances in modeling capabilities and ADS technologies offer significant opportunities for responding to these challenges.

SPECIFIC TASKING

(1) Review current utilization of DON M&S/ADS.

(2) Evaluate the strengths and weaknesses of M&S/ADS technologies from DON perspective.

(3) Recommend specific research areas related to M&S/ADS technologies that warrant DON investments.

(4) Identify key areas that would benefit from an investment in M&S/ADS.

(5) Identify candidate demonstration projects to evaluate M&S/ADS utility.

BRIEFINGS/VISITS

3-4 May / Washington, DC	**"Policy Baseline"**
OSD M&S Policy, OSD T&E Policy, Service M&S Offices, Joint Warfighting Center, Naval Research Laboratory, Center for Naval Analyses, ARPA	
17 May / Fort Leavenworth, KA	**"Army Programs"**
Army's National Simulation Center	
19 May / China Lake, CA	**"Navy Programs"**
Naval Air Warfare Center - Weapons Division	
8-10 June / Orlando, FL	**"Distributed Interactive Simulation"**
Naval Air Warfare Center - Training Simulation Division (NAWC-TSD), Simulation Training & Instrumentation Command (STRICOM), Institute for Simulation Training (IST)	
20-23 June / Washington, DC	**"Applications"**
Service (O&D) Test and Evaluation, ARPA, Boeing, Chrysler, Ford, NRL, Defense Systems Management College, Littoral Warfare Study, Electric Boat, Newport News Shipbuilding	
7-8 July / Falcon AFB & Kirtland AFB	**"Air Force Programs"**
National Test Facility, AFOTEC, 58th Special Operations Wing, Joint Advanced Distributed Simulation, Ballistic Missile Defense Office	

IV. BRIEFING SLIDES/TEXT

BRIEFINGS/VISITS

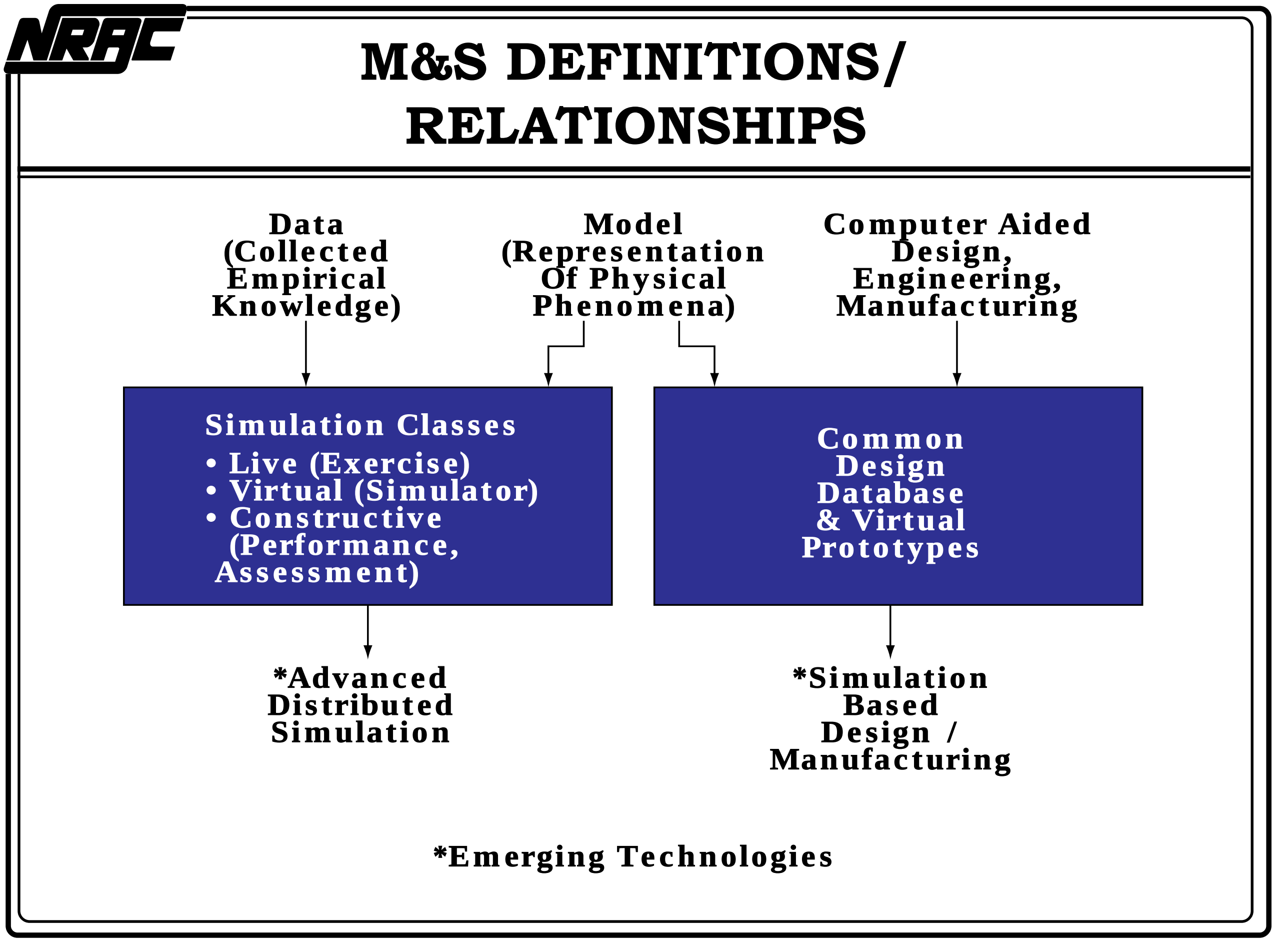
The Panel had a limited time frame in which to achieve the following:

- Evaluate the current technologies (architectures, networks, protocols, visual displays, software, databases, computers) that support Distributed Interactive Simulation (DIS)

- Sample the broad applications of Modeling and Simulation within the Department of the Navy, the other Services, the Joint community, Defense Agencies, Industry and Academia

- Determine recommended programs and suggestions for further research.

Six separate meetings were conducted from 3 May 1994 through 8 July 1994, and the final study convened for the last two weeks in July. The slide above outlines the Panel meetings and visits. A detailed agenda for each meeting is provided in Appendix A.



M&S Definitions/Relationships: Emerging Technologies

This report will focus on two emerging simulation technologies - Advanced Distributed Simulation and Simulation Based Design/Manufacturing. A review of the definitions and relationships that lead to these two emerging technologies begins with models of physical phenomena. The DON's principle investment in modeling has been in this area, and hundreds of high-quality physical models have been developed over the past few decades. These simulations have been predominately physics models, running large digital codes on main-frame computers much slower than real-time. Other DON investments include hardware-in-the-loop (HWIL) simulations predominately run in real-time. In some HWIL simulations, people are included, doing tasks that they do in the real operational system. In addition to these simulations, the study of military encounters has historically been done using models and/or war games with real military commanders participating. Digital computers are frequently used to support these war games.

These simulations that combine physical models with empirical knowledge can be grouped into three general classes of simulations - live, virtual, and constructive. A live simulation uses real forces and real equipment, as in the Team Spirit exercise in South Korea. Virtual simulation combines physical models and electronics, as in an aircraft simulator for an F/A-18. A constructive simulation includes all other types of simulations, such as the war games developed at the Naval War College and the physics based models that represent ocean circulation. A simulation that includes two or more simulations, usually geographically distributed, forms an Advanced Distributed Simulation. (These definitions are consistent with the Defense Science Board Report on Simulation, Readiness, and Prototyping.)

Simulations that combine physical models with the common design database from computer-aided design, engineering, and manufacturing, and add the visualization of virtual prototypes form another emerging technology - Simulation Based Design/Manufacturing.

ENABLING TECHNOLOGIES

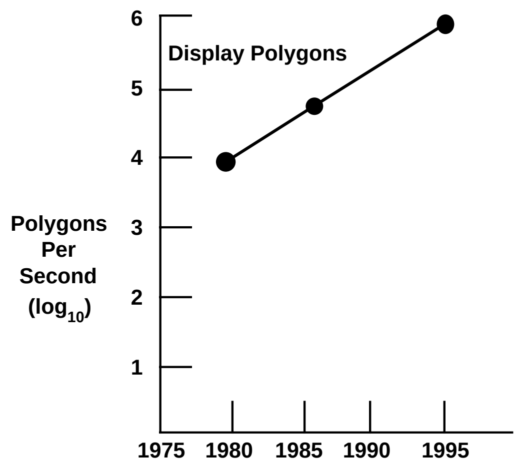
Area	Trend vs. Year 70s	80s	90s	2000
Graphics Display Rates (Polygons Per Sec)	100s	10,000s	Millions	Billions
Computer Memory (Bits Per Chip)	1000s	10,000s	10 Millions	Billions
Network Transmission (Mega Bits Per Sec)	0.1s	10s	1000s	?
Computer Power (FLOPS Per $)	10s	100s	10,000s	Millions

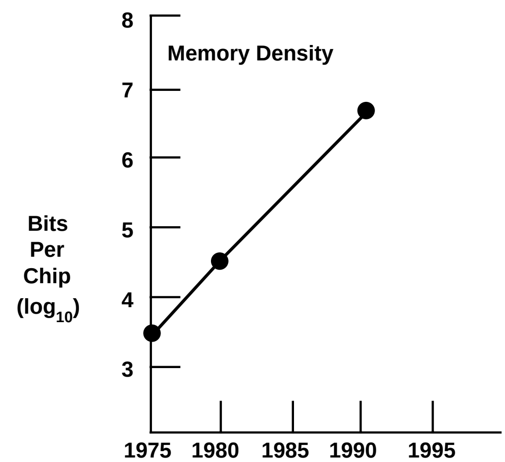
Exponential Growth in Capability
Exponential Decrease in Cost

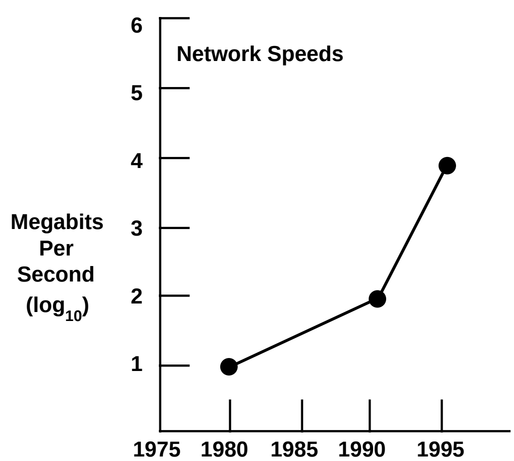
Enabling Technologies

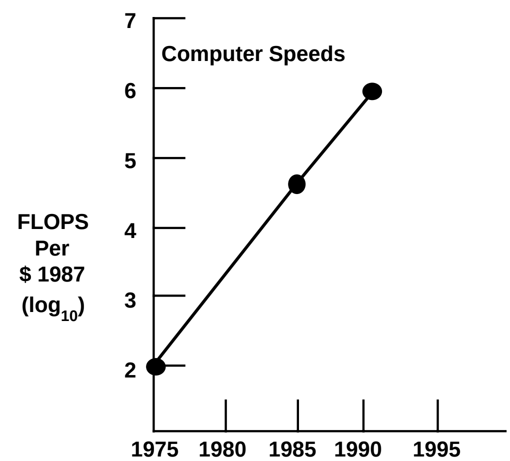
Advances in the world of modeling and simulation have been driven by the explosion in computer technology. Explosive growth in computer memory capacity, graphics display rates, network transmission rates and computer power per dollar have made large simulations realistic and economically feasible. Costs of functions such as a bit of memory or a logic switch on a chip have, in recent years, decreased at 25 to 30% per year, and this trend is expected to continue until critical dimensions on chips are reduced to about 0.05 microns expected at about the turn of the century. Thus today's 16 million bit memory chips could grow to billion bit chips. Furthermore in the graphics arena, new developments in chips technology will further decrease cost another order of magnitude, and computer power will become still more cost effective. The recent increase in network band widths by a factor of ten will facilitate improved distributed simulations. All of these advances can be integrated into powerful low cost computing graphics and data storage capabilities, the application of which, can revolutionize the acquisition and system design process in the Navy and Marine Corps.

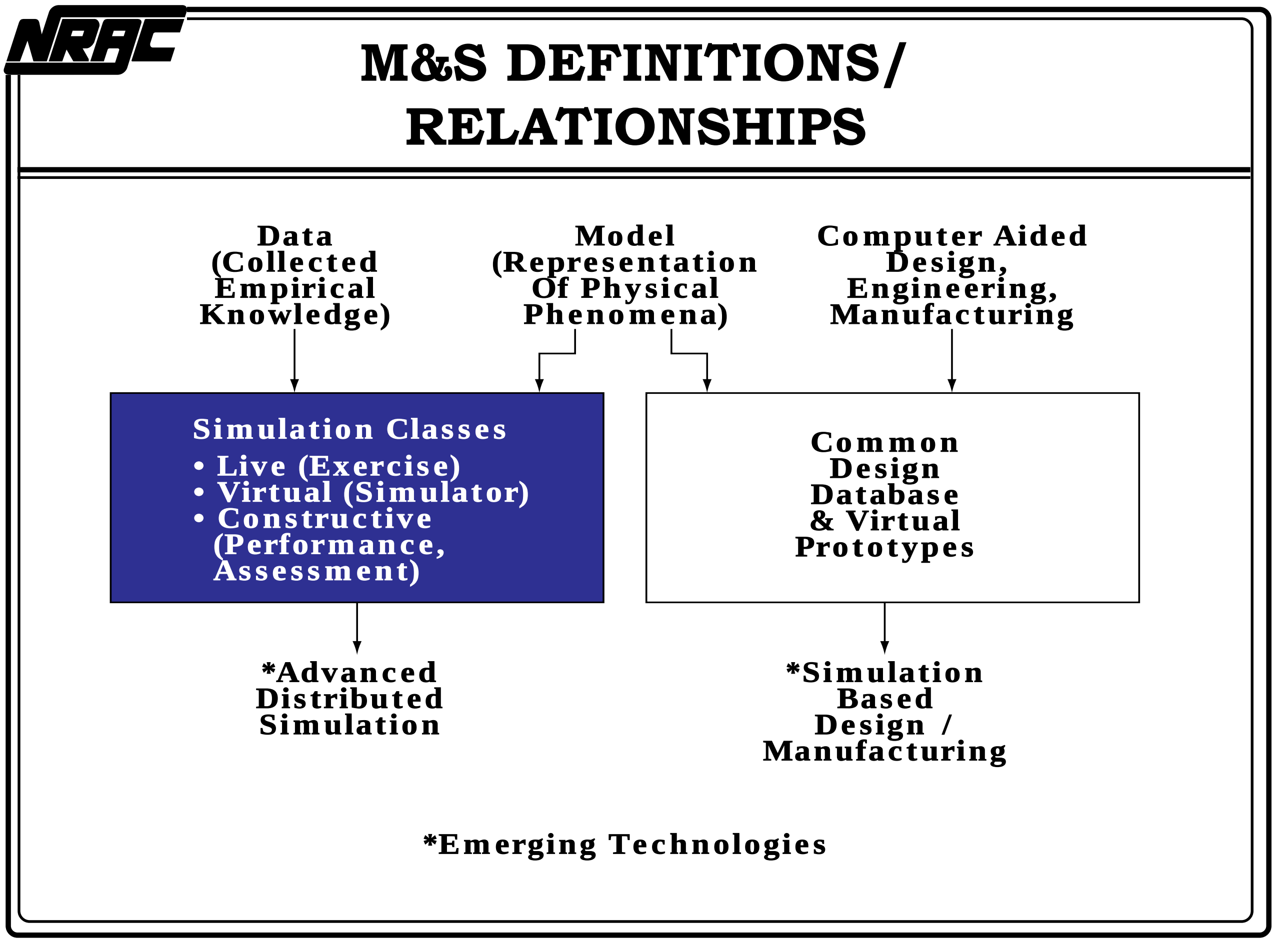
The following charts contain specific data points for the development of the key enabling technologies for display polygons, memory density, computer speed, and network speeds. (This data was prepared by The Center for Naval Analyses Corporation.)







