Topic B2.
V&V for M&S with hardware or systems in the loop (including all manifestations of distributed simulations)

Foundations for V&V in the 21st Century Workshop (Foundations '02)

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Validation of Hardware-In-The-Loop (HWIL) and Distributed Simulation Systems

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The authors for this paper have considerable experience supporting HWIL and distributed simulations within the DoD, and whose VV&A experience and roles cover the gamut from M&S VV&A policy formation to V&V planning and activity execution.

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Agenda

I. Introduction

II. HWIL and Distributed Simulation Systems VV&A Processes, Techniques and Technologies

III. VV&A Issues Facing HWIL and Distributed Simulation Systems

IV. Major VV&A Research Areas for HWIL and Distributed Simulation Systems

V. Conclusions

Agenda

Introduction

Thesis

The need for explicit verification, validation, and accreditation (VV&A) of hardware-in-the-loop models and simulations (M&S), distributed simulations, and their simulation components, particularly within the Department of Defense (DoD) environment is **clear**.

What processes, techniques, and tools, beyond those that are normally available for VV&A are necessary for support of this significant class of simulation assets is **not entirely clear**.

Introduction

Objective-Systems Engineering Environmental Context:

- Resource constraints, range and treaty limitations, environmental impacts of physical testing and scheduling requirements come together to force decision makers to rely less on expensive field and operational testing, and more on the results of simulation-based systems analyses.
- Many new M&S hardware-in-the-loop (HWIL) and distributed simulation tools are being developed in response to this circumstance to support analysis, research and development programs, test and evaluation, and training.

Introduction

M&S VV&A Operational Context:

- The essence of V&V is to establish the degree to which decision-makers may have confidence in the results of studies and analyses conducted using the pertinent M&S tools:
  - Much of the V&V process consists of generating, organizing, and reporting in an auditable form the evidence that may be developed or originates in the system development, test, and configuration management activities.
  - The special concern of this paper is to consider these special qualities of HWIL and distributed simulation assets, to analyze the peculiar requirements for VV&A processes, practices, and tools, and to identify both the problems and opportunities of dealing with VV&A of these special systems.

Introduction

HWIL and Distributed Simulation System State of Practice:

- The V&V strategies and methodologies presented have been successfully used by a number of organizations:
  - The VV&A state-of-practice for HWIL and distributed simulation is detailed through the actual experiences of representative M&S development organizations from the Army, Navy, and Air Force.
- Our focus:
  - Relating the hard-lessons learned from V&V practitioners in the field operating within cost and schedule constraints.

Scope

- This paper addresses the systematic verification and validation of HWIL, software-in-the-loop (SWIL), and distributed simulations, which often-incorporate complex, all-digital M&S, linked test beds, and associated test resources.
- The definitions of key M&S VV&A terms are provided and an assessment of the current DoD state-of-practice is discussed.
- Key policies and practices are reviewed.
- A few critical concepts are introduced which we believe are essential for establishing tailored, sufficient VV&A Plans for HWIL and distributed simulations, which can support decision makers and Accreditation Authorities in managing risks inherent in the use of simulations to solve their day-to-day problems.

Scope

- We will look at three HWIL facilities that have distinctive emphases (product areas):
  - Army facility focused mainly on missile systems:
    - US Army Aviation and Missile Command Research, Development, and Engineering Center (AMCRDEC)
  - Navy facility which deals primarily with underwater and surface operations:
    - US Navy Undersea Warfare Center Weapons Analysis Facility (WAF)
  - Air Force facility having an electronic warfare (EW) emphasis:
    - US Air US Air Force Electronic Warfare Evaluation Simulation (AFEWES)
- Objective:
  - V&V Issues characteristic of HWIL and distributed simulation frameworks will be identified and ameliorative strategies will be proposed.
  - Potential research topics and technologies to advance the state-of-the-art for validation of HWIL and distributed simulations will be addressed.

Key References and Resources

- General definitions that should be used in developing HWIL and distributed simulation VV&A programs:
  - **VERIFICATION** - The process of determining that a model implementation accurately represents the developer's conceptual description and specifications ***(…is it what We intended?)***
  - **VALIDATION** - The process of determining the degree to which a model (or simulation) is an accurate representation of the real world from the perspective of the intended uses of the model ***(…how well does it represent what We care about?)***
  - **ACCREDITATION** - The official certification that a model or simulation is acceptable for use for a specific purpose ***(…should Our organization endorse this simulation?)***

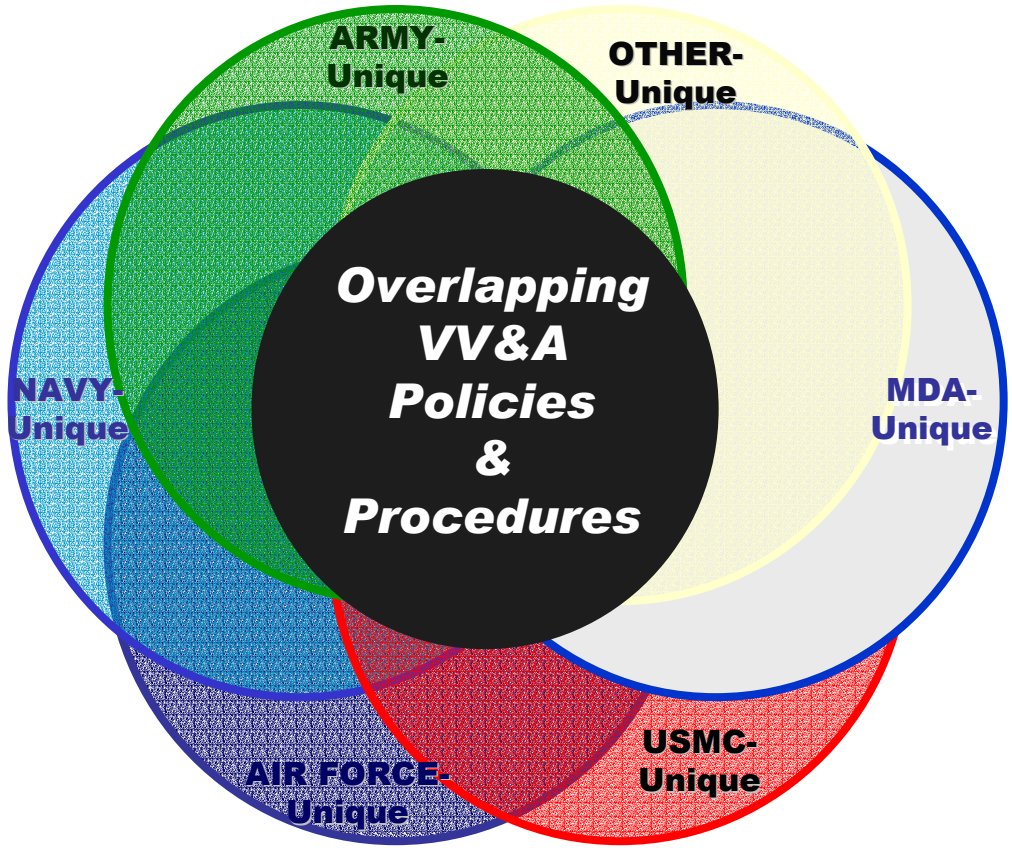
Key References and Resources

Selected Department of Defense M&S VV&A Guidance

DoD COMPONENT	POLICY GUIDANCE	POCs
Department of Defense	▪ Department of Defense Directive 5000.59 ▪ Department of Defense Directive 5000.61 ▪ Department of Defense VV&A Recommended Practices Guide	Defense Modeling and Simulation Office (DMSO)
Joint Chiefs of Staff	▪ Chairman of the Joint Chiefs of Staff Instruction 8104.01 ▪ Joint Staff Instruction 8510.01	Joint Chiefs of Staff (J-8)
US Army	▪ Army Regulation 5-11 ▪ Department of the Army Pamphlet 5-11	Army Modeling and Simulation Office (AMSO)
US Navy and Marine Corps	▪ Secretary of the Navy Instruction 5200.38 ▪ Secretary of the Navy Instruction 5200.40 ▪ Department of the Navy Modeling and Simulation VV&A Implementation Handbook	N81 Navy Modeling and Simulation Management Office (NAVMSMO)
US Air Force	▪ Air Force Instruction 16-1001	XOC
Missile Defense Agency	▪ Missile Defense Agency Directive 5011	MDA / TEM

Key References and Resources

- Using VV&A guidance which is consistent among various participants builds consensus.
- Agency unique guidance issues will need to be resolved during VV&A program execution.
- Consequently, some tailoring of VV&A plans may be necessary to accommodate these differences.
  - Of interest are not just the V&V requirements, methodologies and techniques that may be in common, but those special areas of interest that are resident within only a specific Service or agency.



VV&A Policy Paradigm

Paper's Organization and Structure

- This paper was structured to speak:
  - To VV&A processes, techniques and technologies for HWIL and distributed simulation systems (see Section 2).
  - To major VV&A issues related to the HWIL and distributed simulation systems (see Section 3).
  - Major VV&A research areas for HWIL and distributed simulation systems will be collectively addressed. Specific recommended research areas required for significant progress in HWIL and distributed simulation VV&A will be described. (see Section 4)
  - The VV&A of HWIL and distributed simulations and the challenges in their use are extended to the broader M&S domain and major points of the paper will be summarized and conclusions provided (see Section 5).
  - A bibliography and list of references, which address HWIL and distributed simulation VV&A (see Section 6).
  - Author and contributor experiences relevant to HWIL and distributed simulation systems VV&A are noted (see Section 7).

Agenda

I. Introduction

II. HWIL and Distributed Simulation Systems VV&A Processes, Techniques and Technologies

- 2.1 General HWIL and Distributed Simulation VV&A Management Strategies
- 2.2 US Army AMCOM HWIL & Distributed Simulation Systems
- 2.3 Department of Navy HWIL & Distributed Simulation Systems
- 2.4 US Air Force Electronic Warfare Evaluation Simulator Test Facility

III. VV&A Issues Facing HWIL and Distributed Simulation Systems

IV. Major VV&A Research Areas for HWIL and Distributed Simulation Systems

V. Conclusions

VV&A Processes, Techniques and Technologies

- We will address a few processes that we feel are generally relevant to the management of HWIL and distributed simulation VV&A and that are of particular value given the nature of this special class of simulations.

- We will review the processes, techniques and technologies that characterize the VV&A operational environments of each of the contributing authors.

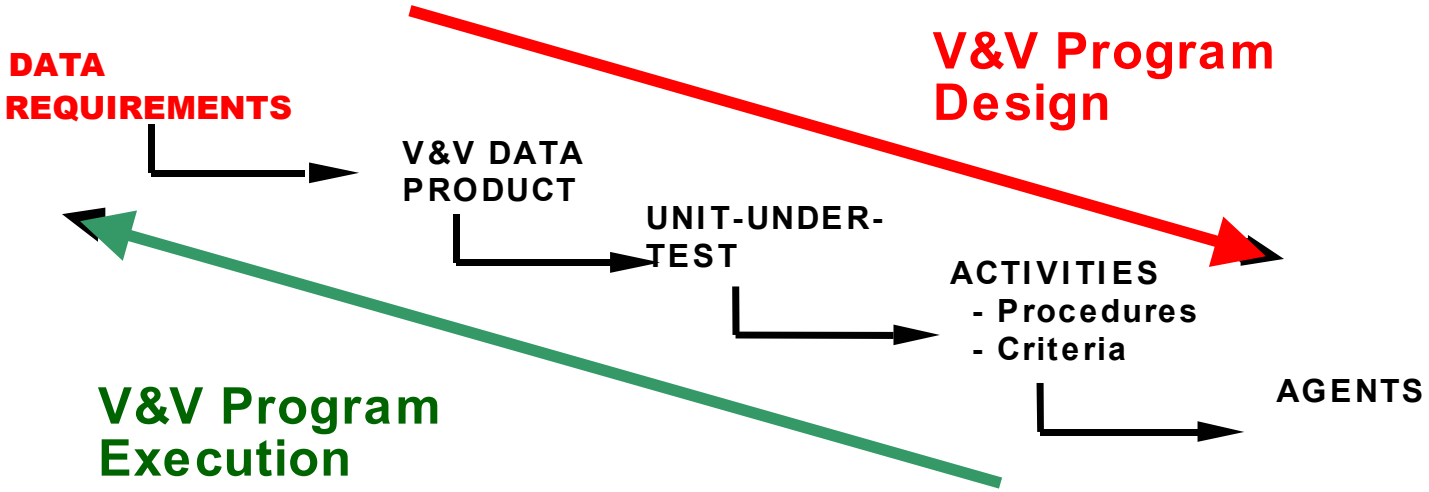
General HWIL and Distributed Simulation VV&A Strategies

- There are four key concepts and operational strategies that should comprise the foundation of HWIL and distributed simulation VV&A planning and execution:
  1. Requirements Driven Program
  2. V&V Evaluation Activity Space
  3. Evaluation Kernel Process-Model
  4. Managed Investment

General HWIL and Distributed Simulation VV&A Strategies

1. *Requirements Driven Program*

- Requirements for HWIL and distributed simulation V&V programs are best driven from the top-down, while V&V program execution is best built from the bottom-up.