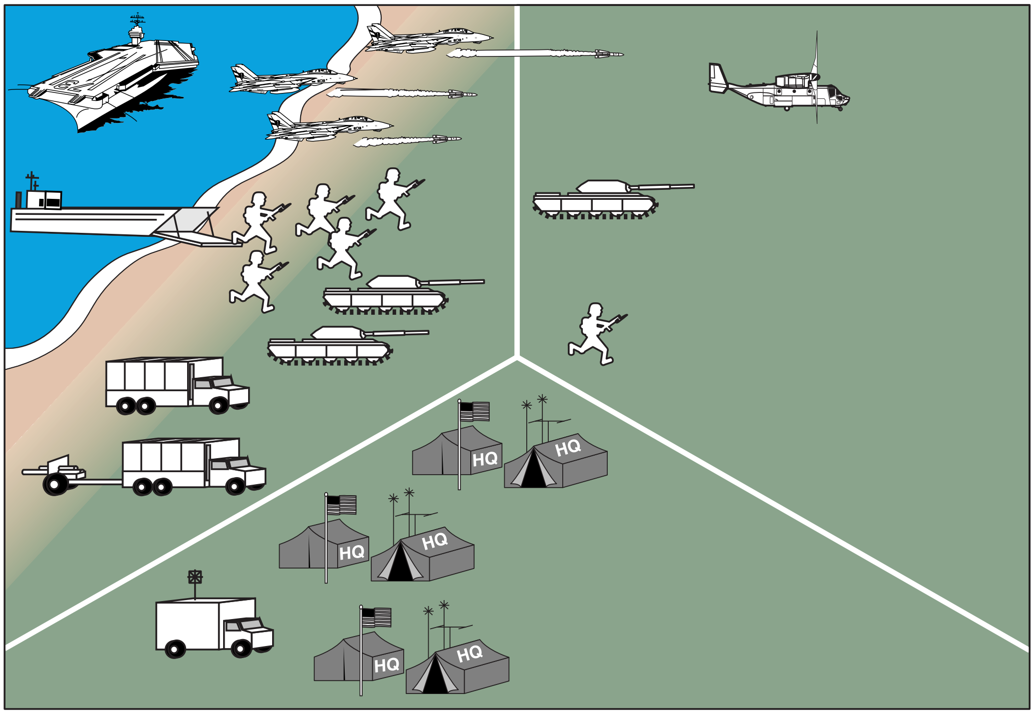




M&S Definitions/Relationships: Advanced Distributed Simulation

An advanced distributed simulation combines elements of more than one class of simulation. For example, a joint allied exercise took place in the Virginia Capes operating area on 30 June and 1 July 1994. The objective was to accustom the task force to the response of their sensor, communication, and command and control systems in defense against Theater Ballistic Missile (TBM) attacks. The National Test Facility (NTF) provided the TBM threat trajectories and a method of injecting those threats into shipboard sensors. In addition to the Joint Task Force (JTF) (Eisenhower Battle Group, Patriot Battalion, Control and Reporting Center (CRC) and various air elements) and the NTF activities, the Army's Airborne Surveillance Test Bed, the Air Force's Talon Shield and High Guard Systems also participated.

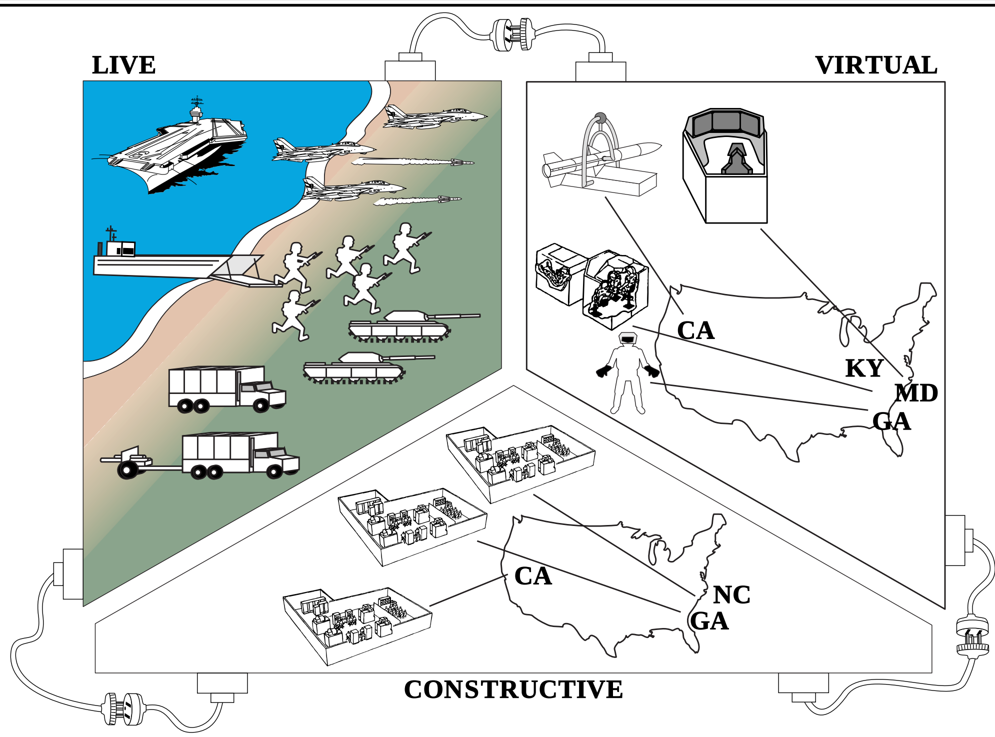
DEPICTION OF A LIVE JOINT EXERCISE...



Depiction of a Live Joint Exercise

Live exercises allow us to train the way that we fight. However, there are constraints on the types of live exercises that we can perform. These constraints are caused by factors such as money, safety, and environment.

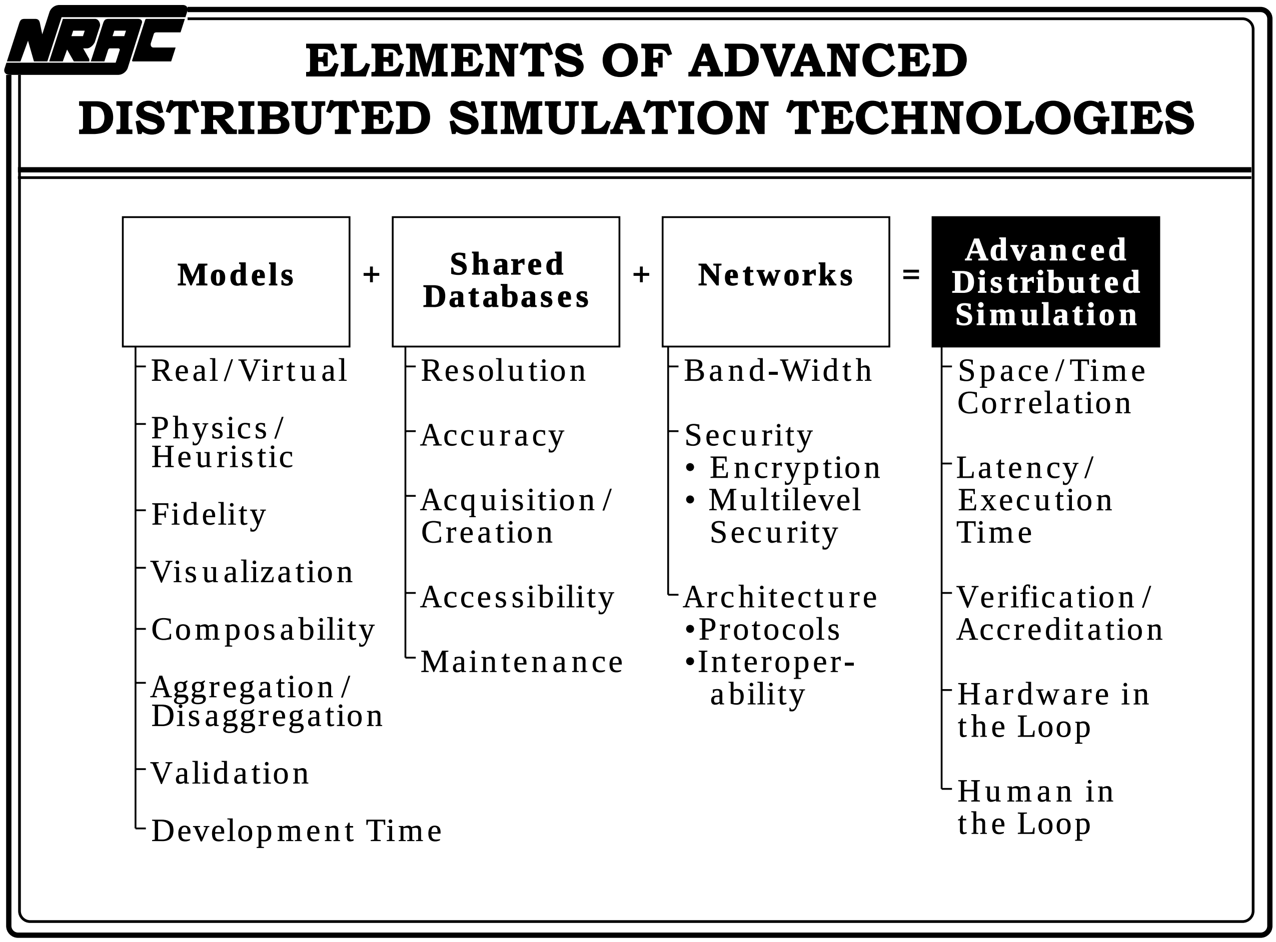
...NOW PERFORMED WITH LIVE, VIRTUAL, AND CONSTRUCTIVE SIMULATIONS



... Now Performed with Live, Virtual, and Constructive Simulations

Advanced Distributed Simulation allows assessment teams to substitute portions of live exercises with virtual environments including flight simulators along with constructive models of the operating systems and sensors. Distributed networks permit the simulated portions of the exercise to be located at installations away from the actual exercise location. The battlefield commander no longer must be on the scene, but can observe and direct the exercise from alternate locations. The magnitude of the substitution will be dependent on the current capability of technology to simulate the real elements of the exercise. Initially, one can expect only simple exercise substitutions such as a flight simulator for an aircraft. In the future, however, one can expect total exercises to be simulated in a believable manner. This capability also allows the DON to analyze rapidly changing military situations with new missions. From an acquisition viewpoint, Advanced Distributed Simulation allows the DON to introduce systems that do not currently exist. The ability to evaluate different capabilities in order to select the most effective ones would allow the DON to continue to advance its capabilities even with reduced resources.

This chart shows the network connections that are required to interface the components of an Advanced Distributed Simulation. The state of art of these connections does not provide a seamless connection; in fact, many of these connections are currently very fragile.



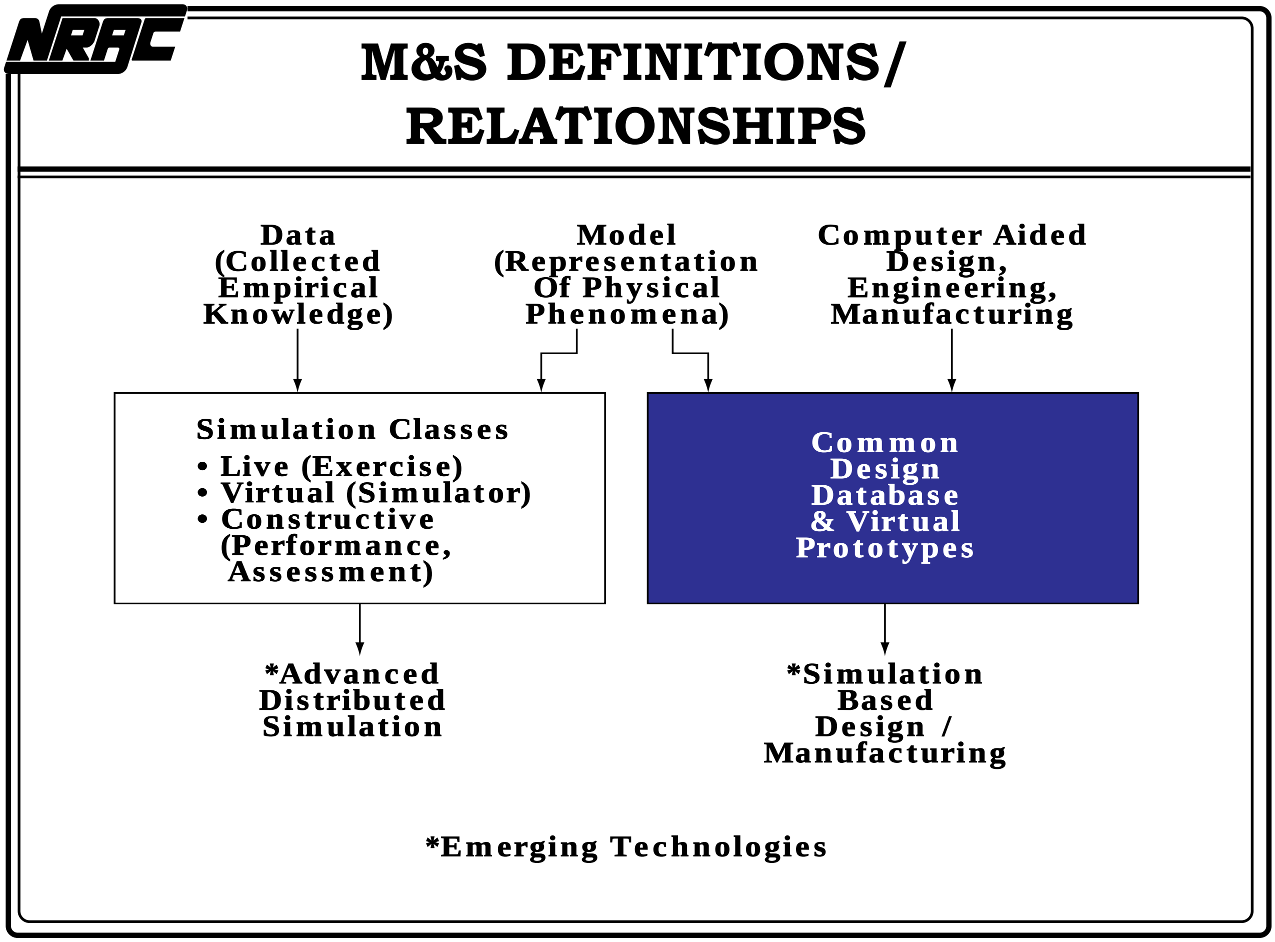
Elements of Advanced Distributed Simulation Technologies

Advanced Distributed Simulation is an outgrowth of many enabling technology developments and their applications. The many elements of ADS technology may be segregated into three major categories: 1) Models; 2) Shared databases; and 3) Networks. There are many issues involved with definition and utility for these major categories.

Some of the critial elements for establishing a fundamental ADS capability are the types of models and their levels of sophistication, access to realistic and useful operator interfaces, capabilities for interaction and combination with complementary models of similar or varying fidelity only to the extent needed, credibility and development time. Closely allied to the models are their utility and upkeep from an operational application standpoint. While development and maintenance of accurate models is always a concern, the distributed and integrated nature of many high power applications calls attention to the need to rely on configuration control and database management. Accuracy and resolution must be understood and managed for the database set, particularly when that database may be shared by a number of users in an interactive common exercise or problem solution.

Finally, it is clear that the issues surrounding the ability to communicate among distributed sites are also fundamental to the process. The type of network, breadth of model (fidelity, composition, number of elements) and means to pass information must be uniform, compatible, and timely. In addition, special attention may be necessary for certain applications to enable secure communication (having a potentially broad impact on the possible success of the ADS effort in terms of adequate bandwidth, time correlations, execution time and information latencies).

The number of detail elements in this chart illustrate the complexity of Advanced Distributed Simulation technologies; it also serves to point out the wide range of maturity levels of the technologies. A broader discussion of the detail elements shown in this chart appears in Appendix B.

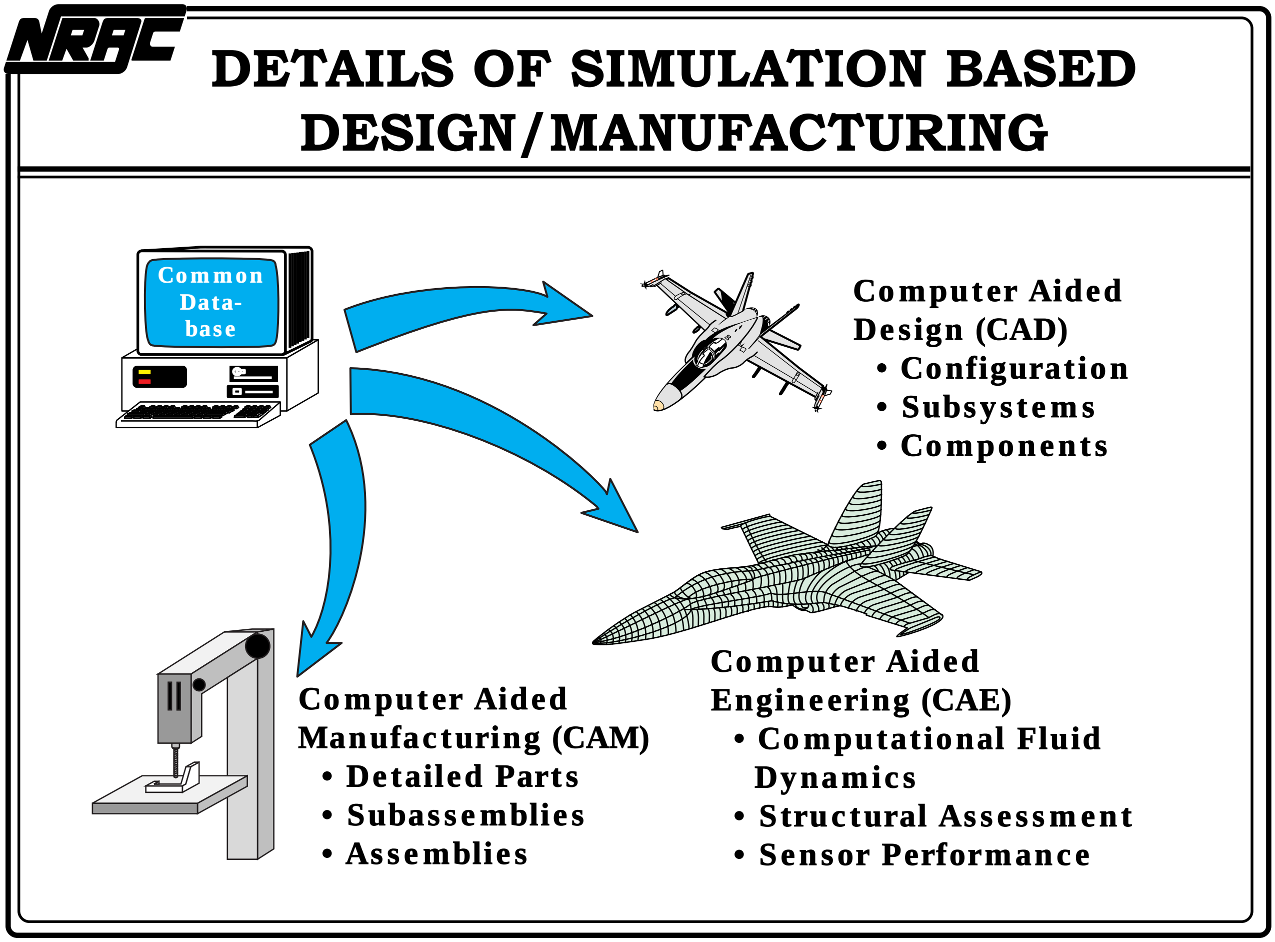


M&S Definitions/Relationships: Simulation Based Design/Manufacturing

A very detailed high fidelity subset of model representation deals with product definition. A set of generic physics-based "tools," "codes," or "simulations" combine with the geometric databases peculiar to a specific product (often a weapon system) to provide a common (across all users) single, digital database. It will later be noted that this common database can be shared by all parties in a "distributed" fashion.

The simulations in this case use the physical models along with virtual representations to enable visualization in a virtual prototype environment. This results in a number of analytical products confirmed by empirical results. Generic "codes," such as Computational Fluid Dynamics, or Computational Electromagnetics are tailored to a specific 3-D representation of the weapon system, interacting to form the design database in phenomenological models representative of weapons system performance.

The computer aided design, engineering, and manufacturing (CAD/CAE/CAM) elements represent the specific weapon system, its external shape and internal design details, specific manufacturing tools or facilities pertinent to each supplier, and provide the definitive linkage to the generic codes. Virtual prototyping can provide definitive assessment of the geometric relationships of sufficient fidelity and confidence to eliminate physical mock-ups. The capability thus represented defines Simulation Based Design/Manufacturing.



Details of Simulation Based Design/Manufacturing

Computer aided engineering has reached an advanced state of development for many applications. Early effort concentrated on computer aided drafting which has now evolved into one of the most powerful definition and enabling tools for new systems. Today's Computer Aided Design (CAD) provides a single digital database, as a 3-D solids model, enabling designer, tool maker, manufacturer and logistician all to work from the same identical digital database - no more translation between users. With solids modeling, whole parts are represented in terms relative to each other and the entire system is represented in free space. Digital data from CAD is transferred directly into Computer Aided Manufacturing (CAM), and, in recent cases, directly to the machine tool. This is a significant time saver; and elimination of a potential error source (e.g. bypassing a secondary programming step for the manufacturing process).

Computer Aided Engineering (CAE) applies to entire sets of engineering definition and analyses which can now evolve from the CAD solids model database. For example, external mold lines now used for loft data can form the basis for Computational Fluid Dynamics (CFD), external loads or Electromagnetic Analyses. When combined with structural models such as NASTRAN, internal load paths are well defined, complete to interfacing subsystems and embedded structure. Evaluation of structural attachments, or subsystem (mechanisms) motion paths, is directly accessible to resolve potential interferences via subsystem solids models.

In addition, sensor performance, e.g. radar or IR coverage, can be assessed based on line of site blockages from the sensor mount and aperture. The resulting CAD/CAM/CAE model capability is a major enabling structure for Integrated Product Definition (IPD) or Concurrent Engineering (CE) providing for cross-use of all those involved in design, design for manufacture and assembly, and design for supportability. Major improvements in systems definition, quality and cost are possible with Simulation Based Design/ Manufacturing.

DEFINITION: SIMULATION BASED DESIGN/MANUFACTURING

- **A <u>Synthetic Environment</u> in Which a Geographically Distributed Team of Design Engineers Can Collaborate**
- **An Interactive Set of Physics-Based <u>Virtual Prototypes</u> of Design Objects and Systems**

(Illustrated by Video Clip from ARPA May 1994 Demonstration of Simulation Based Design)

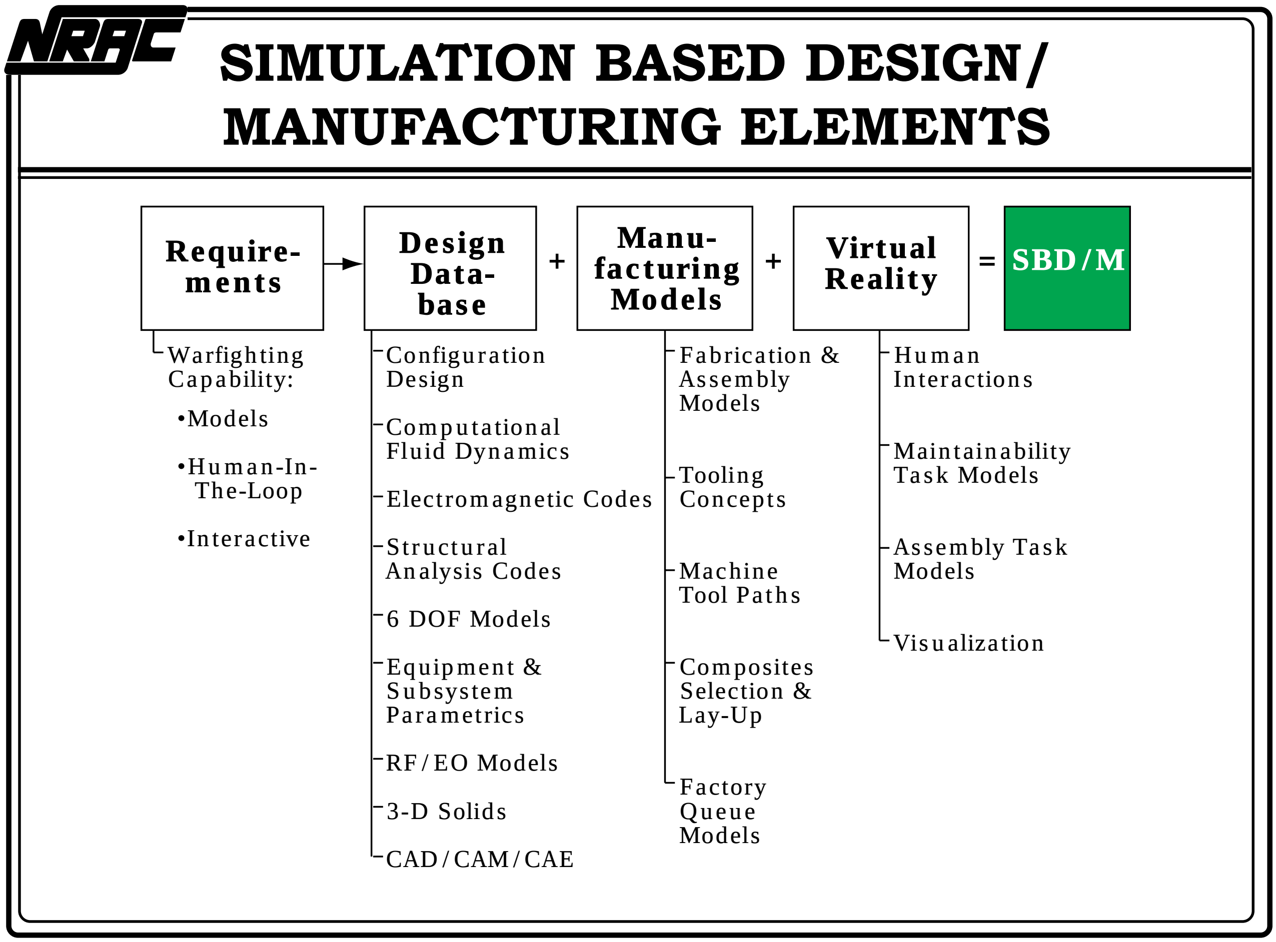
Definition: Simulation Based Design/Manufacturing Elements

Elements of geometric based models are combined with those that are representative of physical phenomena to form the common design database and the means for virtual prototyping, or product definition represented in a synthetic environment.

Simulation Based Design/Manufacturing utilizes this synthetic environment and the power of the common database protocols and architectures to enable a geographically distributed team to share that common base and collaborate on the product design. A transparent, seamless interface will provide subsystem and component suppliers a consistent definition for geometric interfaces, load paths, and clearances.

The opportunity for advantageous use of physics-based virtual prototypes occurs at a number places in the definition process, whether distributed among the suppliers, or confined to a supplier's location. These include: 1) visualization and representation of geometric clearances for design objects, components and systems; 2) machine tool (e.g. cutter) path; 3) factory queue; 4) ship-board interactions (e.g. doors, elevators, deck space); and, 5) expansion to human-in-the-loop for maintainability, manufacture and assembly actions.

(A short video clip from an ARPA May 1994 demonstration of simulation based design was shown at this time in the briefing to illustrate the synthetic environment for virtual prototypes.)



Simulation Based Design/Manufacturing Elements

Simulation Based Design/Manufacturing begins with understanding the weapon system requirements. Early interaction between the operator/tester and developer is facilitated via use of war fighting models to define desired operational system characteristics in a six degree of freedom environment, from a holistic level down through individual systems, such as sensors and weapons.

These feed the design database, where the overall configuration and size (including performance parameters) are defined. An outgrowth of these elements is the detail design and assessment, which includes definition of subsystems (such as radar or electro-optical sensors), their capabilities and geometric relationships, structural load paths, mold line characteristics and influences such as computational fluid dynamics and electromagnetics.

The use of 3-D solids modeling from the CAD database facilitates definition of manufacturing for detail parts to near net shape, selection of machines and processes for fabrication of the parts, and the tools required to support this effort. A key is the integral use of Design for Manufacturing and Assembly with tooling and manufacturing engineers participating in product definition, thereby eliminating false starts, manufacturing and tooling errors. Use of manufacturing models for specific machines, tooling concepts, assembly processes and factory arrangement allow the manufacturing process to be optimized at each supplier's location (hence, distributed and interactive).

Finally, a virtual environment is introduced to enable human interactions with hardware design (e.g. internal/external clearances) for manufacturing, assembly, and maintenance (thereby supporting the entire life cycle). Examples include location of crew station or control center components or door openings and clearance for removals.

This combination of elements leads to a new capability to "design it right the first time," from concept to hardware. Refer to Appendix B for a more detailed discussion of these elements.

DON M&S STATUS (TASK 1)

M & S	R & D Activity	Current Utilization	Benefit
Constructive Models	High	Extensive	Proven
Advanced Distributed Simulation	Some	DON: Modest Joint: Minimal	Emerging
Simulation Based Design / Manu-facturing	DON: Growing Industry: High	Application Dependent	Growing

DON M&S Status (TASK 1)

The Department of Navy has placed various levels of effort into constructive models, Distributed Simulations and Simulation Based Design/Manufacturing.

The vast majority of constructive models are found in the Research and Development activity. Such models as MEDUSSA, the High Fidelity AEGIS Weapon Control System Simulation, are sponsored by specific programs. Consequently the utilization of these types of models, which provide performance measures, are extensive. Although the benefit of these constructive models have been proven, additional gains can be realized.

Distributed simulation has not had the same degree of activity as constructive models. However, as network technology progresses, more and more activity will occur. Because there has been little integration effort of dissimilar simulators within the DON, the utilization of this M&S technology has been minimal. However, as activity increases, the utilization will increase and the potential benefit will emerge to significant levels. This emerging benefit will be partially the result of getting the user involved in the front-end of concept development.

Simulation Based Design/Manufacturing has been used extensively within industry. Indeed, high use has been made of simulation to aid in the design of semiconductors as well as functional end items for many years. The DON is just scratching the surface of this approach. The utilization of SBD/M is significant within the DON's supplier base. It is with this technology base that the DON is reaching out to "conceive, design, build, test and operate a ship in a computer." As the utilization increases, the potential benefit will grow. This growth is directly proportional to the technology evolution and transfer to implementation. The benefit will be realized in warfare analysis, engineering, manufacturing, testing, training, operations, and supportability.

OBSERVATIONS ON ADVANCED DISTRIBUTED SIMULATION

- **Key Elements:**
  - Human/Hardware In The Loop
  - Models That Support Visualization
  - Interoperable Models
  - Simulation Architectures & Communication Networks that Support Interconnection of Distributed Models
- **Key Benefits:**
  - Train With Assets that Cannot Be Brought Together Physically
  - Experiment With Future Systems/Concepts
  - Assess Alternative Systems And Tactics
- **Good Examples:**
  - Simulations Network (SIMNET)
  - Louisiana Maneuvers (LAM)
  - Internetting Range Interactive Simulation (IRIS)
  - Joint Advanced Distributed Simulation (JADS)

Observations on Advanced Distributed Simulation

The power and significance of this advanced distributed simulation technology may be greater than anticipated. Used with real military commanders leading opposing forces, this technology has the potential of exposing major strengths and weaknesses of military forces and tactics. The ADS technology can allow exercises to be performed with military systems and commanders located around the world at remarkably low cost. Before ADS, this would not have been possible.

Even more significant, from an acquisition viewpoint, is the ability to introduce into these ADS exercises military systems that do not actually exist. Advanced system concepts that have only been defined analytically, or perhaps in experimental breadboards, can be introduced into the "virtual" world created in ADS exercises. Real military commanders can become involved in their use and bring seasoned military insights into their design and operational requirements. Their effect on existing tactics can be understood and insights gained on how opposing military commanders might react to their presence on the battlefield. Acquisition mistakes will be reduced. Minimum requirements for military payoff can be identified. Acquisition cycle times will be reduced, as a result of early user involvement and the ability to combine acquisition phases.