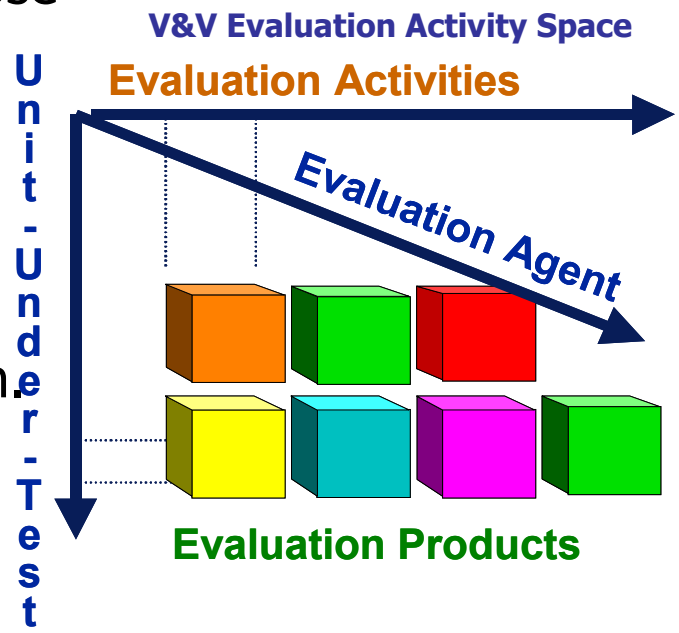
HWIL and Distributed Simulation V&V Requirements Planning and Execution

- The focus is not requirements compliance, but information gathering to support the government Accreditation Authority in accrediting the HWIL or distributed simulation and resultant data for use.

General HWIL and Distributed Simulation VV&A Strategies

2. *V&V Evaluation Activity Space* (1 of 4)

- Systems engineer's multi-dimensional view of the enterprise whose dimensions exhaust the important attributes of the conceptual space.
  - Here we posit an "evaluation space" whose (relatively orthogonal) dimensions are:
    1) V&V activities
    2) V&V agents
    3) Units-under-test
  - V&V products comprise the evidence for user acceptance and formal accreditation. Anticipated classes of data products that may be considered in the accreditation decision include:
    1) SW V&V Administrative Documentation
    2) Simulation System Documentation
    3) Evaluation Documentation
    4) Other Technical Reports and Data



General HWIL and Distributed Simulation VV&A Strategies

2. *V&V Evaluation Activity Space* (2 of 4)

- **Activities** are selected V&V techniques and assessment procedures to be applied to relevant HWIL or distributed simulation UUTs to generate V&V data of interest.

- Several considerations are pertinent to HWIL and distributed VV&A activity planning which are extensible to M&S VV&A planning in general:

VERIFICATION:	VALIDATION:
- Documentation Assessment	- Sensitivity Analyses
- Requirements Trace	- Face Validation
- Methodology Review	- Benchmarking
- Code Walkthrough	- Test / Field Data Comparison
- Data Certification...	- Peer / Red-Team Review...

Potential V&V Activity Classes

  - Activity definition requires careful specification of the evaluation procedures and criteria.
  - The details of activity specification effectively define the V&V program.
  - Activity flow and duration determines the program schedule
  - Assessment activities determines the level-of-effort (LOE) and associated resource requirements.
  - Every V&V assessment activity should be required to yield a valuable data product that facilitates user understanding, acceptance and accreditation.

General HWIL and Distributed Simulation VV&A Strategies

2. *V&V Evaluation Activity Space* (3 of 4)

- **Agents** are those principals that serve at the behest of the simulation sponsor and, or other Accrediting Activity; execute the planned V&V and test assessments; and generate the reports that serve to document the activity.
  - Coordination among this diverse set of potential V&V agents is required to execute a balanced, comprehensive VV&A program.
  - A ***Lead V&V Agent*** should be assigned responsibility for coordinating the overall VV&A program execution.

General HWIL and Distributed Simulation VV&A Strategies

2. *V&V Evaluation Activity Space* (4 of 4)

- **Units-under-test (UUTs)** are those components of the HWIL or distributed simulation to which V&V evaluation activities are applied and upon which judgments are made.

- Because the variety of entities that comprise a HWIL or distributed simulation is quite large, and because the items are themselves so disparate, a variety of evaluation procedures are required.
- Explicit identification of UUTs within the VV&A Plan is therefore imperative.

SYSTEM SOFTWARE
- System Configuration Code
- Framework
- Common Model Set Code

SYSTEM CAPABILITY
- Experiment Preparation
- Experiment Execution
- Experiment Analysis

ANALYSIS TOOLS

SYSTEM MODELS
- Common Model Set Algorithms
- Specific System Representations (SSRs)

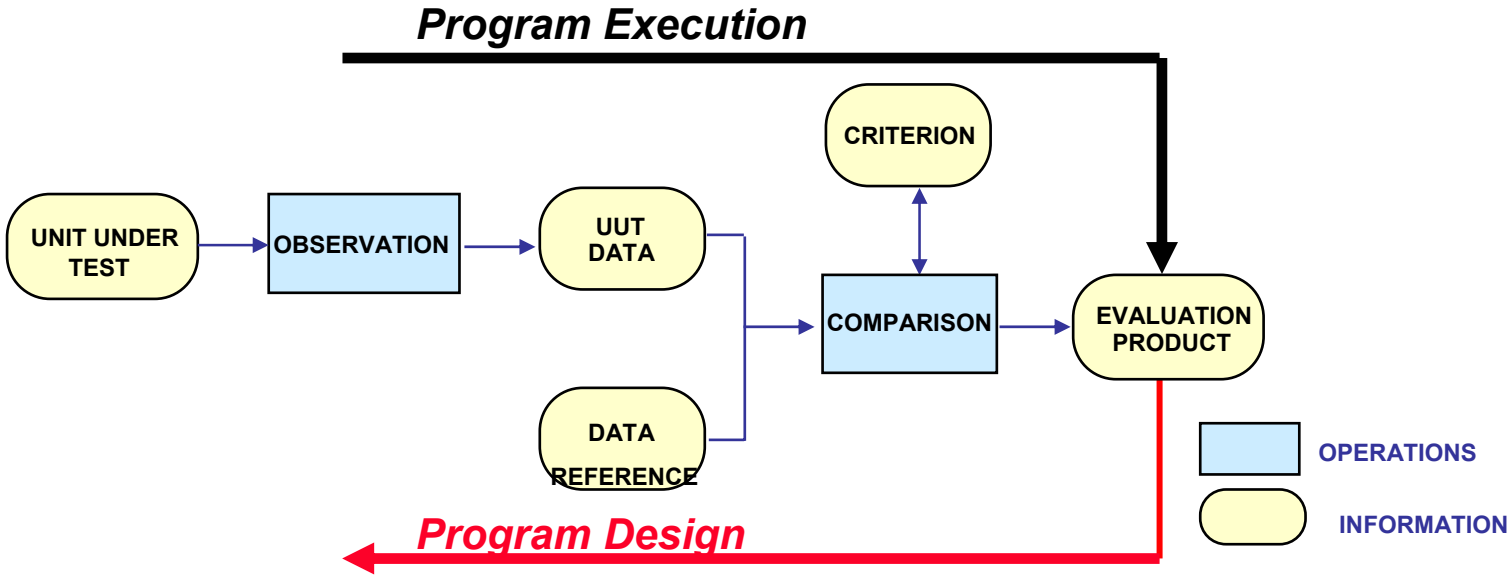
DATA
- Rulesets
- Characteristics Data
- Gameboard Data
- Scenarios

DOCUMENTATION

Candidate HWIL UUTs

General HWIL and Distributed Simulation VV&A Strategies

3. *Evaluation Kernel Process-Model*

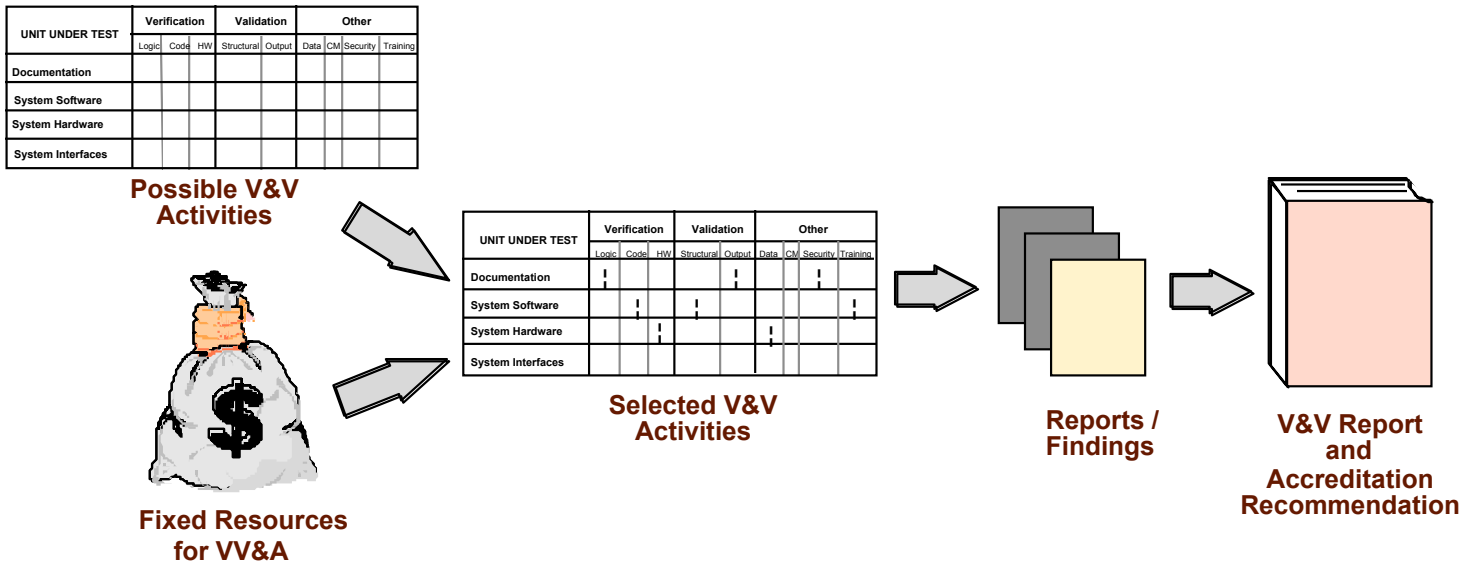


- This evaluation process model involves the following components and associated activities:
  - An observation of a M&S UUT and its attributes of particular interest.
  - A comparison of derived data pertinent to the UUT under consideration to reference data established by independent means.
  - Subject to criteria for acceptance.
  - Generation of an evaluation product (results).

General HWIL and Distributed Simulation VV&A Strategies

4. *Managed Investment* *(1 of 2)*

- Managed investment is the execution, from all the possible candidate V&V activities, of a carefully selected subset of V&V activities:
  - ***Offering the "best return on investment"*** by providing the essential information necessary for V&V reports findings.
  - ***Providing the required evidence*** supporting the accreditation review decisions of Service and DOD agencies and activities.



General HWIL and Distributed Simulation VV&A Strategies

4. *Managed Investment* *(2 of 2)*

- Cost as an independent variable must be considered during the selection and execution of the V&V assessment activities.
- The V&V activities subset is chosen based upon the:
  - Assessment data needs of the Accreditation Authority.
  - Realities of the program (schedule).
  - Fixed resources (budget) available for assessment and V&V activities.
- A managed investment (progressive outlay) strategy addresses the problem of specifying scope and detail of V&V activities and allows for a near-optimal investment for V&V activities and products for an economically constrained environment.

US Army AMCOM HWIL & Distributed Simulation Systems

AMRDEC HWIL and Distributed Simulation VV&A Strategies

The Systems Simulation and Development Directorate (SSDD) of the Research, Development, and Engineering Center (RDEC) of the U.S. Army Aviation and Missile Command (AMCOM) provides a range of simulation support services to Army missile and aviation developers.

US Army AMCOM HWIL & Distributed Simulation System

Context

- The mission of AMRDEC SSDD is stated (in part) as:

  "*…to assist in the evaluation and analysis of new weapon systems, provide technical and simulation support to all elements of the parent organization, project managers, and other government agencies. To conduct weapon systems research, exploratory and advanced development and provide engineering and scientific expertise.*"

Where is AMCOM RDEC Today? (1 of 14)

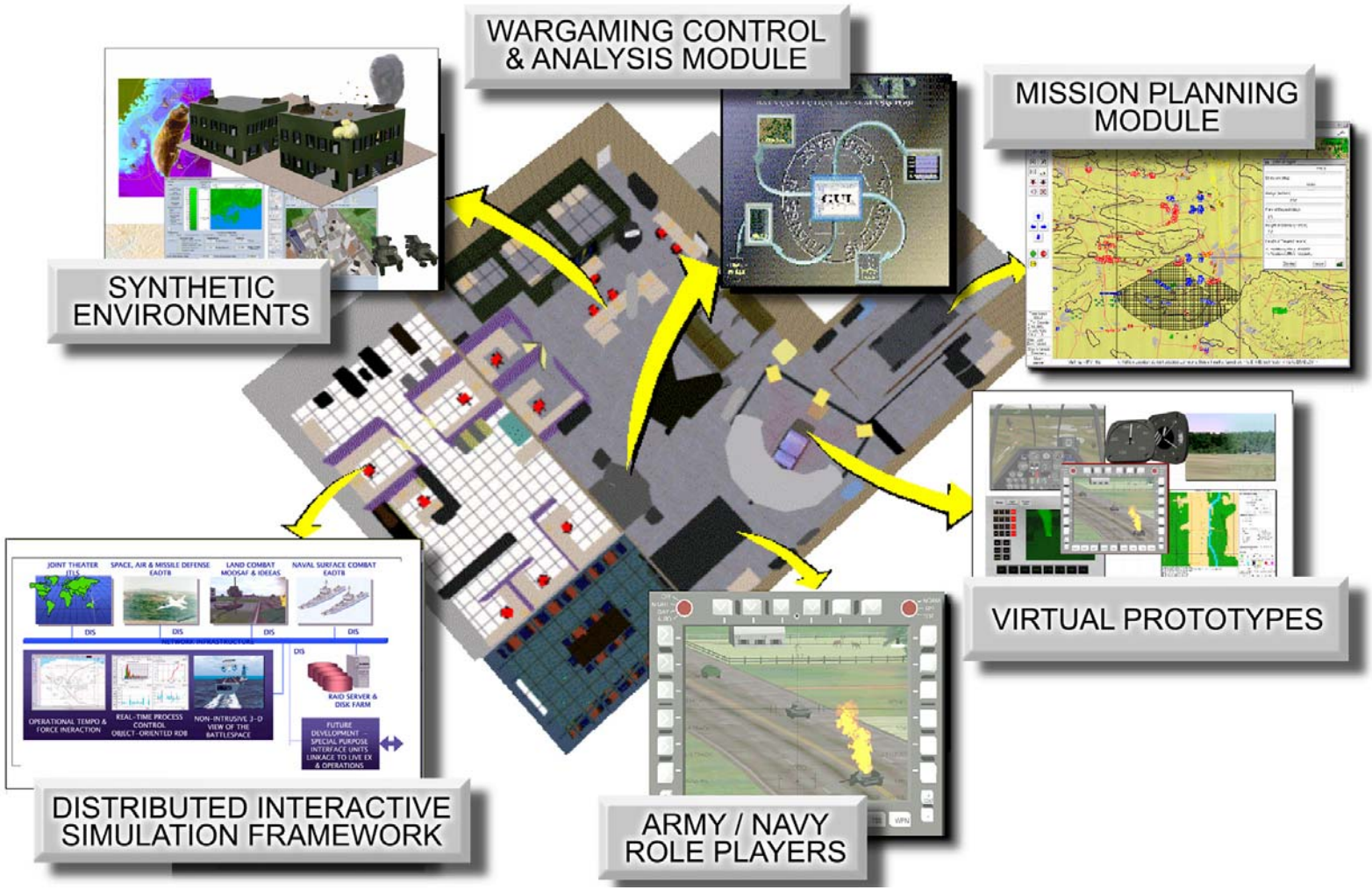
Description of AMCOM Objective Systems

- SSDD HWIL simulation activities range from:
  - Applications to air-surface submunitions and missiles (BAT and LONGBOW HELLFIRE).
  - Air defense surface-air weapons (STINGER, PATRIOT PAC-3).
  - Ballistic missile defense systems (THAAD, Ground-based Midcourse Defense Segment).
- HWIL simulation activities are conducted in the AMRDEC Advanced Simulation Center (ASC) that consists of 10 individual simulation facilities.

US Army AMCOM HWIL & Distributed Simulation Systems

Where is AMCOM RDEC Today? (2 of 14)

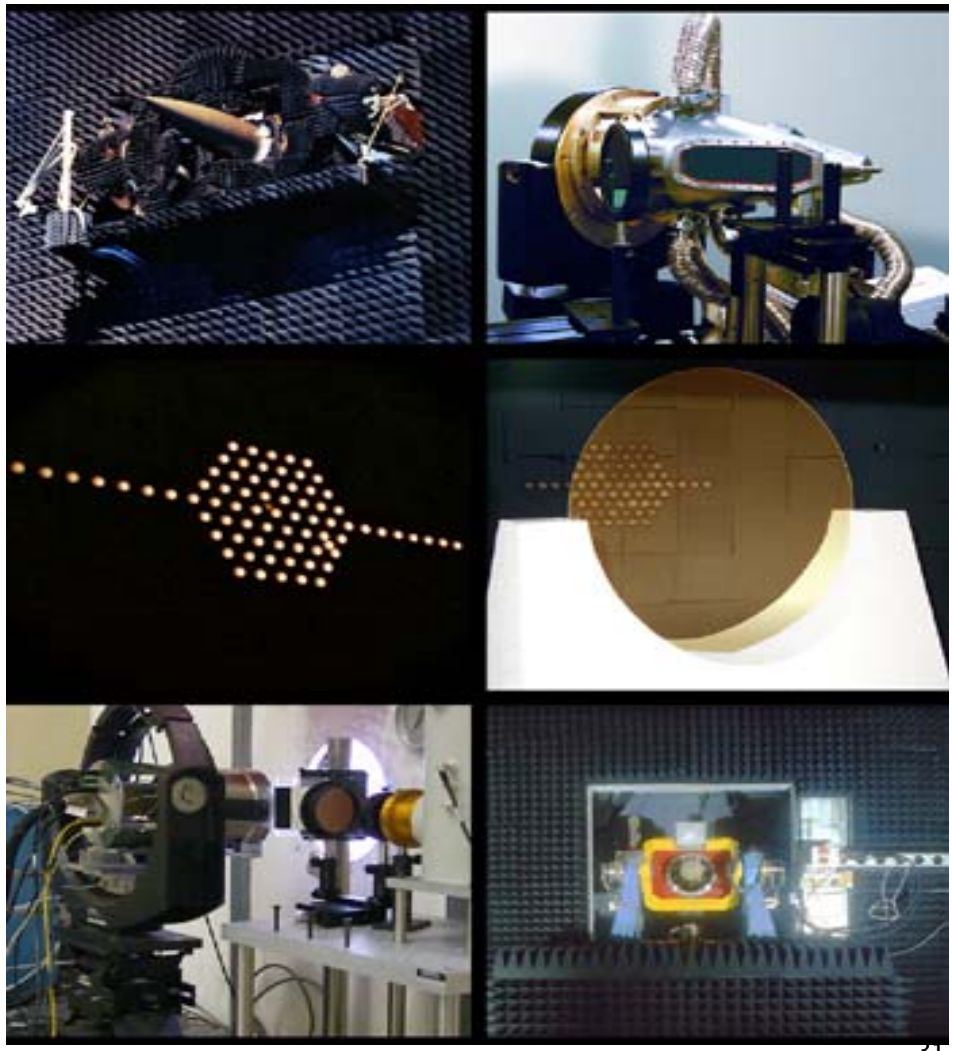
Example APEX Laboratory



Where is AMCOM RDEC Today? (3 of 14)

ASC Activities and Equipment

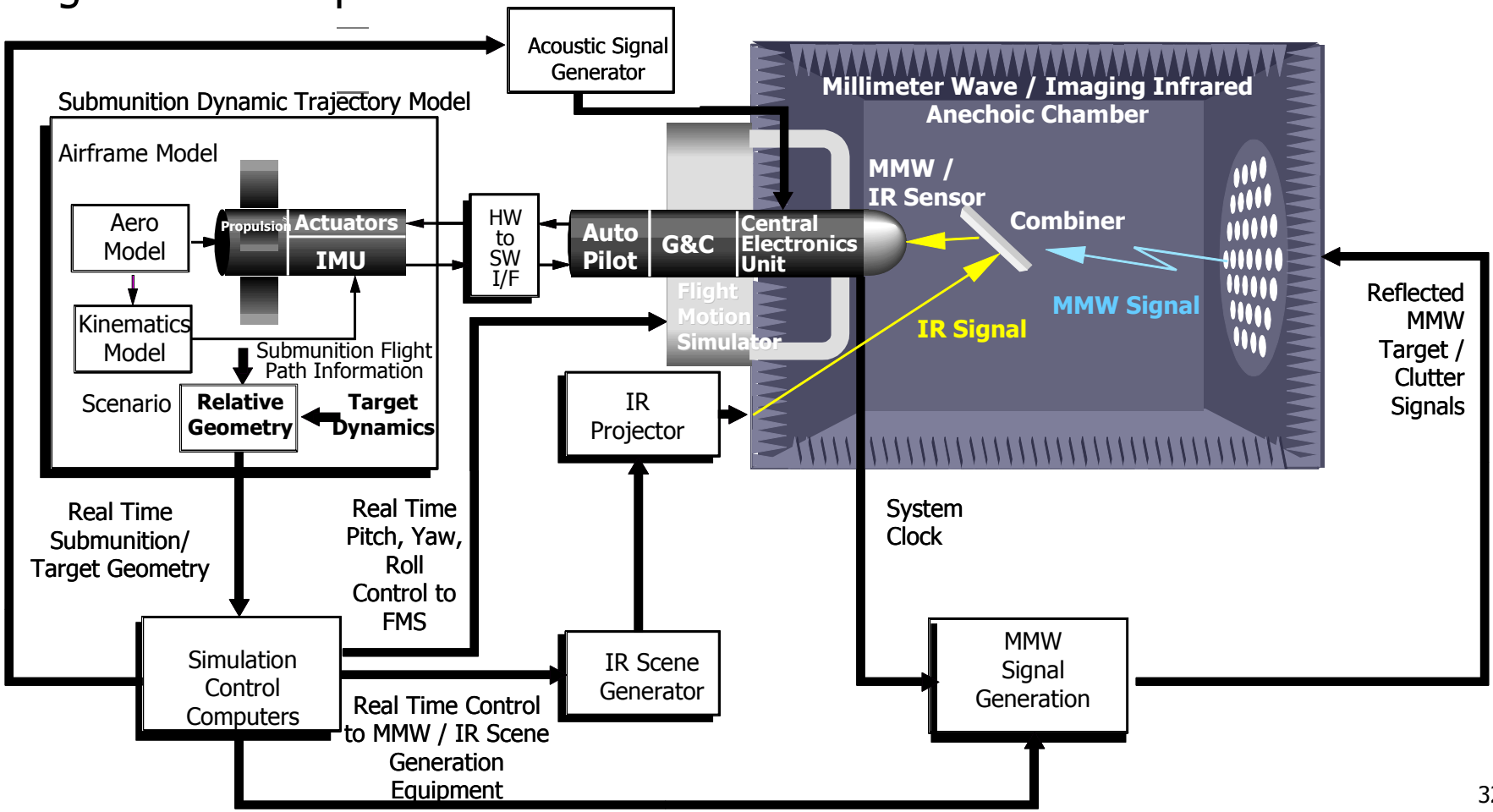
- Distributed simulations associated with the Advanced Prototyping, Engineering, and eXperimentation (APEX) Laboratory consist of:
  - Federated simulations interacting with federates at other Army and DoD facilities using Distributed Interactive Simulation (DIS) and High Level Architecture (HLA) standards.
- Provide an integrated virtual battlefield for system performance and battlefield effectiveness studies.



US Army AMCOM HWIL & Distributed Simulation System

Where is AMCOM RDEC Today? (4 of 14)

- Example block diagram of one of the simulation facilities designed for evaluating multi-spectral missiles and submunitions illustrates the general concept of all ASC facilities.



Where is AMCOM RDEC Today? (5 of 14)

Fundamental Strategies For Business Operations

- SSDD provides simulation support to a wide range of weapon system developers to assist in system design and acquisition decisions.
- Simulation support requirements to project managers are usually defined by a Simulation Support Plan with an associated VV&A Plan tailored to the specific weapon system under development:
  - Intended to apply throughout the system life cycle, from initial concept and risk reduction phases through fielding and final disposition.

Where is AMCOM RDEC Today? (6 of 14)

V&V Techniques & Technologies

- Validation of HWIL simulations is based on measured data from a range of measurement programs, including:
  - Target signature measurements.
  - Captive-carry of sensors and seekers.
  - Sled and flight tests of missiles and submunitions.
- Test programs are structured to yield data that support the simulation validation process.
- The validation process for an overall system simulation is then a piecewise operation:
  - The simulation system is divided into sub-systems and a validation process is applied to each sub-system individually before applying an overall system validation process.

Where is AMCOM RDEC Today? (7 of 14)

V&V Techniques & Technologies

- The validation process then compares simulation data with measured data to determine whether the validation criteria are met.
- After each individual model or simulation is verified and validated, the integrated suite must undergo V&V to ensure a level playing field, data consistency, synchronization, and federation-level performance.
- Accreditation is usually performed informally for a specific instance of a distributed simulation experiment or analysis series, based on customer needs and measures of effectiveness.