In addition to gaining insights on potential new systems, valuable knowledge will be gained on how to use existing systems better. Tactics can be reviewed, challenged, and perhaps changed. Joint military operations can be examined using ADS, again with service commanders directly involved. The ability to examine new military situations in this way can provide valuable insights in a rapidly changing military situation with new missions emerging frequently.

This technology was first integrated by ARPA in the Simulations Network (SIMNET) program. Good examples that demonstrate the capabilities of Advanced Distributed Simulations include the Internetting Range Interactive Simulation (IRIS), the Joint Advanced Distributed Simulation (JADS), and the Synthetic Theater of War (STOW) applications within Army's Louisiana Maneuvers (LAM).

OBSERVATIONS ON SIMULATION BASED DESIGN/MANUFACTURING

- **Key Elements:**
  - **Models That Support:**
    - **Virtual Prototyping**
    - **Visualization**
    - **Interoperability And Distribution**
- **Key Benefits:**
  - **Analyze Many More Alternative Approaches**
  - **Identify Mistakes Early, Before They Become Costly**
  - **Propagate Changes To All Players Instantly**
  - **Predict Costs And Analyze Cost Tradeoffs**
- **Good Examples:**
  - **Boeing 777 Development**
  - **Chrysler Neon**

Observations on Simulation Based Design/Manufacturing

Computer-aided manufacturing technology is moving through three stages:

(1) Replacement of drafting tables with computerized drawing systems.

(2) Replacement of physical models with simulations grounded in physical models.

(3) Augmentation of human engineering knowledge with automated reasoning systems working over large knowledge bases.

Of course, manufacturers in some industries are ahead of manufacturers in others. For example, integrated-circuit manufacturers entered the second, Simulation-Based Design (SBD), stage twenty-five years ago, and many use early stage-three tools. Manufacturers in other areas, facing the harder problems that characterized the modeling of diverse materials in three-dimensions, are moving more slowly, but leading-edge companies are becoming famous for their successful stage-two programs.

Many factors, some technical and some nontechnical, have promoted movement from the first stage to the second, SBD stage in the aircraft and automotive industries:

- Lower-cost, higher-performance computer hardware and software.
- The emergence of high-quality graphics and world-wide networks.
- The development of widely-used standards, both official and de facto.
- Competitive pressure.

Because success stories demonstrate that obviously needed technologies have been developed, and that no surprising, show-stopping technology blockers remain, conspicuous success stories often drive periods of rapid acceptance. For SBD, the universally-referenced success story is the development of the Boeing 777. Before the development of the 777, individual Boeing engineers specified parts; during the development of the 777, teams of engineers (integrated product teams) specified models, from which drawings and/or other manufacturing information are derived automatically.

More importantly, the capture of the model in digital form enables several key benefits. One such benefit is the early avoidance of blunders. For example, a part that weighs too much, that will not fit, or that cannot be accessed for maintenance, or that costs too much to manufacture can be spotted at design time, without the delay and cost involved in building a physical mockup, or worse yet, introducing a downstream engineering change order.

A second benefit is realistic visualization. System visualization is important because it provides engineers with information that engages more of the idea-stimulating power of the human visual system, giving engineers a better feel for design quality, a better sense of where design effort should be focused, and a better starting point for identifying solutions.

A third benefit is that individual work, with incidental communication, becomes team work, with copious communication. Everyone works on the current design, not on yesterday's. Such benefits, translated to the bottom line, have dramatic effects. Boeing reports that engineering on the 777 was completed within budget, with under-weight targets, and with a dramatic reduction in change requests. An equally dramatic reduction occurred in part count and fastener count, both of which improve product quality and lower manufacturing cost.

OBSERVED STRENGTHS OF DON M&S (TASK 2)

- **Many High Quality Models and Simulations Exist**
  - **Built Over Decades**
  - **Accurately Represent Physical Phenomena**
  - **But... Tightly Coupled to the Experts that Run Them**
- **Constructive Simulations Used Effectively to Support System Development**
- **Stand-Alone Simulators Used Extensively in Training Environments**

Observed Strengths of DON M&S (TASK 2)

Naval forces operate in the broadest array of environments, including;

- underwater
- ocean surface
- land surface
- air
- space

A broad assortment of sensor types is required to operate within these environments, including active and passive optics, radars, and active and passive sonars. These sensors support a broad array of weapon systems and platforms operating in all these environments.

To design, build, and operate these systems and platforms, the DON has built virtually hundreds of high quality models and simulations - probably more than any other service. These models and simulations are dominated by large, physics-based models of platforms, weapon systems, and the interconnecting C^4I systems. They have been built up over decades, running primarily on large main-frame computers and not in real-time. They represent a core strength of the Naval service. A significant part of the DON institutional knowledge is stored within these models and simulations, and their associated databases.

A large number of the models are constructive simulations of these Naval systems, created during the development process. They are used initially to define and verify system designs...later they are used to support development and operational testing, predicting system performance and highlighting the differences between these predictions and test results.

In addition to these constructive simulations, another class of simulation is used extensively within the DON. These simulations use mock-ups of actual platforms and weapon systems, coupled with computer-generated visual scenes, and operated by DON military personnel. They are used primarily for training. As an aside, this military technology created the base for a significant commercial airline pilot training industry.

As these training techniques have been developed, it has become possible to do some of this training on operational equipment, rather than the mock-ups described above. The ability to do this is the result of improved computer technology built into this operational equipment. These high-performance, flexible digital computers contained within the operational equipment have been configured so that training scenarios can be realistically inserted.

These three capabilities provide a strong base for extending into advanced distributed simulation. The DON has already created a draft M&S policy that identifies this path.

OBSERVED WEAKNESS OF DON M&S (TASK 2)

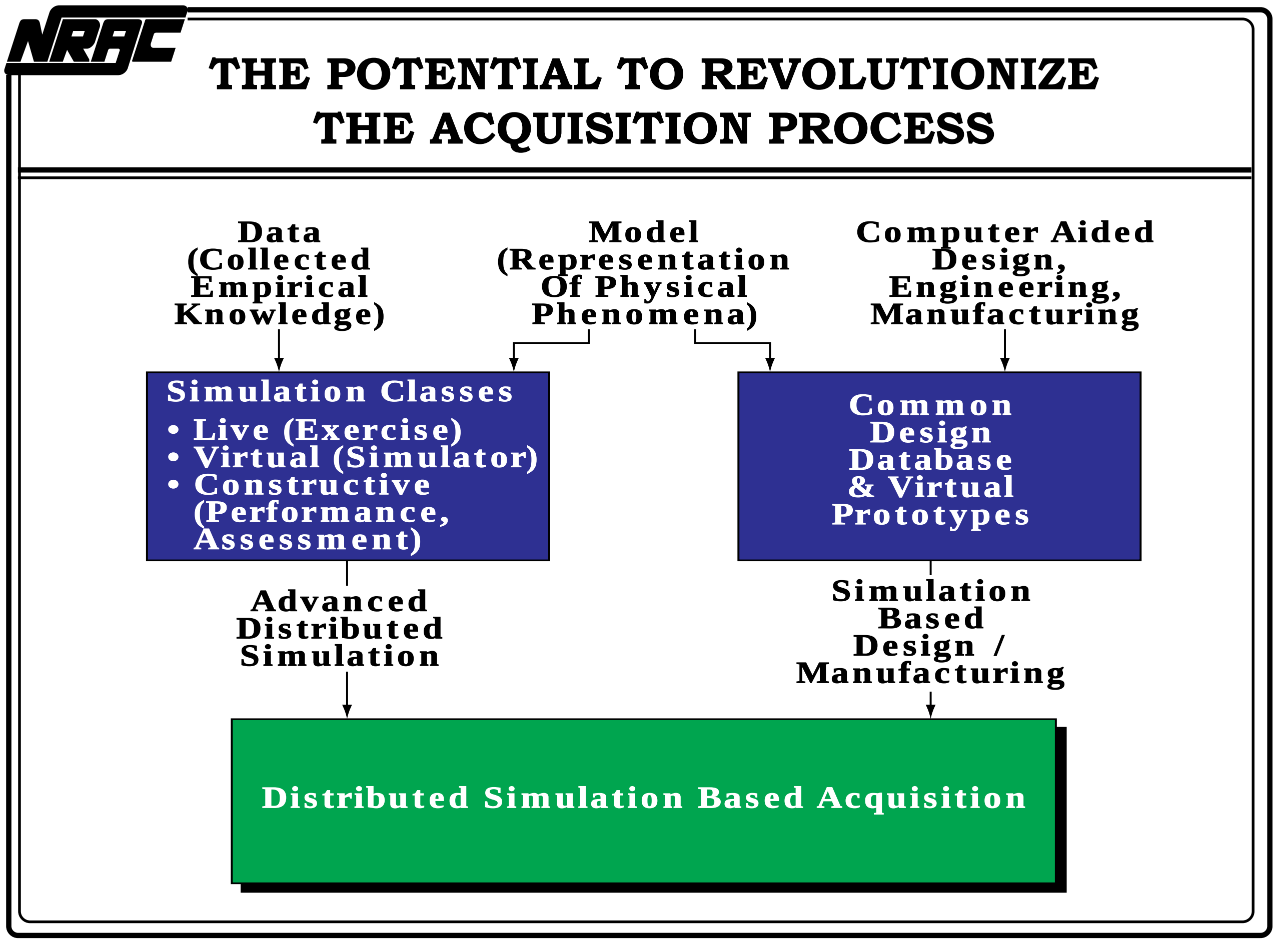
- **The Current Distributed Interactive Simulation (DIS) Architecture is Not Mature Enough to Support Naval Needs**
- **Quality and Credibility are Often Suspect**
  - **Validation, Verification and Accreditation (VV&A) is Complicated and Expensive**
  - **No Validation, Verification and Accreditation (VV&A) Standards**
  - **Reality Checking and Assumption Visibility Need to be Built In**
  - **"Spielberg Effect"**
- **Environmental Models Must be Updated to Support the Littorals**
  - **Sea-Land Interface, Surf Zone, Surface, Sub-Surface...**

Observed Weakness of DON M&S (TASK 2)

Communication standards for ADS are progressing at a rapid pace, but further maturing of those standards is needed, along with work in other architectural dimensions that are less well advanced. In particular, further work is needed on communication and database architectures and standards to support large scale (1000s of entities) operations, to provide a substrate for mixing live and synthetic targets, and to enable the integration of high and low fidelity simulations.

High-quality models are difficult and costly to build, especially models for phenomena that are not firmly grounded in well-understood physics. Once built, models are difficult to evaluate and compare, and often remain suspect. Assumptions are explicit only in the thoughts of the model builder, not in model-implementing software, and model software is rarely self-checking. Consequently, the Verification, Validation and Accreditation (VV&A) process does not work well, and few are satisfied with it. At the same time, we are in a period in which model developers are able to create high-quality visual models of their results. We must be aware of the potentially false credibility that is attributed to models that drive gala visualizations, of the sort that previously were done only in the film industry. The term “Spielberg Effect” most correctly describes this false sense of authenticity.

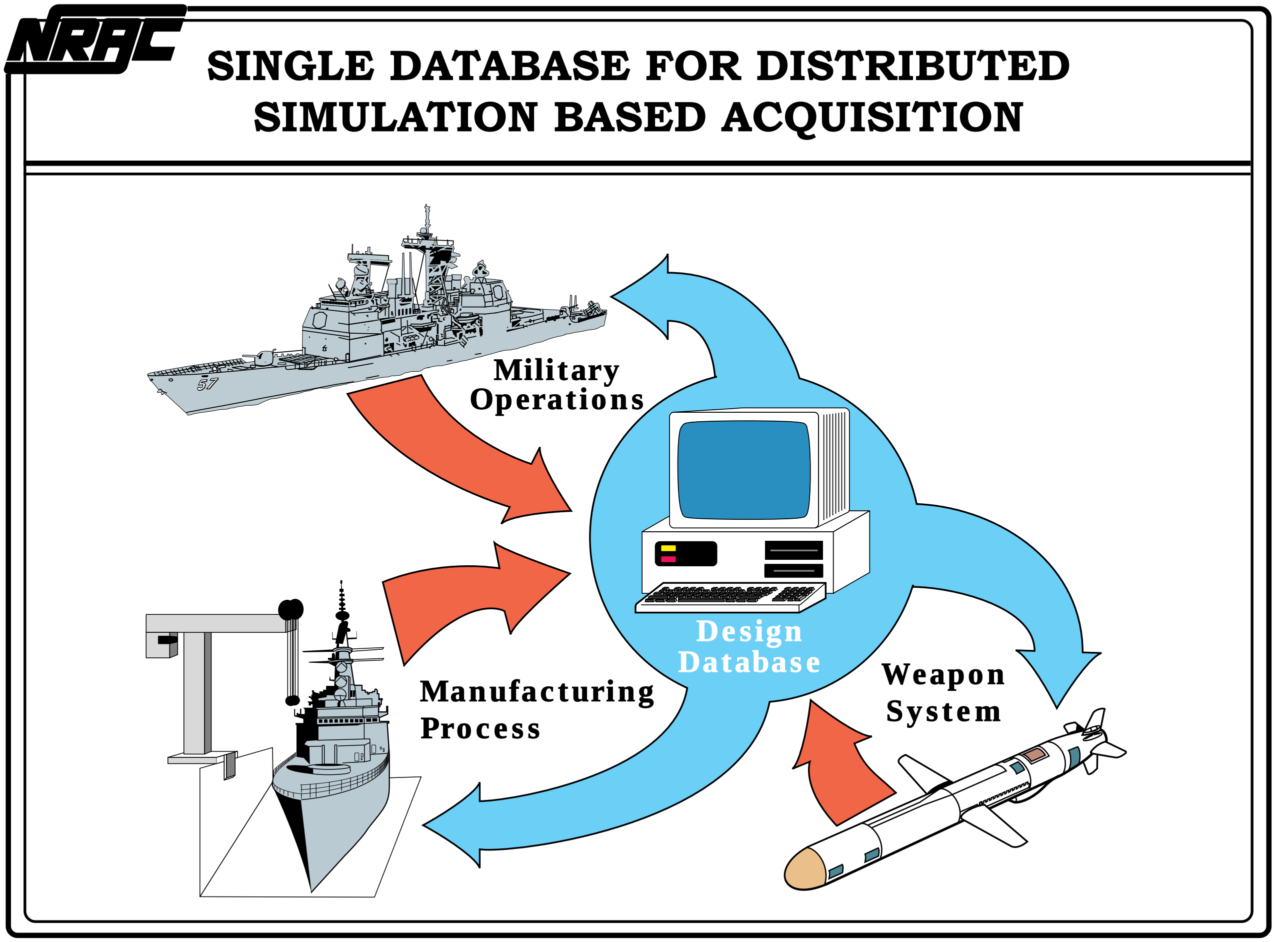
Although the DON has invested heavily, over a long period, on models, with many excellent results, those models predate the emergence of ADS for acquisition, training, and rehearsal and the emergence of an emphasis on littoral operations. Accordingly, existing models do not provide the connectivity-ready interfaces needed to support ADS, and they do not provide the full range of capability needed in light of the Navy's "Forward…From the Sea" doctrine.



The Potential to Revolutionize the Acquisition Process

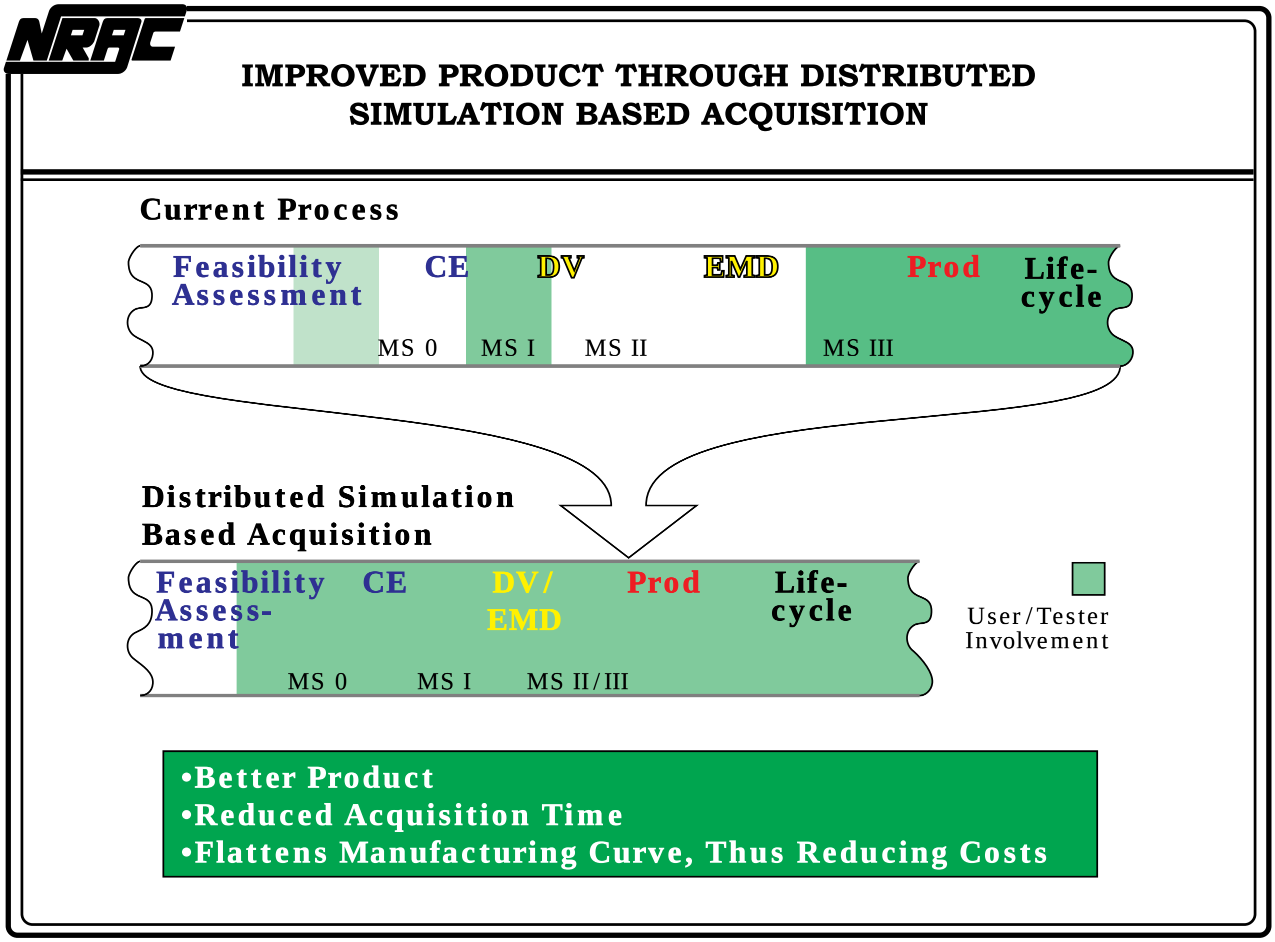
The tools embedded in Simulation Based Design/Manufacturing and Advanced Distributed Simulation Technologies provide a capability by which we can revolutionize the acquisition process. We have defined this as Distributed Simulation Based Acquisition (DSBA).

A DSBA process enables end-to-end verification of requirements matched to design, manufacturing, supportability, cost and performance trades for the complete life cycle, from pre-concept feasibility studies through development and on to training. The distribution of the common database, and interactions with live and virtual simulations, is equally valuable to training as it is to confirming operational requirements levels. Of equal (if not more) importance, DSBA also provides a mechanism to continually support user (operator/tester) involvement in needs, evaluation and training, and to facilitate all the principles of integrated product and process definition throughout the life cycle. If properly implemented we should be able to "try before buy," using distributed interactive simulation to solve many of the problems that usually are first evidenced only after a hardware construct. The DON should move this technology forward to conquer the "acquisition battlefield."



Single Database for Distributed Simulation Based Acquisition

A single database allows us to perform simulations to verify product performance, develop design parameters, and address manufacturing concerns.



Improved Product Through Distributed Simulation Based Acquisition

The concept of Distributed Simulation Based Acquisition promises to shorten the acquisition cycle, while simultaneously yielding better products.

Linked simulation tools will be used in all of the phases of an acquisition providing particular benefits during the Concept Evaluation (CE), Demonstration/ Validation (DV), Engineering/Manufacturing and Development (EMD), and Training phases.

An obvious key feature of the concept is the inclusion of the operational community (the ultimate users of the product) early and continually during the acquisition process.

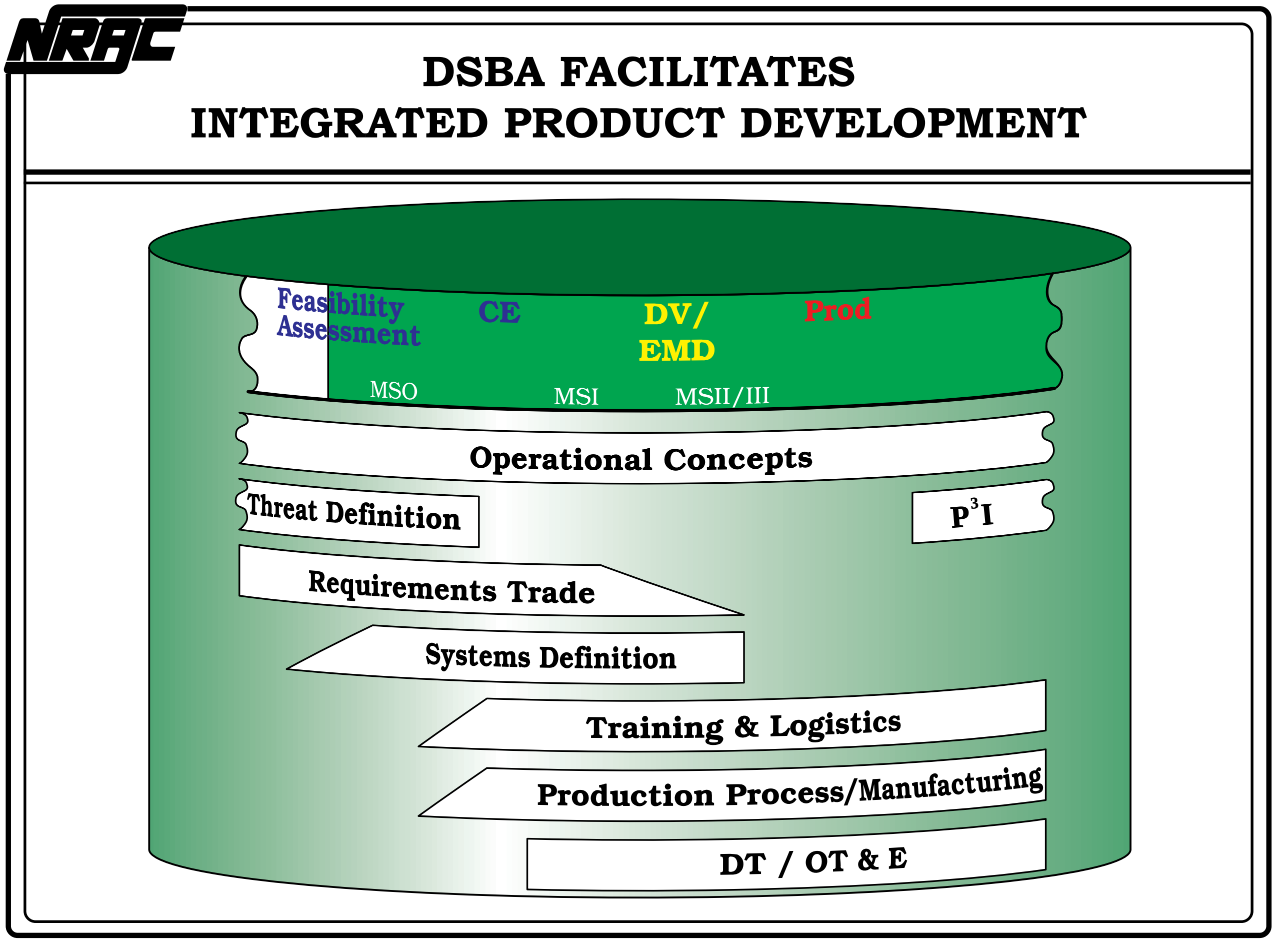
It is entirely reasonable to expect that the DV phase and the EMD phases can be collapsed into a single phase, typically saving years of effort. Simulation Based Design and Manufacturing will dramatically shorten the product development cycle requiring that the elements of the system be built and tested only once rather than twice as is common practice today. At the same time system utility can be effectively evaluated by the operational community before committing to production.

DSBA's strongest potential is to provide a "do it right the first time" capability, from design through manufacture. Design errors are either eliminated or found early enough in the process to enable smooth manufacturing. Use of SBD/M to develop new tooling and manufacturing concepts, facilities, and equipment for "lean manufacturing" provides a natural mesh with product design. Also, the synergistic use of both SDB/M and ADS elements to demonstrate lean manufacturing techniques in a virtual prototyping environment provides the confidence in product and process prior to commitment of significant resources by the user, the procurement authority, or supplier.

DSBA elements allow improvements in product development attained through integrated product definition, or concurrent engineering techniques. Manufacturing products and work flow are better known with the positive quality and cost impact quantified early.

The effect on the operational and requirements communities is that they will "know what they are really getting" before committing to a long program. The effect on the acquisition process is to provide substantial reductions in technical risk on committing to a program (hence an ability to reduce the development time span). The effect upon the production phase allows us to attain "lean manufacturing" objectives by correcting errors and simplifying the product manufacture in a synthetic environment, prior to actual manufacturing.

Both direct and indirect costs are reduced through more efficient design and manufacturing, reduced number of false manufacturing starts, and reduced number of expensive changes. Thus the manufacturing learning curve can be flattened by reducing the high cost of the first few items, and shifted downward (totally reduced) by the combined implementation of "lean manufacturing" facilitated by DSBA.



DSBA Facilitates Integrated Product Development

An integrated modeling and simulation culture and its attendant tool set provide the technical means to pursue Concurrent Engineering, the basis for the Integrated Product Development environment.

Multi-disciplinary teams will concurrently operate on identical or linked databases performing the following functions throughout the program:

- Operational Concepts
  The continual involvement of the operational community starting at a very early phase of the program and continuing throughout the program assures both user acceptance and optimal utilization of the final system, and a dynamic response to a continually changing threat environment.

- Threat Definition
  A historically recurring problem in defense system development has been the changing nature of the threat over the time-span of any particular system acquisition. The ability to dynamically reassess and counter the threat as close as possible to the actual system production phase cannot be overemphasized.

- Requirements Tradeoffs, Systems Definition, Training and Logistics, and Production Process Development
  These phases can proceed with a large degree of concurrency, facilitated by the common developing digital simulation of the overall system. Computer-aided design, engineering and manufacturing (collectively referred to as Simulation Based Design/Manufacturing) as we know it today will dramatically improve the efficiency, the rigor, and the accuracy of these stages of the acquisition process.

- Production
  The actual production process will be facilitated due to the minimization of false-starts and errors in the overall design.

- Testing
  Testing will be facilitated by using simulated tests as "pathfinders" for actual hardware tests. The number of aircraft flights during a test or the expenditure of test ordnance can be markedly reduced by utilizing simulations to plan efficient testing scenarios, and to "test" regions of the weapons-system envelope that are difficult, expensive or impossible to test under ordinary circumstances.

- P^3I and Upgrades
  With the accurate design documentation inherent in the operational and design databases produced by the Distributed Simulation Based Acquisition process, the re-evaluation of the system in the light of new threats is facilitated, as is the development of Preplanned Product Improvements (P^3I).

DISTRIBUTED SIMULATION BASED ACQUISITION PAYOFF

Acquisition Process		Payoff
Feasibility Assessment & CE		•Up Front User Involvement •High Quality COEA •Early Look at Production - Influences Cost •Concept Screening
DV / EMD	DT	•Fewer Test Articles •Early Proof of Mfg. Process
	OT	•Less Assets Required •Higher Acceptance Rates
Production Manufacturing		•Reduced Costs •More Quickly Deployed •Database Support to P^3I
Life Cycle Cost		•Maximize Exercise Training With Less Assets •Enhanced Reliability/Maintenance •Reduced Operational Costs

Distributed Simulation Based Acquisition Payoff

Using Distributed Simulation Based Acquisition during the acquisition cycle has significant payoff, both direct and indirect. The direct payoff occurs during the phase in which the actual simulation is used. An indirect payoff, in some cases larger than direct, occurs at a later phase of the acquisition cycle as a result of the improved output from a previous phase.

Distributed Simulation, when used during the Feasibility Assessment and Concept Evaluation phases of the acquisition cycle has immediate payoff. This occurs by allowing the user to get involved with the projected solution early in the concept development. By so doing, the utility of the projected solution is established prior to hardening the design. The operational advantages and deficiencies of weapon systems are often not understood until deployed in a realistic scenario. In the traditional acquisition approach this may not happen until Operational Evaluation (OPEVAL), sometimes occurring 10 years after the requirement process starts. As a result of realistic simulated environment testing of the concept, a higher quality Cost and Operational Effectiveness Assessment (COEA) will be developed. In addition, trade-offs will be enabled allowing early evaluation of production associated costs. Therefore, the proposed concept entering the DV/EMD phase is more accurately defined.

Direct savings will also be realized in the DV/EMD phases. Since a better defined concept is available there will be few false starts. With the ability to include Distributed Simulation during the development test and operational test phases fewer real test assets are required. As an example, in development test a better defined product results in fewer test articles to prove the adequacy of the design. Prototype military systems will be operated in a simulated operational environment and allow evaluation of performance of the equipment. For operational testing this capability will allow performance evaluation of the tactics as well as the equipment. With a combination of simulation and real world environments during an operational test fewer test assets are required. The result of the added operational insight early in the development cycle also allows operational testing to start with a product more closely aligned with the operational requirement. Consequently, the operational test acceptance rates will increase.

As concurrent engineering is used with real world distributed simulation in the EMD phase, more accurate information will be available to the manufacturing team. Therefore, the production phase will realize a reduction in cost-to-build. In addition, the product will get to its initial operating capability faster with a good database to enable support for any P^3I efforts.

Finally, large savings are projected during training since distributed simulation can augment real world environments. Therefore, with fewer real assets, the training exercise will result in better training. In addition, the operation and support of the weapon system will be less costly with enhanced reliability and maintainability.

The Defense Systems Management College in its March 1994 publication, “Virtual Prototyping,” noted that more than 80% of a program’s life cycle cost is determined prior to Milestone II. Typically, less than 10% of the program life cycle cost is expended by this point in the acquisition cycle.

Distributed Simulation Based Acquisition must be applied prior to Milestone II in order to have the greatest impact on reduction in system life cycle costs. This implies early program investment in DSBA to realize the benefits.

As noted earlier, potential savings included direct as well as indirect savings, predominantly from the systems concept and early definition phases for hardware, software, manufacturing and supportability, while providing both a mature database and audit trail for potential future upgrades.