Where is AMCOM RDEC Today? (8 of 14)

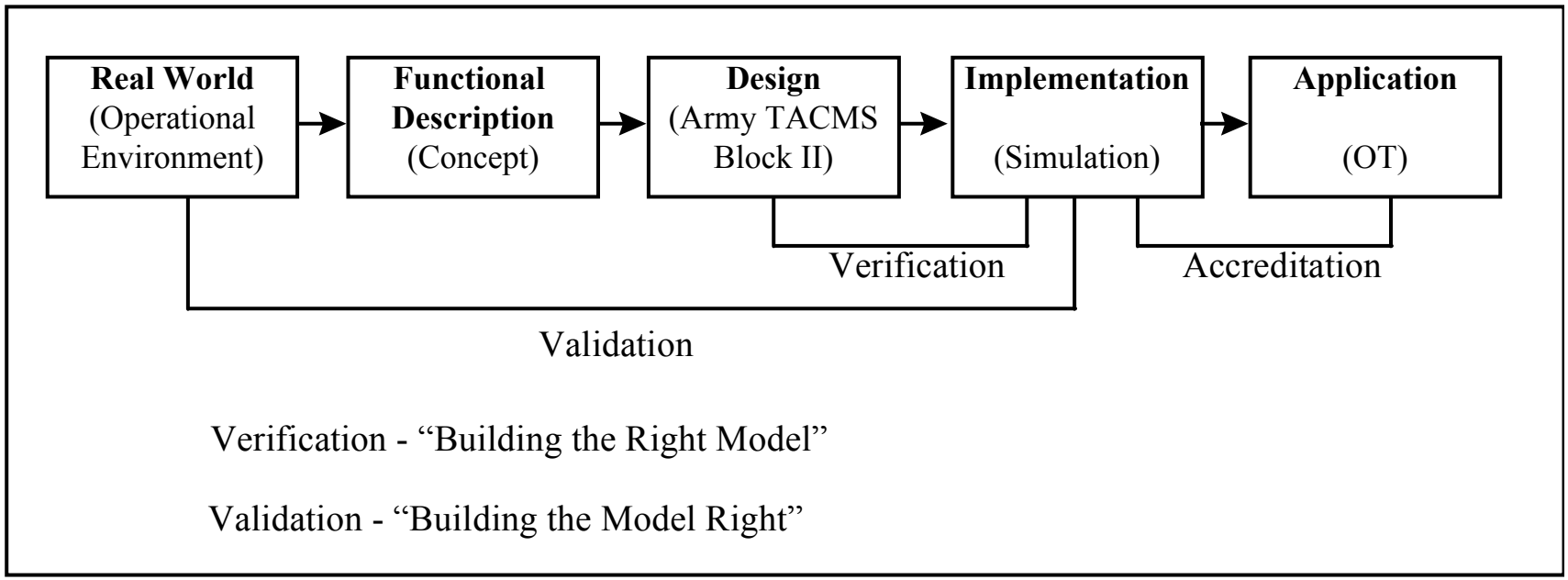
V&V Process Maturity

(1) Existing AMCOM HWIL and Distributed Validation Processes

- Verification is a more straightforward process than validation.
- Focus is ensuring that the simulation is implemented correctly by various means including:
  - Design and code "walkthroughs".
  - Numerical calculation checks.
  - "Sanity" checks.
  - Isolation of subsystems and measurement of their responses.
  - "Handshaking" across interfaces.
  - Timing checks.
- Validation is a more system-specific process, with approaches tailored to the characteristics of each specific weapon system.

Where is AMCOM RDEC Today? (9 of 14)

V&V Process Maturity



US Army AMCOM HWIL VV&A Process (with ATACMS as the Instance)

Where is AMCOM RDEC Today? (10 of 14)

V&V Process Maturity

(2) Validation Procedures and Tools

- Validation procedures for HWIL simulations within SSDD have not been systematized such that a general "across the board" procedure can be applied to any or all weapon systems.
- Distributive simulation VV&A efforts within the APEX lab utilizes:
  - COTS tools to visualize and analyze virtual environment events and visual models.
  - AMRDEC-developed Data Collection and Analysis Tool (DCAT) to monitor real-time and post-experiment battlefield statistics.

Where is AMCOM RDEC Today? (11 of 14)

V&V Process Maturity

(3) The Consequential Effects Of This Circumstance

- For VV&A of HWIL simulations there is scope for attempting to standardize simulation validation.
- For distributed simulation VV&A, the use of tools and processes has allowed the APEX lab to tailor the VV&A process, rely on previous legacy V&V, and also rely on informal accreditation.

Where is AMCOM RDEC Today? (12 of 14)

Measures of Success

- The most basic measure of success of a validation effort is that of a successful accreditation by the accrediting agent for the subject simulation.
- Successful completion of the validation process leads to the accreditation process.
- Identifiable and complete documentation trail of the V&V processes is required to establish the accreditation and, once achieved, accreditation allows the simulation results to be accepted as credible performance predictors of the subject system.
- The ultimate measure of success is approval by the accrediting agent.

Where is AMCOM RDEC Today? (13 of 14)

Synopsis / Summary

- Over the the past 25 or so years, SSDD has implemented a large number of simulations of various types.
- Significant numbers have undergone a formal VV&A process.
- The determining factor in whether VV&A is applied centers on the longevity of the system's life cycle and the level of funding for the system.
- In each case the validation has been tailored for the specific subject weapon system.

Where is AMCOM RDEC Today? (14 of 14)

Synopsis / Summary

- APEX Lab VV&A experience can be traced over the last eight years, beginning with the A2 ATD program, through the stringent live/virtual requirements of RFPI, and into current HLA federation initiatives.
- During A2 ATD, AMSAA/ATEC experts spent hours after each record run comparing test results to predictions, reviewing the run for anomalies, and cross-referencing V&V tests, before accrediting each run as valid.
- This led the APEX lab to develop DCAT, which automated the battlefield statistics process to monitor the experiment in real-time and even make performance corrections on-the-fly, a critical capability when performing live/virtual experiments with 1500 soldiers in the field.
- This automated process is now facilitating a variety of customers, providing analysis-quality results from virtual environments.

Where is AMCOM RDEC Going? (1 of 2)

Intention and Rationale

- The intention of the CSF is that a common approach to validation will arise from the effort and that this common approach will result in improved an overall validation process.

How We Are Going To Get There?

- For HWIL simulations, a process of re-education of the engineering personnel performing the simulations to demonstrate the benefits of an improved validation process.
- For the distributed simulations conducted by APEX, changes in the process will be driven by centralized analysis requirements from organizations.

Where is AMCOM RDEC Going? (2 of 2)

Expectations?

- If the new validation processes are genuinely an improvement they will find ready acceptance among the simulation practitioners of SSDD.

Why Do We Want To Get There?

- Improved validation processes will significantly improve the capabilities of SSDD and hence benefit the Army's Simulation-Based Acquisition initiative.

What Do We Gain From Getting There?

- Better service to SSDD customers in the form of improved simulation support, including faster response and greater credibility for simulation results.

Department of Navy HWIL & Distributed Simulation Syste

NAVSEA
NAVAL SEA SYSTEMS COMMAND
Undersea Warfare Center

NAVSEA
NAVAL SEA SYSTEMS COMMAND
Under

WAF

In this portion of the briefing, we will look at the Department of Navy HWIL VV&A processes from two very different perspectives.

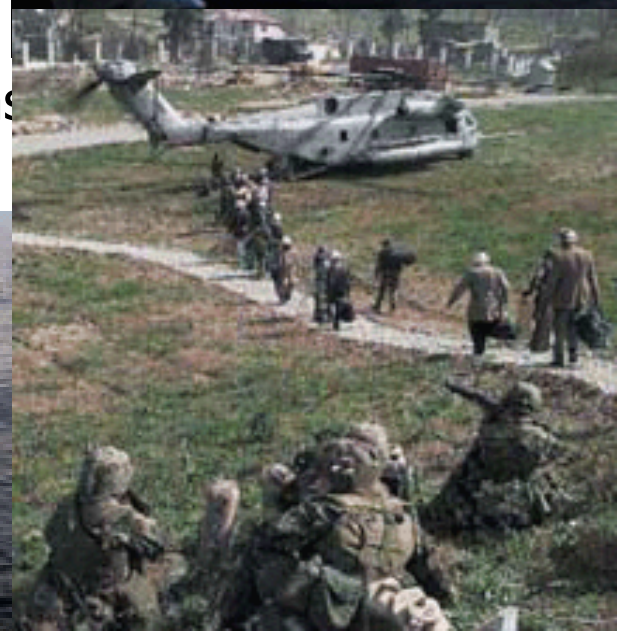
- **Address the broader Navy concerns spanning the full spectrum of simulations encountered within that Department.**
- **Attention given to the Weapons Analysis Facility (WAF) – a HWIL simulation for undersea weapon systems (specifically torpedoes and countermeasures).**

Department of Navy HWIL & Distributed Simulation Syste

NAVSEA
NAVAL SEA SYSTEMS COMMAND
Undersea Warfare Center

Context (1 of 2)

- The Navy is a broad and varied community embracing an extremely large mission space and spanning many operational domains.
  - It is unique in that it operates in the air, on the land, on the sea, and under the sea.
- To perform effectively against highly capable threats while immersed deeply within their operational and environmental context, Naval platforms are necessarily sophisticated, robust, and interdependent systems of systems



Context (2 of 2)

- Below is a poignant and quantifiable illustration of the magnitude of the complexity of Naval Systems.

ATTRIBUTES	M-1 MAIN BATTLE TANK	BOEING 777 AIRPLANE	VIRGINIA SSN
Weight (tons)	65	250	7,000
Length (feet)	25	200	360
Number of systems	25	40	200
Number of components	200	35	20,000
Number of suppliers	600	550	3,600
Crew size	4	10	133
Patrol duration (hrs)	24	8 to 14	2,000
Number of parts to assemble	14,000	100,000	1,000,000
Number of man-hours / unit to assemble	5,500	50,000	8,000,000
Production time (months)	7.5	14 ('97)	55
Production rate (units/yr)	600	72 ('97)	2 to 3

Comparison of System Complexity Across Domains

Where Is The Navy Today? (1 of 18)

- To understand the Navy's approach to the verification, validation, and, ultimately, accreditation of hardware-in-the-loop simulation systems, we must ask ourselves three questions:

1. What is a hardware-in-the loop simulation?

- It is a type of simulation that contains all or part of an operational system.
- By "in the loop" we mean that the hardware is not simply being stimulated in an "open loop" fashion, but rather it is reacting to the simulated world around it, and consequently, altering the simulated world in a "closed loop" fashion.

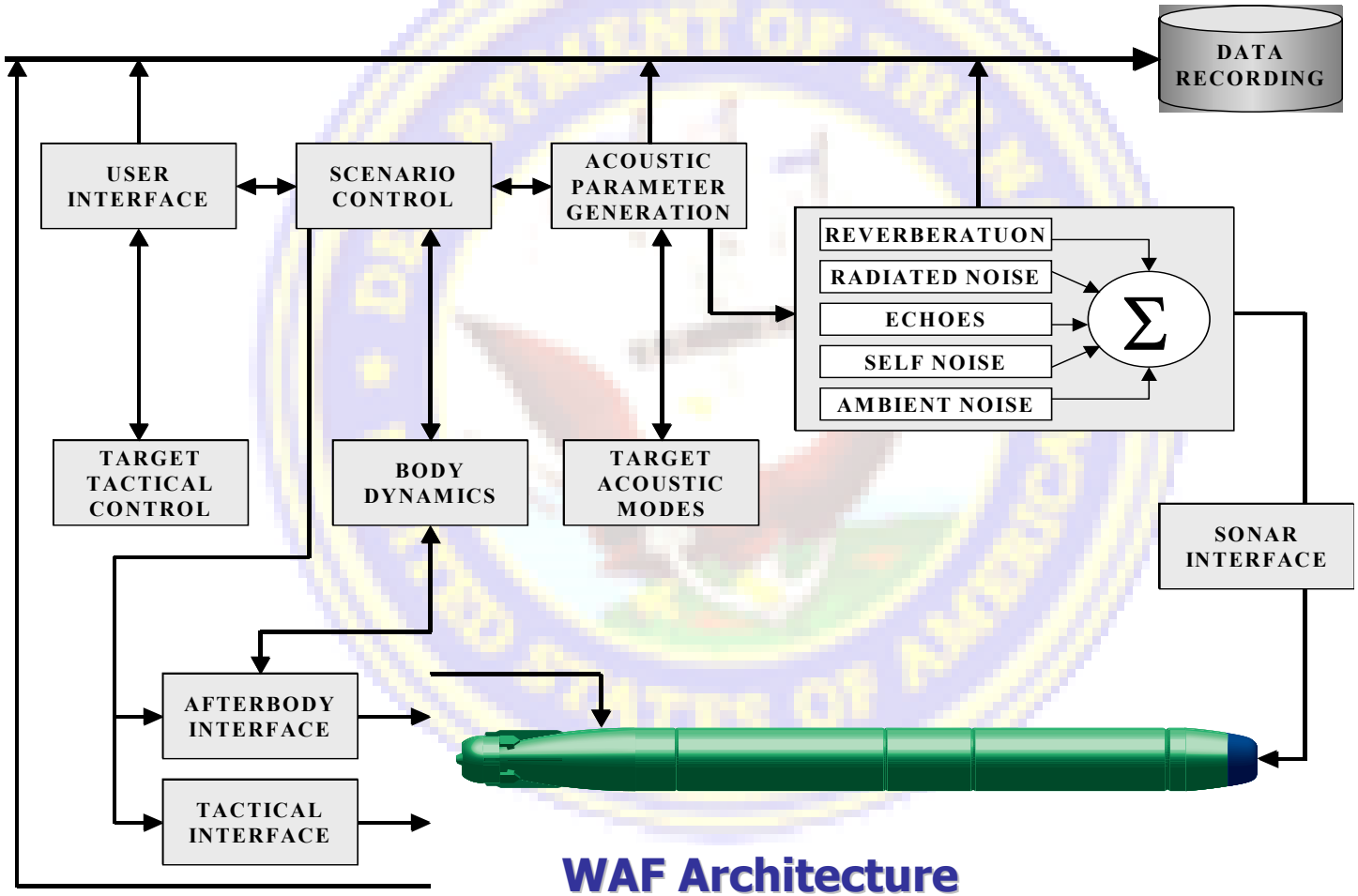
2. What are the defining characteristics of hardware-in-the-loop simulations?

- They contain all or part of a piece of operational hardware. Hardware in the simulated environmental loop leads to some very important considerations?
  - Typical operational systems, at least those of any substantive degree of complexity, understand time as constant, monotonically increasing.
  - The interfaces to the operational system are defined, not by the simulation engineer, but by the engineer responsible for the operational system.
  - The operational hardware is a sample of one in the inventory space.
  - The hardware "is what it is".

3. What are the applications for hardware-in-the-loop simulations?

Where Is The Navy Today? (2 of 18)

- The WAF at NUWC is a HWIL simulator for torpedoes, undersea acoustic countermeasures, and eventually, unmanned undersea vehicles.



WAF Architecture

Where Is The Navy Today? (3 of 18)

- The Synthetic Environment Tactical Integration (SETI) program connects the hardware-in-the-loop torpedo simulation capabilities in the WAF with fleet submarines operating at depth and speed on range at the Atlantic Undersea Test and Evaluation Center (AUTEC).

The Synthetic Environment Tactical Integration (SETI) Program

Where Is The Navy Today? (4 of 18)

Description of Objective Systems

Heavyweight Torpedo

MK 48 Mod 4

MK 48 ADCAP (Mod 5)

ADCAP Modifications (Mod 6)

Inventory Plans & Programs

- SSBN Deployment Support
- Foreign Military Sales
- Bunker / Deep Stowage

- Primary Sub-launch ASW & ASUW Torpedo (IOC 88)
- ADCAP Block Upgrade Program
  - Improvements via software delivery
  - IOC Block I: 1991; II: 1994; III: 1997
- ADCAP Torpedo Improvement Program (ATIP)
  - Improve reliability Via Hardware Ordalt
- Heavyweight Test Equipment Upgrade
  - Combine 48 & ADCAP Equipment (1998)
- Foreign Military Sales

- ADCAP Ordalt Kit: IOC 1997
- G&C: Improved Processors
- Torpedo Propulsion Upgrade
  - Reduce Radiated Noise

Where Is The Navy Today? (5 of 18)

Description of Objective Systems

Heavyweight Torpedo

ADCAP Modifications
COTS Insertion
Commonality Initiative

(COT-DV Program)

Inventory Plans & Programs
Description / Summary

- Torpedo Commonality & COTS Insertion
  - Incorporate Lightweight Hybrid Torpedo Common Torpedo Processor Into Mods
- Future ADCAP Full COTS Processor Use
  - Drop in card processor upgrade
- Software & Algorithm Commonality
  - Common "Core Software" & Unique merged to deliver op software version for lightweight and/or heavyweight torpedo

CBASS Program

- Common Broadband Advanced Sonar System
- Wideband Sonar for ADCAP Torpedo
- Shallow Water & CCM Improvements
- Features Support Close Encounter Capability

Where Is The Navy Today? (6 of 18)

Description of Objective Systems

Lightweight Torpedo

MK 46

MK 50

MK 54

Lightweight Hybrid Torpedo

Inventory Plans & Programs

- Air & Surface Launch
- Large Fleet & World Inventory
- Service Life Extension Program
  - Extend Life
  - Improved Shallow Water

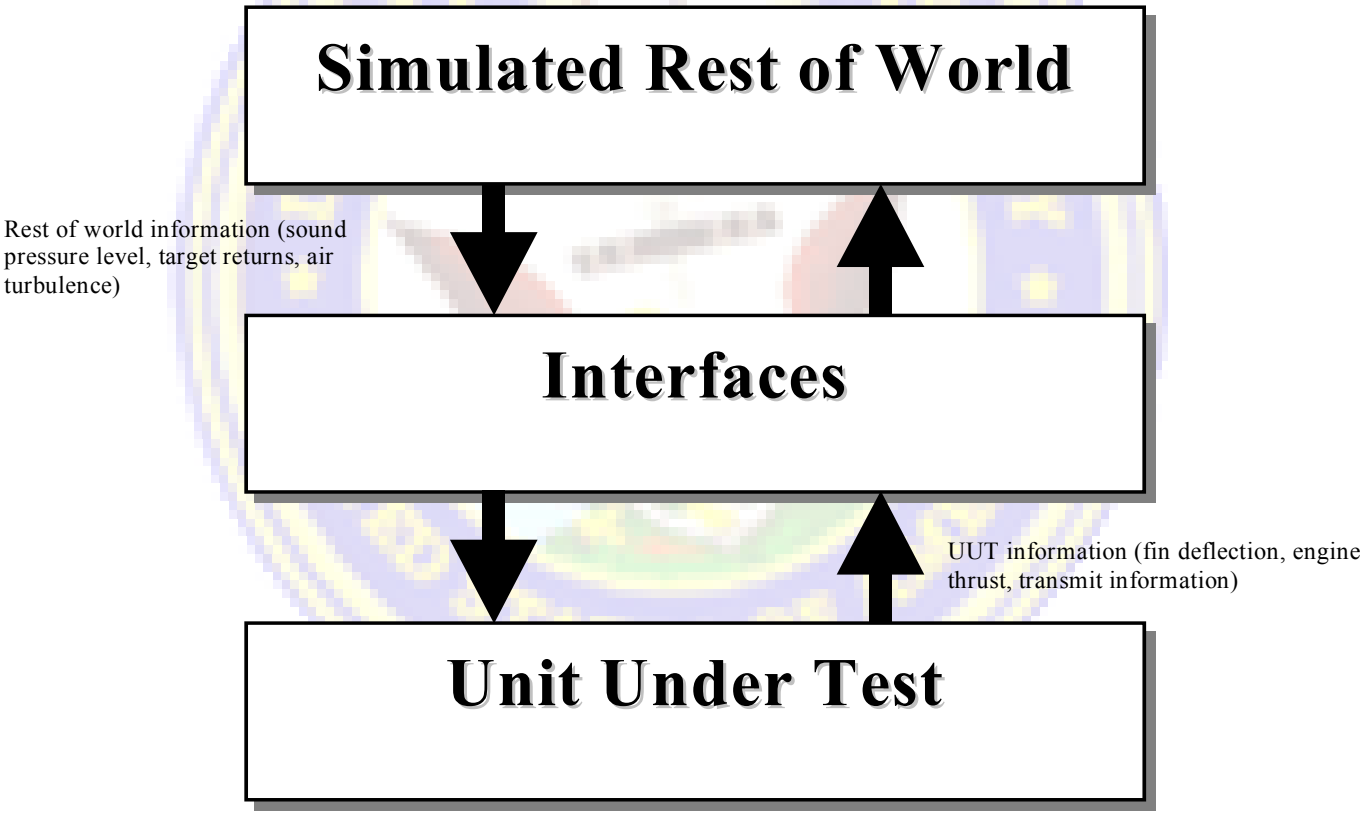
- Advanced Lightweight Torpedo
  - Limited Inventory
  - Software Block Upgrade Program Completed
    - Block I IOC: 96 ; II On Shelf (to LHT)

- New Development
  - COTS Based Common Torpedo Processor
  - Maximum Use of Available Government Furnished Hardware
    - MK 50 Sonar ... MK 46 Propulsion & Warhead
  - Low Development & Life Cycle Cost

Where Is The Navy Today? (7 of 18)

Description of Objective Systems

- If the unit under test "is what it is" there can be little issue over its design accuracy.



Where Is The Navy Today? (8 of 18)

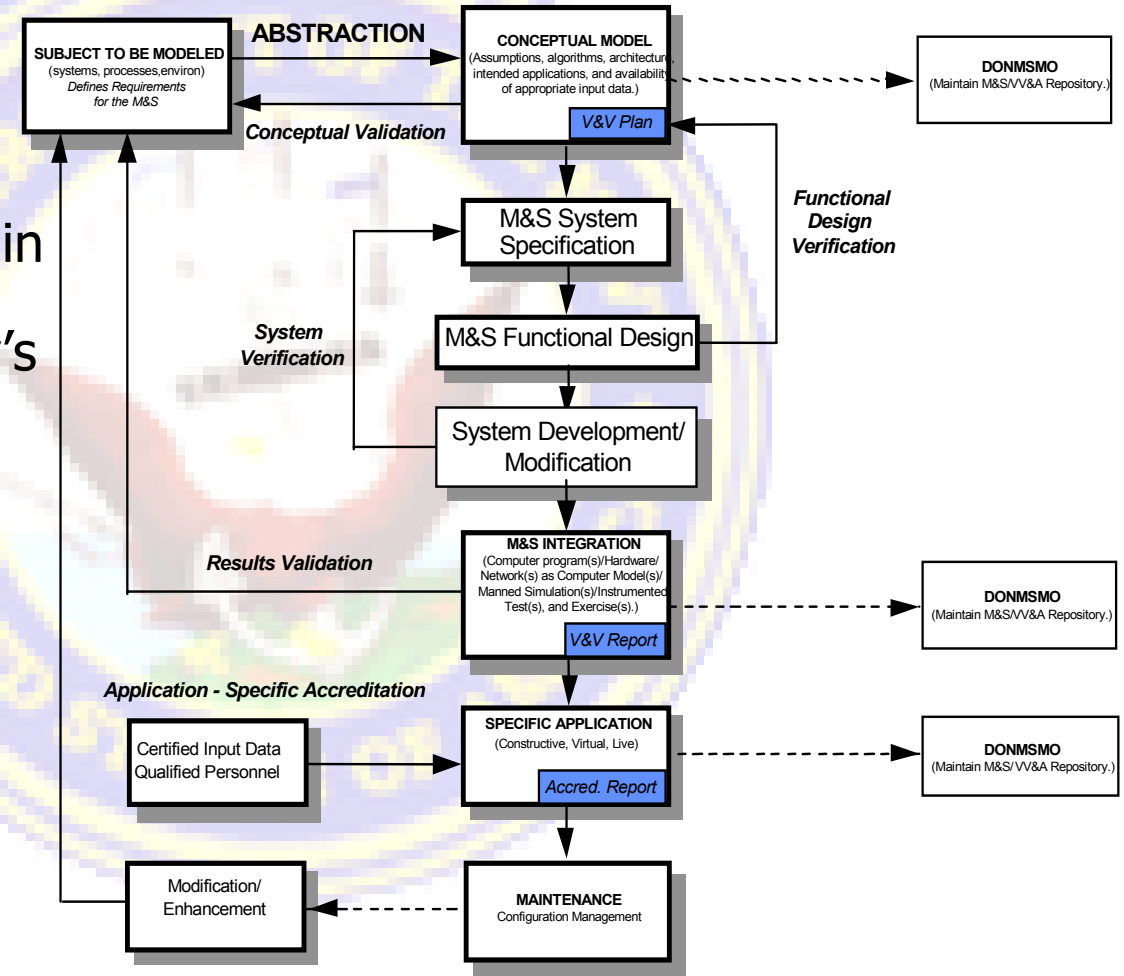
Fundamental Strategies For Business Operations

- **Funding.** Budgets are shrinking and we are all expected to do more with less. VV&A is no exception and it may in fact be the poster child.
  - We all need to strive to:
    1. Change that culture which relegates V&V to a second order fiscal decision.
    2. As a technical community find ways to weave good V&V practices into our design processes.
- **V&V As An Integral Part Of The Development Process.** Apart from some of the documentation and personnel requirements, V&V, when done right and early, does not require a developing activity to do substantially more work than they are already doing.
- **Simulation Control Panel.** The SCP is responsible for watching the development process and overseeing the ultimate verification, validation, and accreditation of the simulation system.
- **Configuration Control Board.** Throughout the development process, the CCB should be at work monitoring software product development.
  - The HWIL CCB must have cognizance over the hardware configuration as well.

Where Is The Navy Today? (9 of 18)

V&V Techniques & Technologies

- The Navy's recommended VV&A process is spelled out in both SECNAVINST 5200.40 and the Navy's VV&A Implementation Handbook.