RECOMMENDATIONS

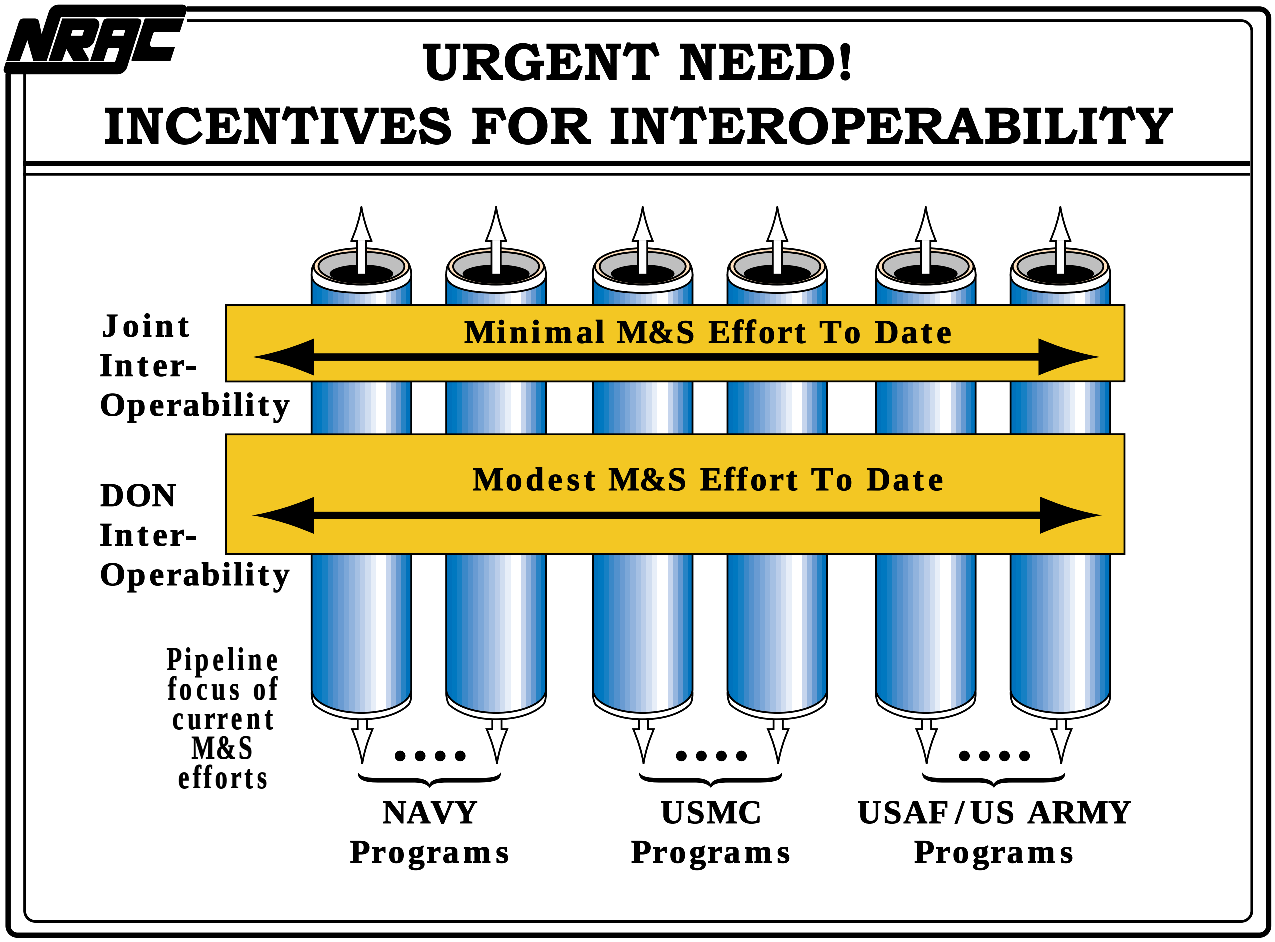
I POLICY

II TECHNOLOGY INVESTMENT

III DISTRIBUTED SIMULATION BASED ACQUISITION PILOT PROJECTS

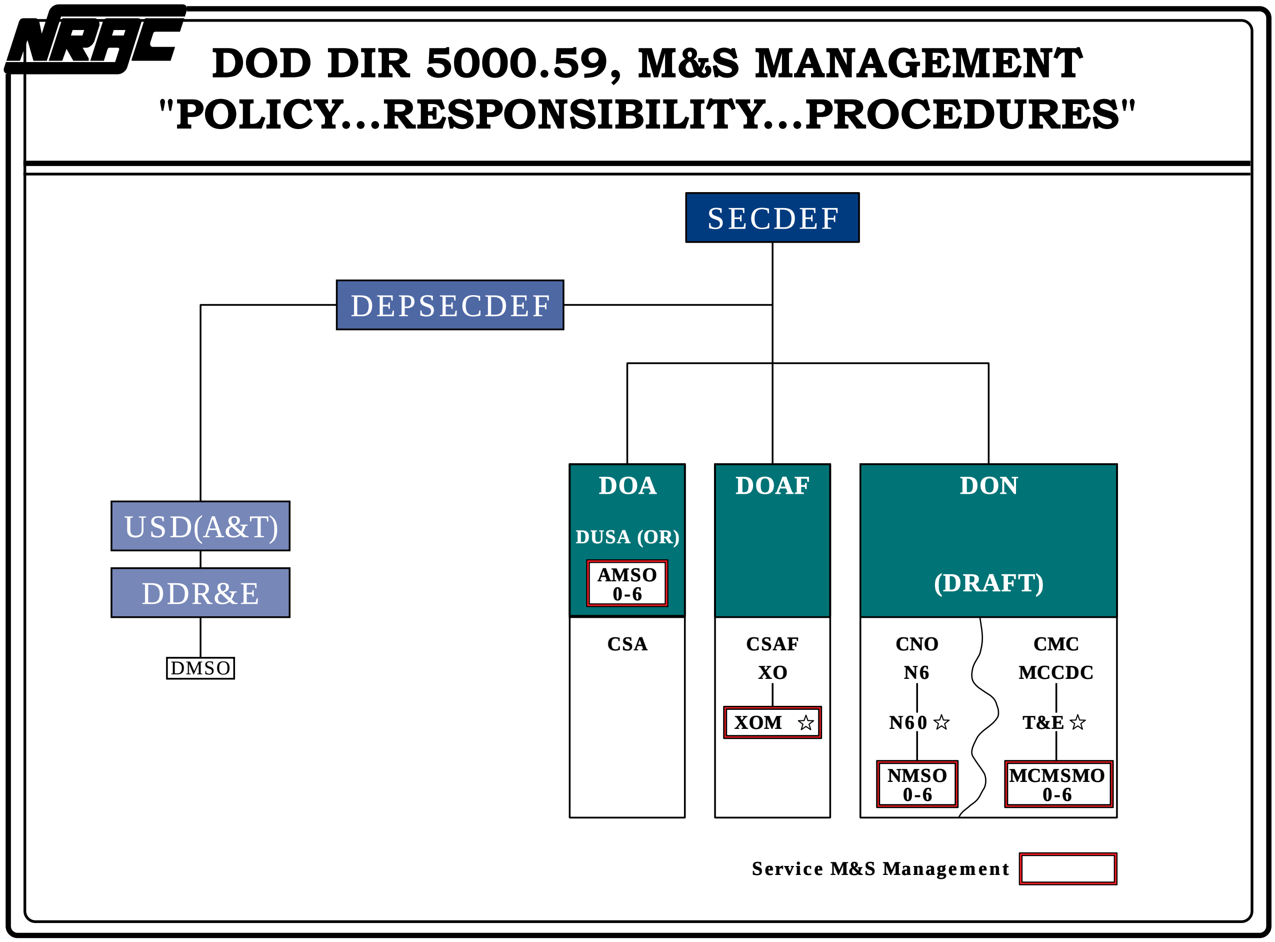
Recommendations

Our recommendations are grouped into three categories - policy recommendations, technology investment recommendations, and recommendations for distributed simulation based acquisition pilot projects.



Urgent Need! Incentives for Interoperability

Modeling and Simulation has been used extensively by the Department of the Navy for many years. However, the focus of the Modeling and Simulation effort has been upon individual DON programs and warfare centers. These Modeling and Simulation thrusts have served the DON well in satisfying program and warfare center requirements. Since most of these Models and Simulations are funded by individual programs, there are no standards or configuration control requirements that allow interoperability between programs. Because of this, there has been little or no benefit to the DON when attempting to transfer the utility of a Model and Simulation to other programs. To date within the DON only a modest effort has been made to link the individual program Modeling and Simulation thrusts. In addition, there has been little or no effort to link the other military services with a common framework to allow integration of related weapon systems models and simulations.



DOD Dir 5000.59, M&S Management "Policy...Responsibility... Procedures"

This organization chart illustrates the current implementation of the service's Modeling and Simulation management. The Defense Modeling and Simulation Organization (DMSO) reports to the Director of Defense Research and Engineering (DDR&E) while the service Modeling and Simulation organizations report within the Secretariat structures. One can't help but notice the difference in the level of management with the services, with the highest level of reporting within the Department of the Army, and the lowest level of reporting within the Department of the Navy. It is also important to note that the DON structure was only recently (18 October 1994) approved by the Secretary of the Navy.

POLICY RECOMMENDATIONS (TASK 3)

1. Designate N8 as Navy Executive Agent for Modeling and Simulation
2. Establish M&S Policy and Plan for Distributed Simulation Based Acquisition
   - Master Plan
   - Schedule
   - Budget
   - Pilot Programs
3. Establish Technology Base Investment Strategy Leveraged Through Cooperative Programs with
   - DMSO
   - ARPA
   - Joint Programs

Policy Recommendations (Task 3)

The Panel strongly recommends that Executive Agent leadership of the Navy be vested in a position that spans all warfare areas. Therefore, we recommend that the Navy modeling and simulation program be vested in N8, Deputy Chief of Naval Operations (Resources, Warfare Requirements and Assessments), rather than with N6, Director Space and Electronic Warfare. Such assignment appears to be a natural fit with N8's responsibilities for the management of requirements and resources and preparation of the Program Objectives Memorandum (POM), which also match those of the Modeling and Simulation Executive Agent counterpart, Commanding General, Marine Corps Combat Development Command. The N8 organization spans all warfare areas, and modeling and simulation are inherently integral and critical elements of the Joint Mission Assessment/Resource Requirement Review Board (JMA/R^3B) process. Further, the Panel believes that utilization of modeling and simulation (an N8 function) outweighs computer technical development and connectivity (N6 functions).

To ensure that the Department of the Navy derives the maximum benefit from the rapidly evolving distributed simulation technology, establishes a credible position within the overall Department of Defense modeling and simulation structure, remains competitive with the other services, and assumes a leadership position for unique

DON requirements, a strong, definitive and formulative DON modeling and simulation policy is urgently required.

The principal focus of the DON modeling and simulation policy should be to formulate a Distributed Simulation Based Acquisition Program (DSBA). The Panel found no significant technology gaps that would preclude implementation of this innovative concept. By exploiting industry advances in simulation based design, engineering, and manufacturing, and integrating modeling and simulation efforts across functional boundaries, across life cycle phases, between different types of models and simulations and between models and simulations of varying resolutions, benefits will be realized in reduced acquisition risks and decreased scope and duration of test and evaluation. In summary, DSBA will permit concurrent rather than serial activity, thus reducing or eliminating traditional development steps. Only a definitive policy is needed to enable DON to proceed into DSBA.

In compliance with DOD Directive 5000. 59, DON is required to produce a Modeling and Simulation Master Plan. The Panel concluded that a number of modeling and simulation issues are, and will remain, beyond near term resolution; and thus, within the M&S Master Plan, Navy and Marine Corps management must address implementation of DSBA. The plan should address a realistic schedule for transition from the current acquisition process into DSBA through a time-phased introduction of pilot programs. There is no need for another study on the feasibility of a distributed simulation based approach to acquisition. A small task force could quickly meld existing M&S elements into an action plan and policy, and identify a funding source to initiate, and then sustain, the program.

Although the principal thrust of the Panel's recommendations is the creation and implementation of a revised acquisition process, DSBA will require a continuing infusion of state of the art advancements in distributive simulation and visualization technologies. A Technology Base investment strategy is required to leverage new developments in those fields through cooperative programs with ARPA, DMSO, Joint Programs, industry and academia.

To minimize interface difficulties and optimize usage of funds, the DON needs to establish and implement a Modeling and Simulation policy. This policy must be responsive to DOD Directive 5000.59, DOD Modeling and Simulation (M&S) Management, of 4 Jan 94. This policy should provide guidance to govern the design, development, application and disposition of software, including standards and configuration control requirements. The policy should develop an oversight committee to promote coordination between programs within the DON and services within DOD. This coordination will allow for such things as common databases, communication techniques, visual representation and response to actions. This type of oversight will allow weapons systems to interface within an operational exercise. Operational advantages as well as weapon system deficiencies are often not adequately understood until exercised with human-in-the-loop features in a realistic deployment. Management and reporting responsibilities also should be identified within this policy.

TECHNOLOGY RECOMMENDATIONS (TASK 3)

1. Exploit Industry Developments in Simulation Based Design/Manufacturing
2. Develop Connectivity-Ready Models, Databases, and Architectures for Naval Unique Advanced Distributed Simulation Problems
3. Develop New Technology for Model Reality-Checking, Evaluation, and Comparison

Technology Recommendations (Task 3)

Our technology recommendations fell into three categories.

Industrial Development

Industrial development and use of SBD/M has begun to take off, as demonstrated by the use of SBD/M by Boeing for the design and manufacture of the 777 and by the increasing use of SBD/M in the automotive industry. Billions of dollars have been spent by users of SBD/M and by suppliers of SBD/M technology, which has produced a huge reservoir of software and expertise. Accordingly, Navy investment in this area should be focused on leveraging existing technology, rather than attempting to advance that technology inside Navy laboratories.

Connectivity-Ready Models and Databases

The DON can and should leverage the investment ARPA and other services have made in ADS for air and ground combat, and should takes steps to ensure that systems developed for the DON are guaranteed to be seamlessly interoperable with systems developed for the Army and Air Force.

Littoral warfare, however, is an example of an area of unique importance to the

DON. To realize the acquisition, training, and rehearsal benefits of ADS for littoral warfare, the DON must assume responsibility for such modeling. In particular, new models must be built and existing environmental models must be modified or extended to satisfy the needs of littoral ADS, with particular attention to the unique problems emerging from the need to deal with interfaces between the air, the water surface, the subsurface, and the land. In some cases, the adaptation can be done by using existing models to provide databases for ADS models.

The DON should also press its needs on standards groups to ensure that evolving standards meet the Navy's requirements for exchanging sensor and image data and for mixing live and virtual data.

Modeling Technology

The recent development of technology for building reality-checking elements into software models demonstrates that modeling technology can be advanced in important ways. On the other hand, the amount of research activity in this area of modeling technology is disproportionately small, given the increasing importance of high-quality model development. Accordingly, ONR should invest in the development of new model-construction, evaluation, and comparison technology.

RECOMMENDED DON M&S VISION (TASK 4)

M & S	R & D Activity	Current Utilization	Benefit
Constructive Models	High	Extensive	Proven
Advanced Distributed Simulation	Some	DON: Modest Joint: Minimal	Emerging
Simulation Based Design /Manu-facturing	DON: Growing Industry: High	Application Dependent	Growing
Distributed Simulation Based Acquisition	Some	Minimal	Revolutionary

Recommended DON M&S Vision (Task 4)

By combining constructive models with the simulation based design/ manufacturing and employing the network technology of distributed simulation, a gain in the acquisition process is realized. This approach describes Distributed Simulation Based Acquisition. Although research and development in this arena is currently small and the utilization is presently minimal, the potential benefit is projected to be revolutionary. This projection is based upon the utility of a common design database available and integrated from the feasibility assessment and concept evaluation phases through a common demonstration and validation and engineering and manufacturing development phase and into the production and operational and support plans. An integrated, common database simulation capability and real world exercise allows increased user involvement. This will yield more successful results and less false starts.

EVOLVE TECHNOLOGY THROUGH PILOT PROGRAMS (TASK 5)

Suggested Pilot Programs

- **Advanced Short Take-Off Vertical Landing (ASTOVL)**
  - Leverage ARPA Technology Demonstration Programs
- **Unmanned Aerial Vehicle (UAV) Landing Deck on LPD-17**
  - Bounded Near-Term Project
- **Mine Countermeasures**
  - Key Littoral Warfare Deficiency
- **Sea-Based Theater Ballistic Missile Defense (TBMD)**
  - New Navy Mission
- **Ship Self Defense**
  - Critical Warfare Deficiency

Evolve Technology Through Pilot Programs (Task 5)

The Navy has a number of important decisions to make regarding its operational needs in the newly defined littoral environment. These include: the selection of the optimum aircraft for both offensive and defensive operations, defense of the fleet and land areas against theater ballistic and cruise missiles attack, selection of an optimum approach to detecting and avoiding mine fields as well as selection of operating platform configurations for conducting these missions. The following suggested programs are good candidates for pilot programs, but we are not suggesting that they are the best candidates or the only good candidates. The first two programs are near-term programs which would offer the opportunity to get feedback reasonably soon; the other programs are longer term programs, but are ones that would benefit greatly from Distributed Simulation Based Acquisition. We also think that the Surface Combatant for the 21st Century (SC21), a major ship acquisition program scheduled for a Milestone 0 Defense Acquisition Board review in the near future, is another good candidate.