Where Is The Navy Today? (10 of 18)

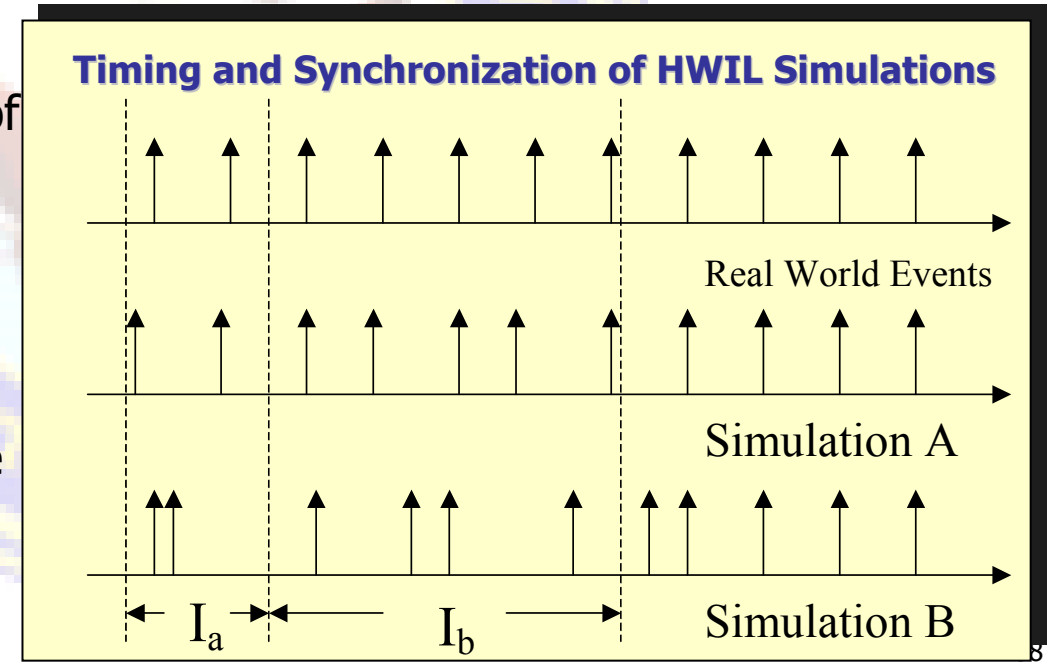
V&V Techniques & Technologies

- Issues associated with the V&V process as they relate to HWIL include:
  - **Requirements Definition.** The process of defining requirements for an HWIL simulation is driven by:
    - Customer and user needs that evaluated in light of available modeling science and available dollars.
    - Then these needs are translated into requirements.
  - **Operational Hardware.** Introduction of real operational hardware into a simulation environment introduces specific requirements can be characterized as either Interface Requirements or Timing Requirements.
    - Interface Requirements are tied to the specific piece of hardware in question and may be so specific that they relate to particular versions of hardware and operational software.
    - Weapon interface requirements as they relate to signal injection strategies, will drive, to a point, the models used in the simulation world.
    - Timing requirements have a profound influence on the selection of models used in the simulation world.

Where Is The Navy Today? (11 of 18)

V&V Techniques & Technologies

- **Timing and Synchronization.** Two simulations, represented by "Simulation A" and "Simulation B" are used to interface to hardware that expects something like that depicted in the timeline at the top.
- Over large intervals of time, both Simulation A and Simulation B appear to meet the hardware's requirements.
  - But for shorter integration intervals, Simulation B will, in some cases (I_a), be ahead of the hardware and, in other cases (I_b), events happen late and result in invalid behavior.
  - Some hardware platforms will flag this as a failure and stop execution. Others may not be so smart and actually continue running.



Where Is The Navy Today? (12 of 18)

V&V Techniques & Technologies

- **Conceptual Model Validation.** During this phase, a VV&A plan should be developed that takes into account all of the requirements associated with designing, building, and testing a HWIL simulation system. Specifically, the plan should address the following:
  - Assumptions about the interface design.
  - How the models used in the "simulation world" fit the hardware application.
  - Where exploitation hardware is used, rigorous verification and validation, in concert with those performing the exploitation, some consideration to the verification and validation of the interfaces needs to be addressed.
  - Timing requirements should be documented and a statement of how both model and simulation computer selection meets these requirements be included.
  - For Installed System Test Facilities (ISTFs), document the impact of the local environment to the signal as it's received by the hardware.

Where Is The Navy Today? (13 of 18)

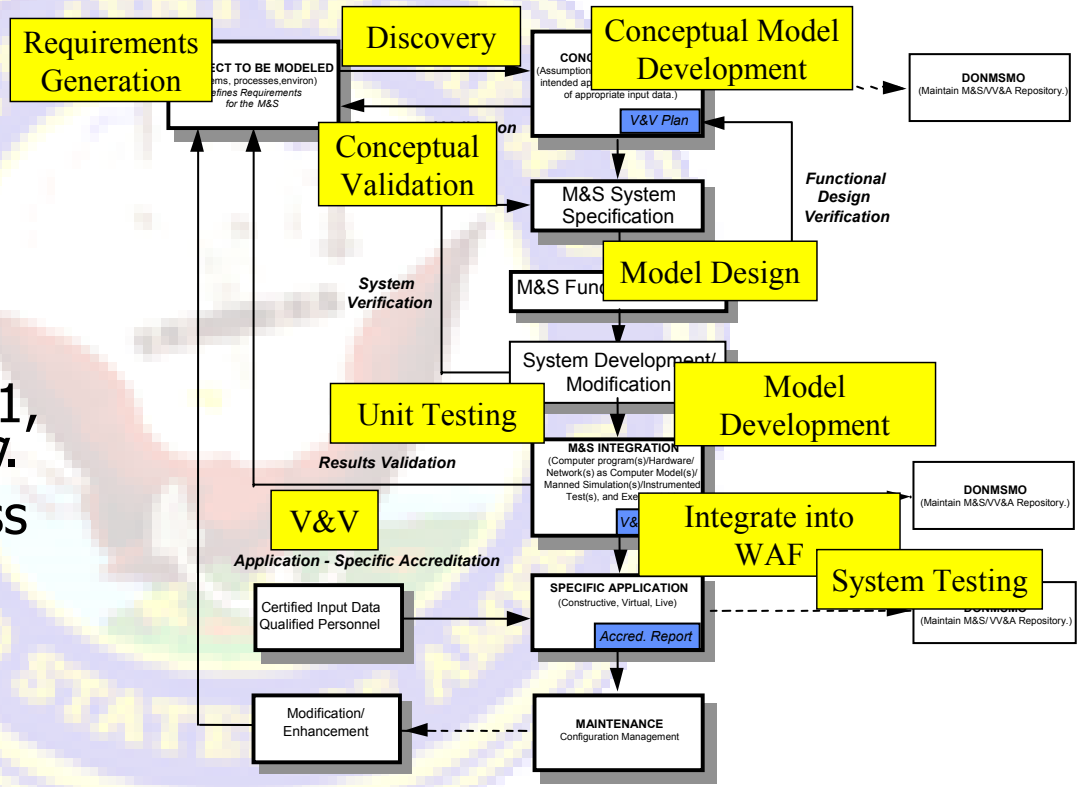
V&V Techniques & Technologies

- **Specification, Design, And Development.** During these phases, the V&V and accreditation teams should be reviewing the documents produced by the simulation engineers as well as the implementation strategies followed by the development team.
- **M&S Integration.** During the integration phase, unit and system testing should contribute to results validation. Instrumentation of the simulation at this point is critical.

Where Is The Navy Today? (14 of 18)

V&V Process Maturity

- Navy's V&V process has evolved and is well-defined by several layers of instructions.
- NUWC's HWIL simulations operate under DoDINST 5000.61, DoD *M&S VV&A*, and SECNAVINST 5200.40, *VV&A of M&S*. For OT&E, NUWC also follows COMOPTEVFORINST 5000.1, *M&S in Operational Testing*.
- Assisting in the V&V process is the Navy VV&A Recommended Practices Implementation Handbook that is designed to provide amplification and practical guidance for those responsible for implementing the SECNAVINST.



Where Is The Navy Today? (15 of 18)

Measure of Success

- Measures of success can be categorized into two different groups:
  1. *"Did the V&V process add value to the development process?"*
  2. *"Did the V&V process provide a rigorous enough basis upon which to make an accreditation decision" and, as a corollary, "Was the simulation used for the intended purpose?"*

Where Is The Navy Today? (16 of 18)

Measure of Success

- **Value Added.** V&V may be the deciding factor in using (or not using) a particular simulation.
  - If we think of V&V simply as a robust testing process, it's not hard to change our thinking from *"V&V is something I must do"* to *"V&V is something I should do".*
  - V&V, as defined by so many policy and guidance documents, provides simulation developers with a framework for detailed testing of a simulation.
- **The Accreditation Decision.** V&V should lead directly to an accreditation decision from the ultimate user of the simulator.
  - Positive accreditation decisions should lead directly to use of the simulation for the intended purpose.
  - Negative accreditation decisions can also be valuable.
    1. The negative decision provides the simulation proponent insight into where their simulation fell short for a particular application.
    2. The accreditation authority can refine their methodology for initially choosing one simulation over another for particular uses.
    3. A potential travesty (i.e. using the wrong tool for the right job) can be avoided.

Where Is The Navy Today? (17 of 18)

Synopsis / Summary

- **M&S VV&A reports currently on file with the Navy Modeling and Simulation Management Office**

Program	Document Title
AAAV	Accreditation of the TIGER Simulation for Calculation of Mean Time Between Operational Mission Failure (MTBOMF)
CEC OT-IIA3	Verification and Validation Assessment Report for the Cooperative Engagement Capability Hardware-In-The-Loop Systems for OT-IIA3
CEC OT-IIA4	Accreditation of the Cooperative Engagement Capability (CEC) Hardware in the Loop (HWIL) Simulation in Support of CEC AN/USG-2 System for OT-IIA4 Operational Evaluation (OPEVAL)
CEC OT-IIA4	Verification and Validation (V&V) Report for the Cooperative Engagement Capability Eastville Tower, Eastville, VA Hardware-in-the-Loop System for OT-IIA4
CEC OT-IIA4	Verification and Validation (V&V) Report for the Cooperative Engagement Capability Surface Combat Systems Center, Wallops Island, VA Hardware-in-the-Loop System for OT-IIA4
CEC OT-IIA4	Verification and Validation Report for the Cooperative Engagement Capability NP-3D Airborne Research Platform Hardware-in-the-Loop System for OT-IIA4
CEC OT-IIA4	Verification and Validation (V&V) Report for the Cooperative Engagement Capability Multi-Function Land Based Test Site Dam Neck, VA Hardware-in-the-Loop System for OT-IIA4
FA-18E/F	Accreditation of Capability of the FA-18E/F Manned Air Combat Simulator 3 (MACS 3) and FA-18C/D MACS 2 Simulator to Support Operational Test and Evaluation of the FA-18E/F
GCCS-M	Accreditation of the Land-Based Test Facility (LBTF) for the Mobile Operations Control Center (MOCC) Component for the Global Command and Control System-Maritime (GCCS-M) Software Qualification Test (SQT) / Follow-On Operational Test and Evaluation (FOT&E) (OT-IID6)

Where Is The Navy Today? (18 of 18)

Synopsis / Summary

- **M&S VV&A reports currently on file with the Navy Modeling and Simulation Management Office**

Program	Document Title
GCCS-M	Accreditation Assessment Report for GCCS-M Mobile Operations Control Center Land-Based Test Facility to Support GCCS-M OT-IID6
MJU-52/B BOL/IR	Accreditation of Capability of the Naval Surface Warfare Crane Seeker Test Van and Airborne Turret Infrared Measurement System Pod to Support Operational Test and Evaluation of the MJU-52/B (BOL-IR) Infrared Countermeasure
Navy Theater Ballistic Missile Defense (NTBMD)	Modeling and Simulation Requirements [Navy Area Theater Ballistic Missile Defense (Navy Area TBMD) System]
TOMAHAWK	Final Accreditation of the TOMAHAWK Land Attack Missile (TLAM) Mission Validation System (MVS) / Register Level Simulation (RLS) Version 5.1 to Support Follow-on Operational Test and Evaluation of the TOMAHAWK Mission Planning Center (TMPC) Version 3.2.
V-22	Accreditation of the Air Combat Environment Test and Evaluation Facility (ACETEF) MV-22 Full Mission Simulator (FMS) to Support Operational Test and Evaluation (OT-IIE) of the V-22
Virginia Class NSSN	Accreditation of NSSN Command and Control Systems Module (CCSM) Off-Site Assembly and Test Site (COATS) for use in NSSN OT-IIB Event
Virginia Class NSSN	Accreditation of SIMII/SSTORM (Scenario Structured Torpedo Requirements Model) to Support the Operational Assessment (OT-IIA2) of the Virginia Class SSN

Where Is The Navy Going? (1 of 3)

- In the last several years, Navy leadership has recognized the need for a Revolution in Military Affairs (RMA).
- *"Forward from the Sea",* a visionary document developed by the Chief of Naval Operations (CNO), highlighted the decisive shift from blue water operations to the "brown water" of the littoral following the Cold War.
- The move to the littoral is not merely a change in location; this shift represents a monumental challenge to the Navy's technical and operational personnel:
  - Overcome a more complicated physical environment.
  - Face an increased threat capability and density.
  - Address heightened vulnerability.

Where Is The Navy Going? (2 of 3)

Intention and Rationale

- The complexity of the Navy's new (littoral) operational environment implies that no *one* platform has either the perfect picture of its immediate operational space or a comprehensive picture of the theater of operation.
- This RMA will lead to a vast improvement in speed of command by vesting all of the platforms with the operational picture and pushing command authority to lower levels in the command chain.

How Are We Going To Get There?

- Both acquisition and operations will view the platform, the battlegroup, the fleet and the navy as a highly interconnected, and by extension interdependent, collection of sensors, shooters, and weapons.

Where Is The Navy Going? (3 of 3)

Expectations?

- Changes in the scope of Navy's mission will have profound effects on Navy's operational, acquisition, and R&D budgets.
- Navy will shift from a platform-centric view to a force-centric view of the world which will result in a heavy emphasis on architectures, communication, and platform interoperability.

Why Do We Want To Get There?

- For some, it is synonymous with modernization and focused on material acquisition.
- Others more appropriately see transformation going beyond modernization to embrace innovation and fundamental changes in our theory of war.

What Do We Gain From Getting There?

- Greater war fighting capability.

US Air Force Electronic Warfare Evaluation Simulation Test Facility

This section is very specific to the particular challenges faced by the US Air Force Electronic Warfare Evaluation Simulator (AFEWES) Test Facility.

This section will address HWIL simulations used to assess effectiveness of countermeasures and techniques used against threat weapons, particularly infrared and radio frequency guided missiles.

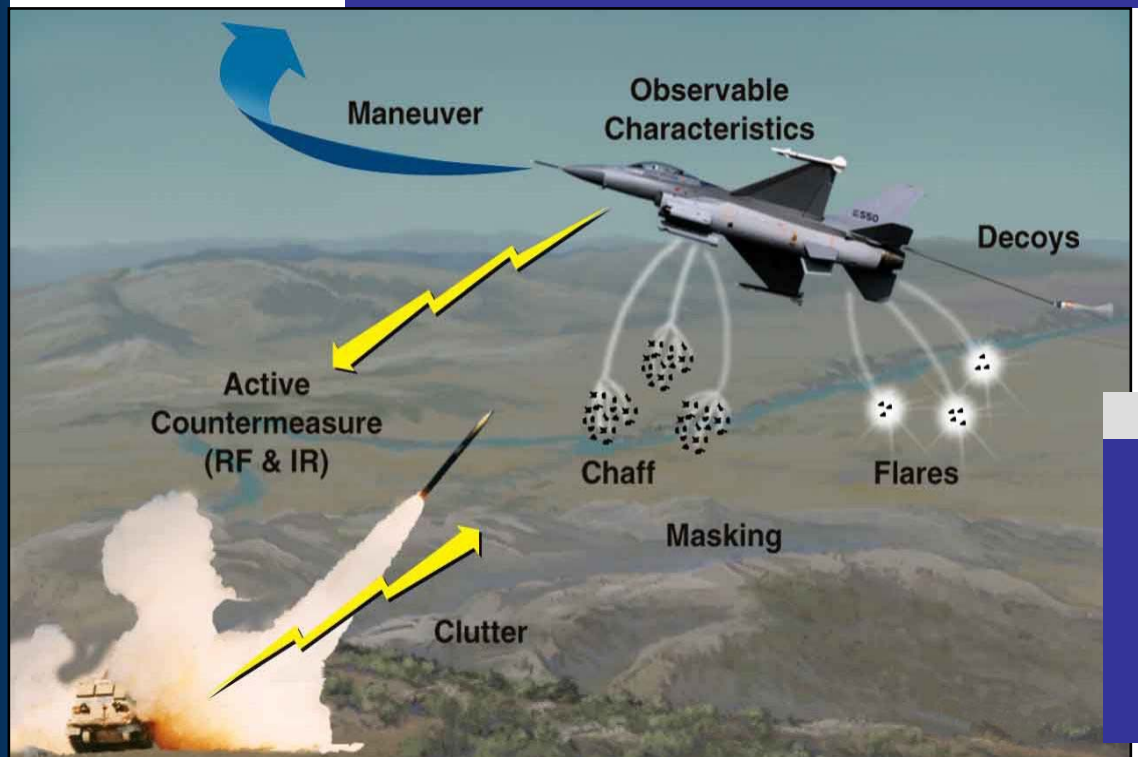
US Air Force Electronic Warfare Evaluation Simulation Test Facility

Context (1 of 6)

AFEWES

Mission: Provide technical evaluation of the Effectiveness of Electronic Combat Systems and techniques in a Simulated IR and RF Threat Environment

Usage: By All Services and Allies in Every Phase of the EC System Life Cycle – From Concept Definition through Operational Deployment



KEY FEATURES

- Actual Frequency/Wavelength
- Real Time
- Dense Signal Environment
- Evaluation of EC Effectiveness
- Fully-Dynamic Engagements

Context (2 of 6)

EW Systems/Techniques Evaluated

AFEWES simulations support evaluation of several different types of electronic warfare equipment including:

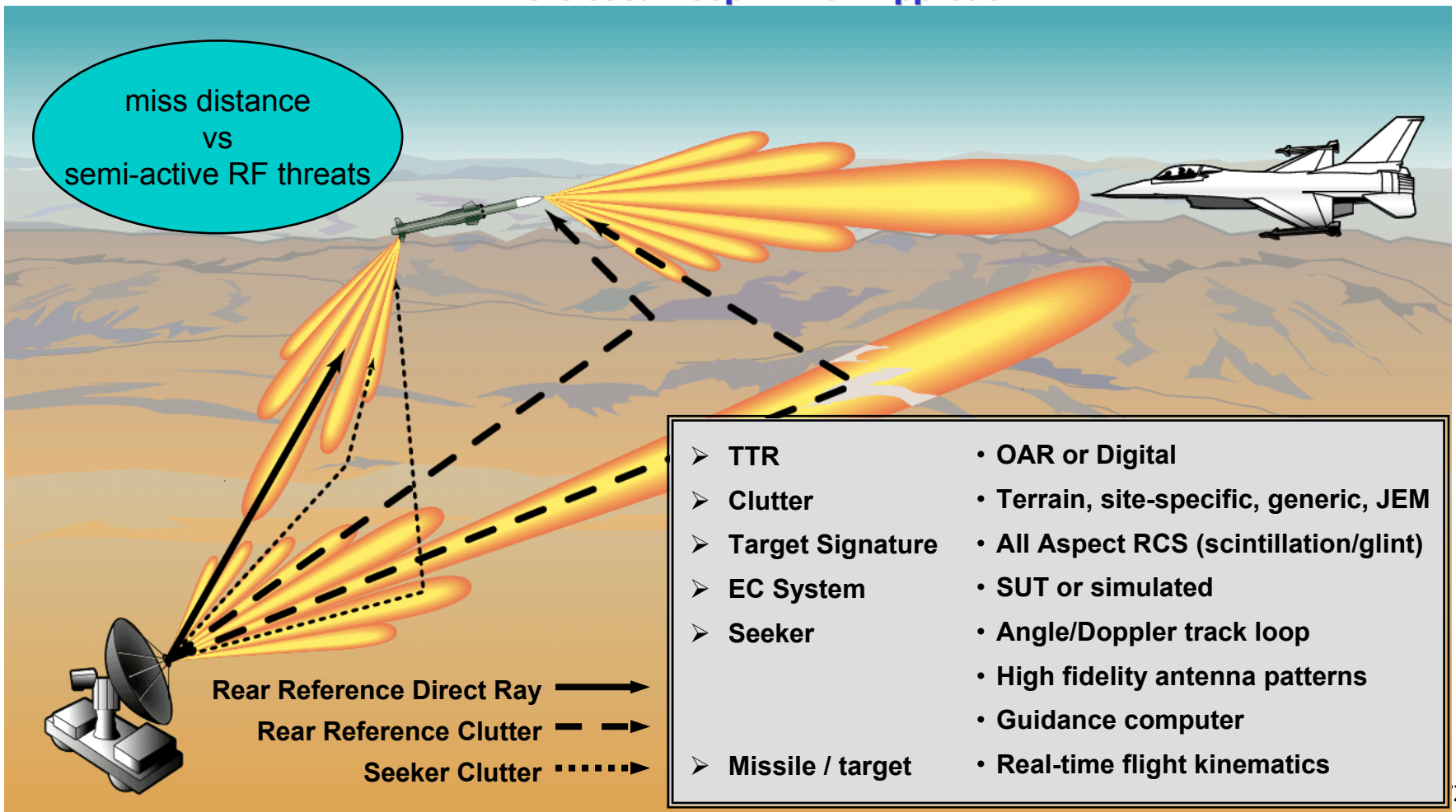
- Onboard RF Jammers
- Towed Decoys
- Radar Warning Receivers
- Self-Protect Chaff
- Integrated RWR & Countermeasures
- Aircraft Maneuvers
- Lamp and LASER IR Jammers
- Conventional, Thrusted, and Aerodynamic Flares

US Air Force Electronic Warfare Evaluation Simulation Test Facility

Context (3 of 6)

AFEWES RF Simulations

AFEWES Closed-Loop RF T&E Approach

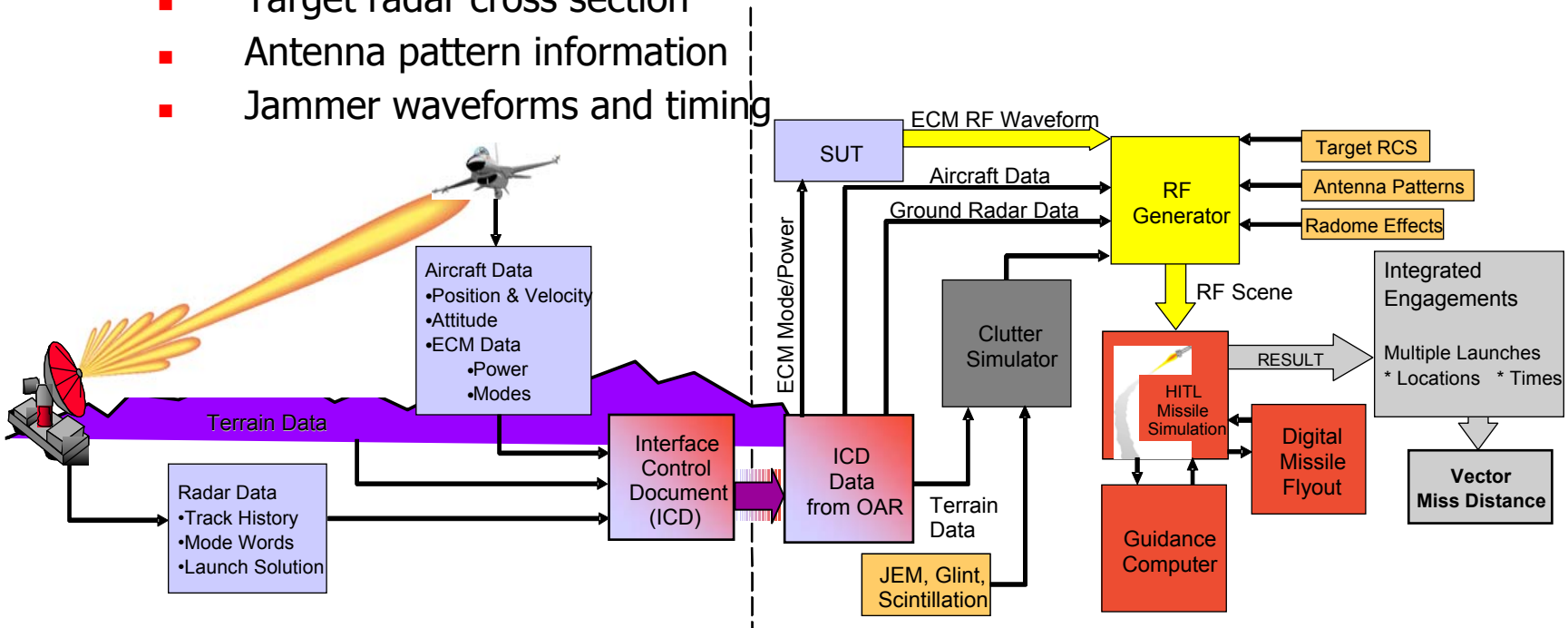


➢ TTR	• OAR or Digital
➢ Clutter	• Terrain, site-specific, generic, JEM
➢ Target Signature	• All Aspect RCS (scintillation/glint)
➢ EC System	• SUT or simulated
➢ Seeker	• Angle/Doppler track loop
	• High fidelity antenna patterns
	• Guidance computer
➢ Missile / target	• Real-time flight kinematics

Context (4 of 6)