• Advanced Short Takeoff Vertical Landing: ASTOVL offers the potential to transition some demonstrated ARPA/NAVSEA (Naval Sea Systems Command) Simulation Based Design and technology efforts to an aircraft program in its earliest stages by leveraging ARPA's Affordable Aircraft Acquisition and ASTOVL technology demonstration initiatives. A resulting demonstration pilot program conducted interactively with the Joint Advanced Strike Technology (JAST) program could provide the basis for a program development architecture analogous to the embedded technology development efforts currently targeted for transition by the JAST program. Such a pathfinding program offers the potential to dramatically reduce weapon system costs.

• UAV/Landing Deck on LPD-17: The LPD-17 development process is currently being simulated in a Simulation Based Design initiative by ARPA. A key issue for distributed simulation, both in development and in subsequent training, is the marriage of databases to provide platform design interactions in a virtual environment to facilitate definition of UAV launch and recovery parameters. For design features and geometric interfaces, this requires relatively high fidelity; which, if validated and verified, may provide screening of design and test criteria to surface and solve critical issues for subsequent development and operational evaluation. One specific issue is a better understanding of recovery techniques for UAVs aboard the smaller air capable ships. The current mishap rate during recovery operations is about 10%, i.e., one UAV (costing about $1M) is damaged or destroyed during every ten shipboard landings on an LPD. This pilot effort proposes the use of surrogate landing platforms and air vehicles to obtain, define and model such elements as air vehicle controls, deck pitch, wind shears, and "burbles." The product would be a technical approach, techniques, and a sample database for a development simulation to be interactively employed in the LPD-17 design process.

• Mine Counter Measures (MCM): New technologies and platforms exist that can impact the MCM task. The introduction of unmanned air surveillance vehicles, air cushion surface vehicles, and high sweep rate sensors such as blue green lasers could change the way MCM is conducted. The UAV's could detect mines being deployed as well as the presence of a mine field in place. The air cushion vehicle could provide an improved sonar sweep rate. These concepts require investigation. Modeling and Simulation could provide a real assist to establish definitive criteria in a realistic environment.

• TBM and Ship Self Defense: Growing threats to littoral operations are both TBM's and low Altitude Cruise Missiles (CM's). The best system and tactical counters to these threats need to be determined drawing upon full technology and tactical resources available. It is difficult to perform live fire assessments with such threats and, consequently, Modeling and Simulation can serve a role to replace the live threat. As a result, current hardware systems effectiveness can be evaluated along with possible new simulated systems.

CAVEAT

- Some of This Technology is Taking Off Like a Rocket
- Some of the Technology is Just Emerging
- Capturing and Integrating These Technologies will be a Long Term Process

Caveat

A caveat is necessary. While some of this technology is taking off like a rocket, other parts are just emerging. It will be a long term process to capture and integrate these various technologies.

CARPE DIEM
"SEIZE THE DAY!"

- **Distributed Simulation Based Acquisition Can Revolutionize the DON Acquisition Process**
  - **Develop a Simulation Based Acquisition Strategy to Guide Investments in Areas Unique to DON and in Areas That Are Not Yet Mature**
  - **Develop "First-Hand" Experience with Simulation Based Acquisition Through Pilot Programs within Existing Acquisition Programs**

It's Time to Change the Way We Do Business

Carpe Diem - "Seize the Day!"

In summary, the Panel believes that Distributed Simulation Based Acquisition has high payoff for the DON in terms of reducing time to production and reducing overall cost. The path to DSBA involves policy changes to endorse and fund distributed simulations. In addition, investments in technology need to be made to assure that the DON is a key player in distributed simulations in its own environments and in joint activities. Finally, application experiments need to lead the way in building hands-on experiences and credibility.

Appendix A **Briefings/Visits**

Washington, DC (3-4 May)

Agenda:

NRAC Chair Welcome...Dr. Jim Colvard
USMC Sponsor (COMMARCORSYSCOM) Welcome...
MajGen Brabham, USMC
Office of Naval Research Welcome...RADM Pelaez, USN
Navy Modeling And Simulation Management Office...
Captain Tom Travis, USN
Marine Corps Modeling And Simulation Management Office...
Col John Kline, USMC
Global Grid...Mr Lee Hammerstrom
Naval Research Laboratory Overview...Dr Susan Numrich
Science Advisor, Office Of Operational Test And Evaluation...
Dr Ernest Seglie
Director, Defense Research And Engineering...Hon Anita Jones
Defense Science Board Task Force On Simulation, Readiness And Prototyping
...Dr Joseph Braddock & Gen Max Thurman, USA (Ret)
Director Modeling, Simulation, Analysis (XOM), USAF...
BGen Frank Campbell, USAF
Army Modeling And Simulation Management Office...
Col Dave Hardin, USA
Deputy Director, T&E, M&S And Software Evaluations,
Albert R. Burge
Advanced Research Projects Agency (ARPA)...
Charlie Stuart, Capt Chris Johnson, USN
Joint Warfighting Center...Capt Stan Bloyer, USN
Assistant Secretary For Defense Programs,
Department Of Energy...Hon Victor Reis
Center For Naval Analyses (CNA) Overview...Dr Tom Taylor
Defense Modeling And Simulation Office (DMSO)...Rob Berry
Navy and Marine POM/Resources Overview...Col Joel Cooley, USMC and
Pete Biesada

Fort Leavenworth, Kansas (17 May)

Agenda:

Welcome...LtGen John Miller, USA,
Army Combined Arms Command
Louisiana Maneuvers Overview...Col Gale Smith, USA
National Simulation Center (NSC) Overview...Dr Robert LaRoque
Battle Command Training Program (BCTP) Overview...
Col John Inesca, USA

Battle Command Battle Lab Elective Overview…Col John Eberle, USA
Training and Doctrine Command Analysis Center (TRAC)…
Mr Kent Pickett
Simulation Demonstration…Mr Kent Pickett
Corps Battle Simulation (CBS)
Aggregate Level Simulation Protocol (ALSP)/
Confederation of Models…Dr LaRoque.

<u>China Lake, California (19 May)</u>

Agenda:

Introduction, Head, Weapons Planning Group…Linda Andrews
Modeling and Simulation Overview…John Morrow
Electronic Warfare Threat Environment Simulation Brief…
Chuck Mattson
Missile Engagement Simulation Arena (MESA)…Rick Lamp
Encounter Simulation Lab (ESL)…Rick Lamp
Electronic Warfare System Support Activities (EWSSA)…
Joanne Wallis
Electronic Combat Simulation and Evaluation Laboratory (ECSEL)…
Harry Banks
Battle Management Interoperability Center (BMIC)…Rick Smith
Battle Management Interoperability Test and Evaluation (BITE)…Rick Smith
NAWC Internetting Capabilities…Herb Barry
Weapons and Tactics Analysis Center (WEPTAC)…
Linda Andrews
Internetting Range Interactive Simulation (IRIS)…Cliff Stone
Joint Environment for Test, Training, and Analysis (JETTA)…
Cliff Stone
Joint Survivability Modeling and Simulation Roadmap Overview…
Tim Horton
Survivability Test Data Integration…Tim Horton
Susceptibility Model and Test Range (SMART) Project…
Dave Hall
Mission Planning Laboratory Brief…Wayne Tanaka
Distributed Analysis Experiment…Linda Andrews

<u>Orlando, Florida (8-10 June)</u>

Agenda

CO NAWC-TSD Remarks and Command Briefing…
Capt Chris Addison, USN
Navy Defense Intelligence Service Agent…John Mills
Technology Transfer/Cooperative R&D Agreement…
Janet Weisenford-Healy

Lab Tour: Organic Combat System Training Technology…
    Bill Parrish & Ron Stratton
Lab Tour: Team Target Engagement Simulator (TTES)…
    Dr. David Fowkles
Simulation in Manufacturing…Dr. Eduardo Salas
Advanced Amphibious Assault Vehicle (AAAV)…Dr. Dave Daly
NAWC-TSD Working Lunch:
    Videos: "AAAV" and "DIS World 93"
Lab Tour: Forward-Deployable Aviation System Trainer…
    Dan Peterson & Jim Burns
Lab Tour: Naval Aviaton Systems Networking Training…
    Vickie Moore & Eric Anschuetz
Impact of Distributed Simulation on Team Performance…
    Dr. Ruth Wills
Deployable Forward Observer Modular Universal Laser Equip…
    Maj Mark McKeon, USMC
USMC ADS Demonstration; "Behind the Curtain"…
    Capt (MajSel) Lance Bryant, USMC
STRICOM Command Brief…BG John Michitsch, USA
M&S Overview/Issues; STRICOM Technical Director…
    Dr. Ronald Hofer
Program Manager ITTS/Simulation & T&E…Col J. Overstreet
Program Manager DIS…Col J. Etchechury
STRICOM Working Lunch:
    Videos: "Concept To Production" & "Tradeoffs"
Engineering Directorate…Mr. S. Goodman
Lab Visit: SAIC-CSSTSS…Col J. Shiflett
Lab Visit: LORAL - FSC-CCTT…Col J. Shiflett
Lab Visit: LORAL-ADST…Mr. J. Collins
IST
Martin Marietta

<u>Washington, DC (20-23 June)</u>

Agenda:
NRL, Information Technology Division…Dr Shumaker
NRL, Global Grid…Ray Cole
NRL, Advanced Information Technology…Bill Smith
ONR Interests…Sue Numrich
NRL, Meteorology…Paul Anderson
NRL, I 4 Wissard…Alan Meyrowitz
Office of Naval Research (ONR) Modeling and Simulation
    Issues…Dr Thomas Warfield
NRL, Remote Sensing Division…George Keramidas
NRL, Space Science Division…Dr Gursky & Dr Heckathorn
General Dynamics/Electric Boat/ARPA Simulation
    Based Design…Gary Jones

Navy Test and Evaluation (T&E)...Dr Kahmi
COMOPTEVFOR...Capt Bob Fuller, USN
COMMARCORSYSCOM (DT&E)...LtCol Mike Przepiora, USMC
MCOTEA (OT&E)...LtCol Brown, USMC
ARPA DIS Overview...Dr Randy Garrett
ARPA//Systems Engineering - WARBREAKER...
LtCol Dave Neyland, USAF
ARPA//Manufacturing...Dr Pradeep Khosla
ARPA//Affordable Aircraft Acquisition (A3) & JAST...
Dr Bill Scheuren
ARPA//Advanced Technology Work in Communications/Networking...
Dr Howard Frank
Model Quality...Dr David W. Peterson, Ventana Systems, Inc
Army O&D T&E Overview...Dr John Foulkes (DACS-TE)
Army OPTEC...Dr Hank Dubin
Army TECOM...Bill Barnhart
Defense Systems Management College: Acquisition Policy/Modeling and Simulation...
Pete Vollmar, LtCol Mercer, USAF, LtCol Piplani, USA
Simulation and Modeling as relates to Mine Counter Measures...
Dr Elin Moritz
NSWC-Dahlgren Division (TADSIM, EADSIM)...Charles McClure
NRAC: "Littoral Warfare Study"; Key Areas Of Investment...
Ken Lobb
DIS Science and Technology - Naval Perspective...Cdr Dennis McBride,
Cdr Guy Purser
Boeing...Dave Sweet, Brian Chiesi
Ford...Dr Howard Crabb
Chrysler...Dr Choon Chon
Model Resolution...Dr Paul Davis, RAND

National Test Facility, Falcon AFB, Colorado (7 July)

Agenda:

NTF Overview...Col Worrell
BESIM
Theater Planning Tool
SPC
ARGUS
BESC/BMC3
M&S Issues of Interest (Lessons Learned, VV&A)
Integration and Testing Support
Training, Exercise and Operations Support

Air Force Operational Test and Evaluation Command &
58th Special Operations Wing, Kirtland AFB, New Mexico (8 July)

Agenda:

- Advanced Distributed Simulation…Col Griffin
- M&S at AFOTEC…Maj Adams
- B-1B Defensive System M&S Experiences…Ms Black
- F-22 Flight Mission Simulator Testing…LtCol Catts
- F-15E TEWS Testing at AFEWES…Mr Ganger
- Advanced Network Simulation for SAR and SOF
- Advanced Mission Training and Rehearsal for USAF Helicopter Force
- Project 2851

Appendix B M&S Element Definitions

Advanced Distrubuted Simulation Elements

Models

Thousands of models are in use throughout the Navy today, but very few were developed with ADS in mind. As such, they have been optimized for specialized applications, and lack the flexibility to interact. Issues related to models are discussed below.

(1) Real/Virtual: Models in the context of ADS refer to computer-based models where some or all of the modeled entity is represented in software. Models which only contain software are called virtual models. Some models require real hardware elements to be interfaced with software if the physical performance of the system is too complex to be emulated entirely in software. Examples of this are a model of an enemy air defense radar or a flight simulator.

(2) Physics/Heuristic: Physics models are those which represent system performance by executing a numerical approximation to known physical equations that control the behavior of the system and its interaction with other systems in the real world. Heuristic models employ deterministic prediction algorithms such as look-up tables to simulate performance. Complex physics models often require extensive computing resources and execute too slowly to be used with ADS. Heuristic models run faster, but often at the cost of accuracy or fidelity.

(3) Fidelity: Fidelity refers to the precision or graininess of a model's outputs. The most apparent manifestation of fidelity is in the quality of displayed graphics, but any loss of information due to quantization errors or algorithm simplification can degrade model fidelity. Achieving variable fidelity (for example, providing closer objects with higher resolution than distant ones) is a major software challenge in ADS.

(4) Visualization: Model output in the ADS environment is generally most useful when presented to the user as images. Visualization deals with both display technology and human perception, including illusion. Display technology, where three-dimensional objects are portrayed on a two-dimensional video terminal or screen, is very demanding of computer resources forcing compromises between fidelity (ie. realism) and execution time.

(5) Composability: Composability deals with the issue of how different models with differing computational objectives, data input/output schemes, or levels of fidelity can be made to pass useful information back and forth. An example is an environmental model which predicts ocean temperature as a function of depth which must interact with both an acoustic torpedo simulator in one instance and a towed array model in another.

(6) Aggregation/Disaggregation: Many complex models generate much more data than is needed or can be handled by other ADS elements. The process of filtering model outputs or simplifying model execution is called aggregation. Disaggregation refers to the reverse process where sparse input data must be interpolated by the model to increase fidelity. It is extremely challenging to aggregate or disaggregate model data without loss of fidelity or precision.

(7) Validation: Validation is the formal process of establishing accuracy and limits of applicability of a given model. The validation task becomes particularly difficult in ADS where it is hard to prevent misapplication of models in the multi-user domain.

(8) Development Time: Good, high-quality models require years to develop and multiple revision cycles to perfect. It is essential that model design begin early since, in the ADS environment, overall system performance will be degraded by the least capable model.

Shared Databases

Shared databases are essential in ADS in order that all participants experience the same environment (often referred to as "ground truth"). Issues related to shared databases are discussed below:

(1) Resolution: Resolution refers to how finely the real environment is portrayed. Different participants have different resolution requirements depending on their vantage point and sensor systems used (for example, 1 meter resolution is too fine for pilots at 40,000 feet, but would be generally inadequate for ground forces).

(2) Accuracy: It is essential that database accuracy be the same for all ADS participants in order for the synthetic environment to correlate. If some participants are based on a flat-earth model while others use an ellipsoid earth model, "reality" will not be the same for everyone. The Simulation Database Format (Project 2851) is an attempt to standardize many of these physical characteristics.

(3) Acquisition/Creation: Shared databases must be created or acquired from other information sources such as satellite imagery or intelligence sources. Huge amounts of raw data must be translated and reformatted in order to be usable in the ADS environment where multiple users have widely varying data requirements.

(4) Accessibility: Shared databases tend to be centralized rather than distributed. Equal access to all users is essential. As the database information changes, it must change for all users simultaneously.

(5) Maintenance: Maintenance of centralized, shared databases which must be accessible to large numbers of network users in real time is a paramount challenge.

Networks

Networks comprise the communications paths for all shared information in the ADS environment. Each user on the network comprises a node. Since the amount of data which the network must carry increases roughly as the square of the number of nodes, eliminating communications bottlenecks becomes a significant ADS challenge. Issues related to networks are discussed below.

(1) Bandwidth: Bandwidth is a measure of the size of the communication "pipe," determining the amount of data that can be passed per unit time. Optical fibers offer enormous increases in network bandwidth. In the maritime environment, however, where communications are often restricted to radio frequency (for example, ship to shore), limited bandwidth presents a major barrier to effective ADS usage.

(2) Security: Encryption and multilevel security (schemes where different users have differing levels of access to shared data) impose an additional premium on communications bandwidth and network computational overhead. The Defense Simulation Internet (DSI) is in the critical path of successful ADS deployment.

(3) Architecture: The network architecture determines how, what, where, and when data can be transmitted on the network. Interoperability requires that the architecture be standardized for all users. This is accomplished by means of standardized network protocols to which all users adhere. The Distributed Interactive Simulation Steering Committee has focused efforts in this area. It is anticipated that the Joint Simulation System (JSIMS) will increasingly drive this effort for DOD in the future.

Distributed Simulations

Distributed simulations present a host of unique technical challenges not encountered in any other field of data processing and information technology. Issues of distributed simulations are discussed below.

(1) Space/time Correlation: All events in the synthetic environment must be synchronized in time and correlated in space within the limits of perceptibility of the users.

(2) Execution Time/Latency: Simulations can be executed in slow motion, fast motion, real time or near real time. Execution is paced by the slowest elements in the ADS system. Latency refers to the delays inherent in computation and communication of changes of entity state.

(3) Verification/Accreditation: Whereas models are validated, simulations are verified and accredited. Verification ensures that the simulation produces an accurate or correct result for the given circumstances while accreditation ensures that the result is appropriate. The result of a simulation can be accurate without being appropriate and vice-versa; for example, a new simulated weapon may perform perfectly in a given scenario, but the scenario turns out to be

inappropriate.

(4) Hardware in the Loop (HWIL): Most ADS scenarios involve a complex arrangement of real and virtual entities. In order for real and virtual entities to interact effectively the distinctions between the two must blur in the synthetic environment.

(5) Human in the Loop (HIL): In many instances in an ADS scenario, whether the participating entities are real or virtual, human operators are interjected to control the behavior of the entity. This adds realism, allows for the element of surprise, and contributes hard-to-model human factors, such as stress, to the simulation.

Simulation Based Design/Manufacturing Elements

Simulation Based Design/Manufacturing is comprised of a design database, manufacturing models, and virtual reality. These elements are fed by the requirements base and interaction of requirements with design and cost trade-offs.

Requirements

An early understanding of requirements is necessary for the developer to provide a responsive product, drawing upon the technology base available at a full-up systems level, as well as at the subsystem and component integration level. The result enables definition of basic weapons systems sizing, range and payload requirements, and subsystems performance specifications. Interaction with the warfighter provides a closed loop assessment of the potential product and its ability to satisfy operational needs and requirements. Early involvement of the development and operational test agencies can provide for test criteria screening relevant to operational objectives.

(1) Warfighting Capability Interactive human-in-the-loop simulation is performed at levels of interaction from constructive engagement levels through integrated vertical and live simulations. These simulations also are used interactively with various system and subsystem performance parameters to reaffirm weapon system design requirements. Depending upon the degree of simulation discipline used for the simulation construct, these requirements can be explored at several levels, down to the basic subsystem or component.

Design Database

The Design Database is the definition of the product, its performance and capability, its subsystems, components and their performance, capabilities, capacities, and potential growth.

(1) Configuration Design - The generation of weapons system characteristics, description, and sizing responsive to the requirement. (e.g., type of aircraft, range, maneuverability, payload, level of stealth, sensor performance). This establishes the external mold line of the weapon system to form the basis for

future detailed fluid mechanics, controls, subsystems and structural integration efforts.

(2) Computational Fluid Dynamics - The capability to use computational codes for solution of fluid dynamic (either aero or hydro) flow characteristics in the presence of the weapon system. The utility is better understanding and requirement of interactive lift, drag, propulsion, and control flow/body phenomena.

(3) Electromagnetic Codes - The capability to use high speed parallel computations to describe physical optics, waveform scatterers or surface and traveling waves which generate radar returns from a radiated configuration. These codes are used interactively with vehicle design, shape, aperture location, and materials selection to describe and refine the weapon system radar cross-section.

(4) Structural Analysis Codes - Computational techniques interactive with vehicle and external loads (i.e., aircraft or ship fluid dynamic pressure) to define optimal load paths for placement of primary and secondary load bearing structures, impact of bulkhead and highly loaded internal points of intensity (i.e., actuator pads, payload bays, concentrated deck loads). Structural analyses interact with the configuration design and control system design (reflecting control deflections, changing loads, and in some cases use of controls to interactively alleviate dynamic loads — such as gusts of wind or weapons launch, as may be determined in a 6 degree of freedom (DOF) Model)).

(5) 6-DOF Models - Generation of weapon systems motion, rates, control performance for development of controls, control system design criteria, and architecture. Also used for fly-out models for missiles, or separation and launch criteria/interactions between missiles, weapons, dispensers, towed arrays and their platforms.

(6) Equipment and Subsystem Parametrics - A combination between the design (geometric) interface, equipment installations or locations, and analysis of needs for capacities, power, cooling, and subsystem performance. Used to size the equipment, interactively for support and determination of other subsystem needs; (e.g., power supply, computational, cooling, purge, hydraulics, pneumatics).

(7) RF/EO Models - Parametric representations for performance and field of regard for radar and electro-optical sensors. Primary use is to provide a description of substem capability responsive to requirements for the weapon system, leading to sizing, power, cooling requirements, and systems integration/ installations.

(8) 3-D Solids - High fidelity geometrical modeling from a computer-based design system. The major benefit is surface geometry and shape for the individually described components, subsystems, or structural members. This capability is a keystone for development of "electronic mock-ups" to eliminate the need for

costly physical mock-ups during system development. Use is not restricted specifically to product. Another principal application is to the machine tools, and production or manufacturing process.

(9) CAD/CAM/CAE - The generic description and representation of Computer Aided Design, Manufacturing, and Engineering. As used in the context of this paper, the term includes logistics and supportability elements in an integrated product definition context. This is a major enabling capability via the development of a single, common, digital design database; which may be ported to, and shared by different, but contributing development teams/facilities.

Manufacturing Models

The manufacturing models (geometric simulations or virtual prototypes) allow refinement of the new machine technology, and enable focus on practical applications in the context of a "real" product…complete through where the process may fit within the factory flow.

(1) Fabrication and Assembly Models - A series of models for component, or piece-part, fabrication and assembly, based upon 3-D solids modeling via the CAD/CAM design database. In effect, this is a geometric simulation of interfaces, with interaction between the manufacturing and tooling engineers and the workers, to hone the process for a specific manufacturing site. Shortened and simplified assembly steps will result, along with the potential to reduce both the number of tools and the number of parts reflective of the basic design. These provide a fundamental reduction in manufacturing costs — on a recurring basis, helping to achieve "lean manufacturing."

(2) Tooling Concepts - An integral part of the computer aided product definition process, drawing upon the 3-D uniform database, enables a representation of the tools (i.e., holding fixtures, bond jigs, assembly fixtures) which are generally the framework for manufacturing and assembly. Tooling concepts may be explored in geometrical simulations, identifying the homogeniety of critical tool design points (reference datum) and critical product design points. Conducted in an interactive framework with the product design and manufacturing engineers, decisions can be made to provide for "lean manufacturing" by influencing the manufacturing process. The user may have a basis for selection of a different, less expensive, material/fabrication concept (e.g., a machined subassembly vs. sheet metal parts/fasteners), or low temperature composites cure vs. autoclave, or a low temperature lay-up composites tool, arc-sprayed for use in fabrication of autoclave parts vs. an expensive steel autoclave tool).

(3) Machine Tool Paths - A specific application of 3-D solids modeling and geometric simulation to evaluate proper machine operation, tool selection (drill, cutter, grinder), cutter path, and sequence of machine operations to provide near net shape (limited waste), high dimensional quality and surface finish (limited scrap) parts. This is usually conducted interactively between design, manufacturing and tooling engineers and the production tool operator. The

payoff is proper tool selection, improved quality and reduced cost, even for reduced quantity and rates of manufacture.

(4) Composites Selection and Lay-Up - While there are many processes for fabrication of composite parts, the use of 3-D virtual geometric (solids) models, as in the machine tool example above, provides an interactive production operator, design engineer and manufacturing/tooling engineer effort to: (1) select the basic composite material system: (2) optimize a given process for rate and quality; (3) conduct cost/rate trade studies; and (4) select the best process for a given part. The development focus may lead to further definition of a capability to design and fabricate large unitary structures; which is a fundamental approach toward achieving "lean manufacturing" objectives.

(5) Factory Queue Models - One of the greatest challenges to lean manufacturing is an understanding and arrangement of the work flow — hence, arrangement of the factory floor. There are a number of commercially available industrial queue models. These allow evaluation of current and proposed fabrication shops, assembly, major joint operations and installation alternatives pertinent to a proposed component, subsystem, or major system development. By running the models interactively, utilizing the previously discussed fabrication and tooling models in conjunction with a cost based assessment, the minimum cost/rate production arrangement for the quantities anticipated may be realized.

Virtual Reality

Virtual reality allows us to introduce a synthetic environment which enables trial and error experiments prior to major hardware commitments. Generation of three-Dimensional geometric models for hardware may be coupled with 6 degree-of-freedom (DOF) models for human interactions to fully explore interfaces for the design (e.g., aircraft cockpit); clearances for maintenance (e.g., removing engines); and steps in manufacturing and assembly.

(1) Human Interactions - The intent is to provide a series of simulations and modeling exercises building upon constructive digital models and leading to visualization in a synthetic environment as the development of the system matures. Initial applications include design guidelines and modeling for crew stations, work spaces, and physical clearances based upon human anthropometric traits. As the design database is built in 3-D solids, this can be merged with human-in-the-loop visualization techniques for the significant design and operational issues, such as an aircraft crew station. Further development and refinement for a fighter weapon system, such as the F/A-18, leads to use of human-in-the-loop and hardware/software-in-the-loop evaluation and development of crew station arrangement, controls and displays, display formats, weapon system operation and interactions and aircraft flight control, and handling qualities for significant operational phases. Of course, these elements may be extended towards distributed interactive simulations with linked development simulators or fleet operational command and control assets.

(2) Visualization - The primary link between modeling and understanding is the ability to "internalize" (i.e., visualize) results, interactions and impact on the product or event. The technology growth in display fidelity and format has been enormous, as has been the growth from static-to-dynamic-to-interactive, multiple participant, dynamic situation representations. This is the key "enabler" for construct of the synthetic environment at meaningful fidelity levels. Human interactions (hand, foot, head motions) with equipment can thus be provided, conclusions drawn, and training accomplished.

(3) Maintainability Task Models - An emerging capability, linked with high fidelity 3-D solids modeling of the weapon system geometric interfaces, is related to simulated "hands-on" access to panels, doors, parts, subsystems and systems and their removal. One can assess the placement of equipment and adequacy of either clearances or tools for conducting periodic maintenance and equipment servicing. The result is conscious decisions during the definition and development process to minimize time and cost for supportability operations, thus providing a direct benefit for maintenance manning, ship crew complement, and sortie rate generation. The offshoot is a basis by which the developer can provide for a maintenance trainer requirement. These will potentially be used to hone skills of the people to be involved in day-to-day operations.

(4) Assembly Task Models - The same technology and product design database maturity for the high fidelity 3-D models discussed for facilitating maintainability tasks can be used for assembly tasks. However, in addition to the product model, representations of: (1) specific assembly tools (or concepts) for each product element; and, (2) specific work station attributes (clearances, tools, kitted parts) need to be included.

Appendix C Glossary of Terms

A^3	Affordable Aircraft Acquisition
AAAV	Advanced Amphibious Assault Vehicle
ADS	Advanced Distributed Simulation
AFOTEC	Air Force Operational Test and Evaluation Command
ALSP	Aggregate Level Simulation Protocol
ARPA	Advanced Research Projects Agency
ASTOVL	Advanced Short Take Off Vertical Landing
BCTP	Battle Command Training program
BESC	BM/C3 Element Support Center
BITE	Battle Management Interoperability Test and Evaluation
BMIC	Battle Management Interoperability Center
BM/C^3	Battle Management/Command, Control & Communications
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CBS	Corps Battle Simulation
CE	Concept Evaluation
CFD	Computational Fluid Dynamics
CM	Cruise Missile
CNA	Center for Naval Analyses
COEA	Cost and Operational Effectiveness Analyses
COMMARSYSCOM	Commanding general, Marine Corps Systems Command
COMOPTEVFOR	Commander Operational Test and Evaluation Force
CRC	Control and Reporting Center

DDR&E	Director Defense Research and Engineering
DIS	Distributed Interactive Simulation
DMSO	Defense Modeling and Simulation Management Office
DOF	Degree of Freedom
DON	Department of the Navy
DSB	Defense Science Board
DSBA	Distributed Simulation Based Acquisition
DSI	Defense Simulation Internet
DV/EMD	Demonstration/Validation - Engineering/ Manufacturing/Development
EADSIM	Extended Air Defense Simulation
ECSEL	Electronic Combat Simulation and Evaluation Labor
EMD	Engineering/Manufacturing Development
EO	Electro Optical
ESL	Encounter Simulation Laboratory
EWSSA	Electronic Warfare System Support Activities
HIL	Human in the Loop
HWIL	Hardware In The Loop
IPD	Integrated Product Definition
IPT	Integrated Product Team
IRIS	Internetting Range Interactive Simulation
IST	Institute for Simulation and Training, University of Central Florida
JADS	Joint Advanced Distributed Simulation
JAST	Joint Advanced Strike Technology
JETTA	Joint Environment for Test Training and Analysis
JMA	Joint Mission Assessment

JSIMS	Joint Simulation System
JTF	Joint Task Force
JWC	Joint Warfighting Center
LAM	Louisiana Maneuvers
MARCORSYSCOM	Marine Corps Systems Command
MCM	Mine Counter Measures
MCMSMO	Marine Corps Modeling and Simulation Management Office
MCOTEA	Marine Corps Operational Test and Evaluation Activity
MESA	Missile Engagement Simulation Arena
M&S	Modeling and Simulation
NAVSEA	Naval Sea Systems Command
NAWC-TSD	Naval Air Warfare Center - Training Simulation Division
NRAC	Naval Research Advisory Committee
NRL	Naval Research Laboratory
NSC	National Simulation Center
NSWC	Naval Surface Warfare Center
NTF	National Test Facility
ONR	Office of Naval Research
OPEVAL	Operational Evaluation
OPTEC	Operational Test and Evaluation Command
OT&E	Operational Test and Evaluation
P3I	Pre-Planned Product Improvement
POM	Program Objectives Memorandum
R^3B	Resource Requirements Review Board
RADM	Rear Admiral

RF	Radio Frequency
R&D	Research and Development
SAIC-CSSTSS	Science Applications International Corporation
SBD	Simulation Based Design
SBD/M	Simulation Based Design/Manufacturing
SC21	Surface Combatant for the 21st Century
SIMNET	Simulation Network
SMART	Susceptibility Model and Test Range
STOW	Synthetic Theater of War
STRICOM	Simulation, Training and Instrumentation Command
T&E	Test and Evaluation
TADSIM	Theater Air Defense Simulation
TBM	Theater Ballistic Missile
TBMD	Theater Ballistic Missile Defense
TRAC	Training and Doctrine Command Analysis Center
TRADOC	Army Training and Doctrine Command
TTES	Team Target Engagement System
UAV	Unmanned Aerial Vehicle
USA	United States Army
USAF	United States Air Force
USMC	United States Marine Corps
VV&A	Verification Validation and Accreditation
WEPTAC	Weapons and Tactics Analysis Center