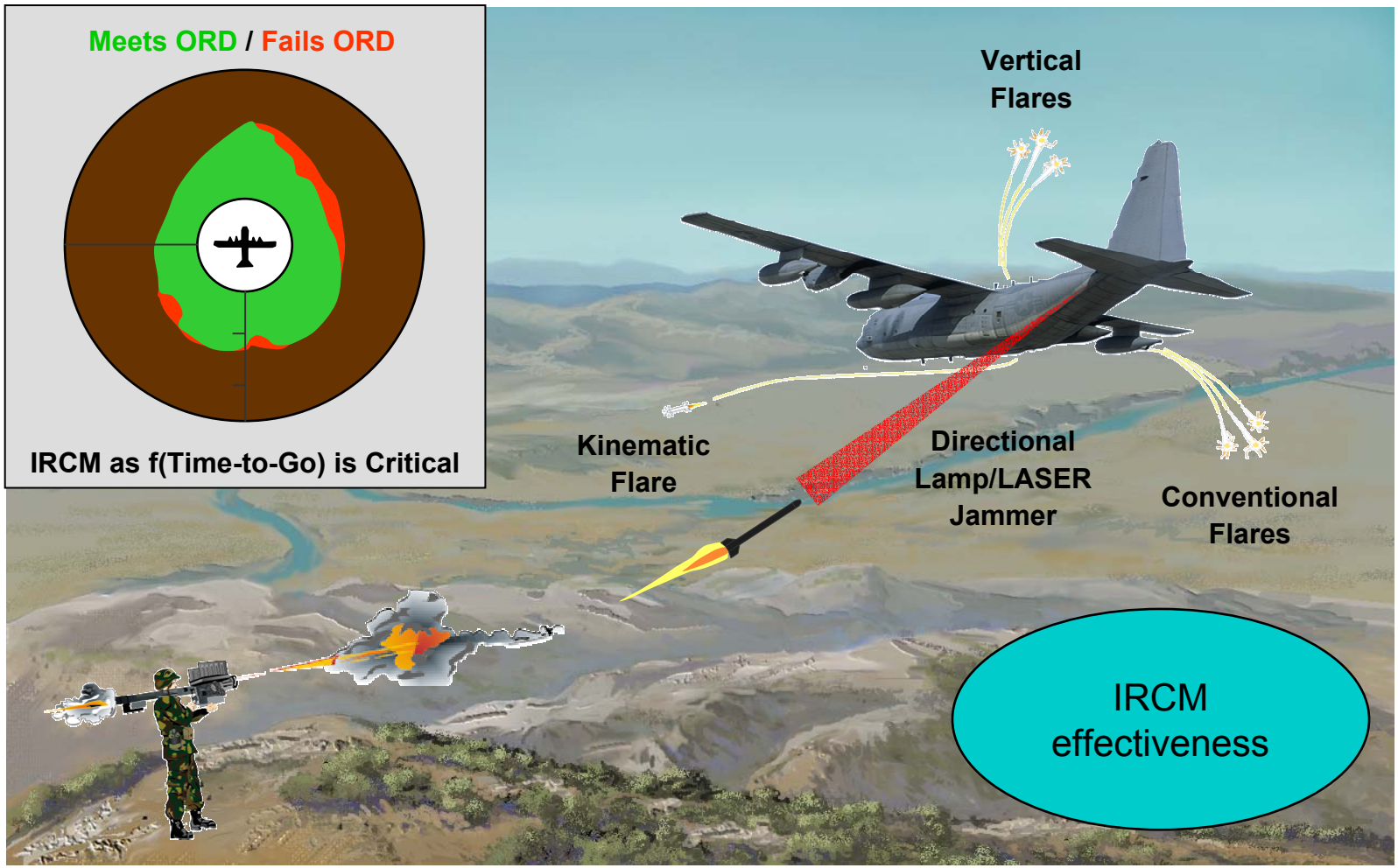
Integrated Open Air Range / HITL Test Approach

- Time correlated OAR data:
  - Target Tracking Radar functions and track errors
  - Electronic warfare system modes and timing
  - Target aircraft time-space-position information (TSPI)
- Customer supplied or derived data:
  - Target radar cross section
  - Antenna pattern information
  - Jammer waveforms and timing



Context (5 of 6)

AFEWES IR Simulations

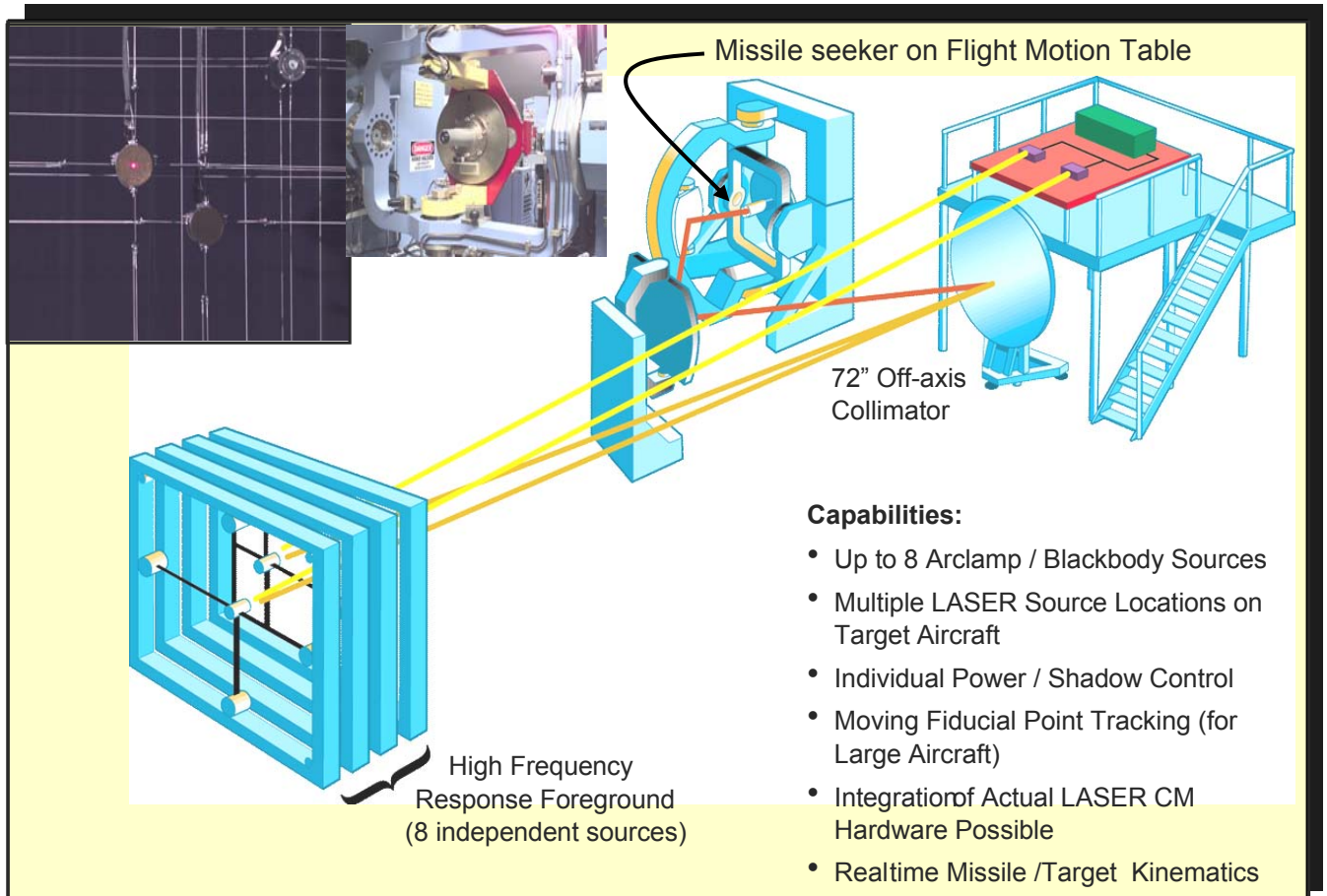


US Air Force Electronic Warfare Evaluation Simulation Test Facility

Context (6 of 6)

AFEWES IR Simulations

- Optimization and effectiveness testing of conventional and kinematic flares, directed lamp and LASER jammers, and combinations of these techniques



US Air Force Electronic Warfare Evaluation Simulation Test Facility

Where Is AFEWES Today? (1 of 7)

Description of Objective Systems

- AFEWES operates high-fidelity HITL simulations
  - RF semi-active threat SAM systems including seeker-aided-ground-guidance missile systems
  - IR man-portable air defense systems (MANPADs), IR vehicle-mounted threats and IR air-to-air threat systems

Fundamental Strategies for Business Operations

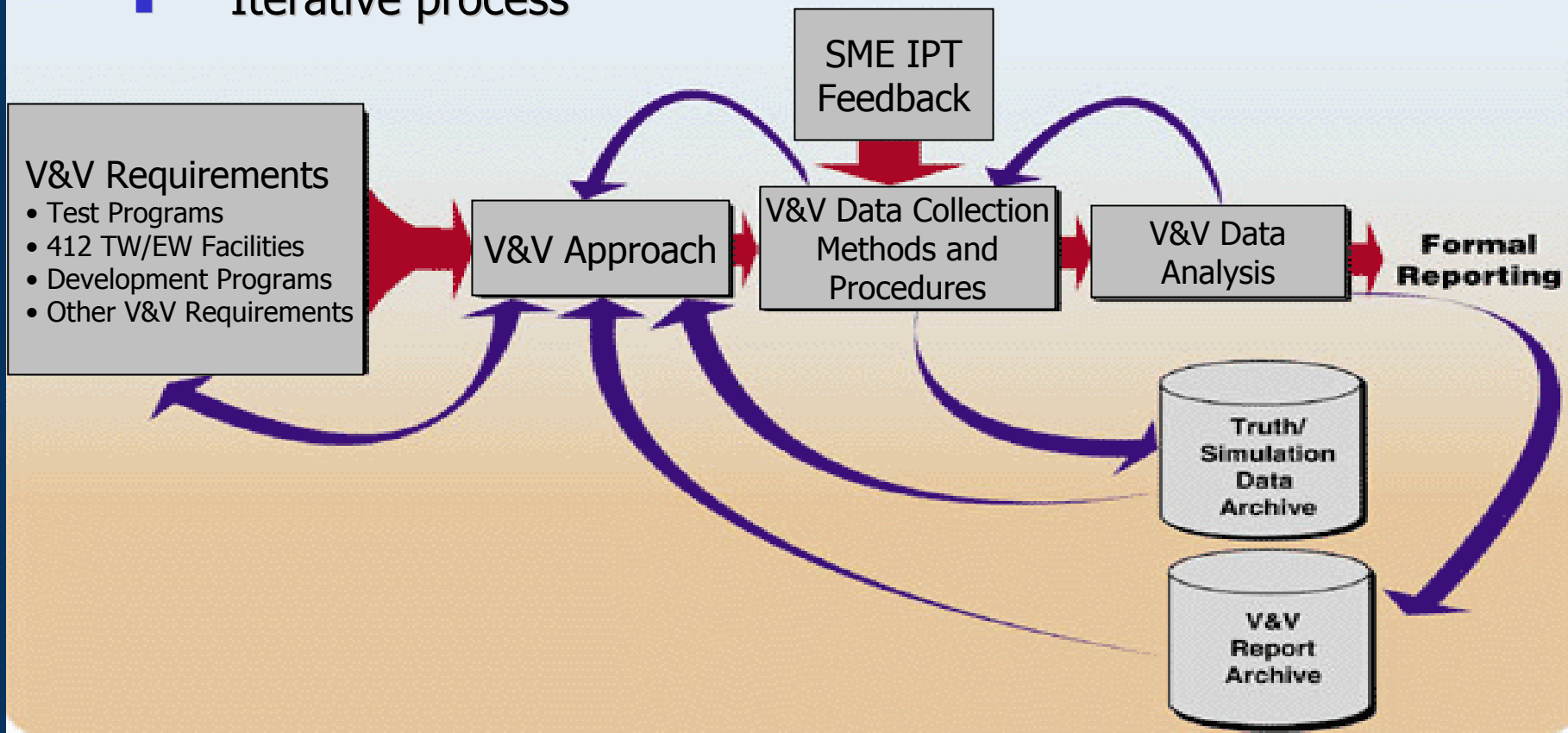
- Rigorous Configuration Management
- Subject Matter Expert (SME) integrated process team (IPT) oversight methodology to instill credibility & rigor into V&V efforts
- Committed to significant Verification and Validation effort to enable customer accreditation for specific use

US Air Force Electronic Warfare Evaluation Simulation Test Facility

Where Is AFEWES Today? (2 of 7)

Techniques & Technologies

- SME IPT provides expert feedback on:
  - Approach
  - Procedures
  - Analysis
  - Results
- Iterative process



Where Is AFEWES Today? (3 of 7)
Techniques & Technologies

- AFEWES IR Common Element V&V IPT is baseline effort
  - 25 Government Organizations Participated
- 15 step iterative process:
  1. Form V&V IPT -- identify IPT organizations / invite participation
  2. Articulate general V&V tasks
  3. Submit task list to IPT for comment
  4. Incorporate IPT comments -- finalize V&V task list
  5. Articulate V&V general data collection approach
  6. Submit V&V data collection approach to IPT for comment
  7. Incorporate IPT comments -- finalize V&V data collection approach
  8. Write detailed V&V data collection procedures
  9. Submit V&V data collection procedures to IPT for comment
  10. Incorporate IPT comments -- finalize V&V data collection procedures
  11. Collect V&V data
  12. Analyze the data
  13. Write the report addressing the findings including limitations
  14. Submit the report to the IPT for comment
  15. Finalize and publish the report and archive the data

Where Is AFEWES Today? (4 of 7)

V&V Maturity

(1) Existing AFWES HWIL V&V Processes

- Rigorous Configuration Management
  - Each complex utilizes a common system architecture
  - ISO 9000 Documentation standards
- SME IPT based V&V processes
  - IR Common Element – 90% complete
  - IR Missile Specific V&V – initiated in late FY02
  - RF SAM V&V
    - First 2 of 6 missile simulations ~70% complete
    - Second 2 of 6 simulations ~ 40% complete

Where Is AFEWES Today? (5 of 7)

V&V Maturity

(2) Validation Procedures and Tools

- **Benchmarking** - Comparison of simulation outputs with outputs of another simulation that is accepted as a "standard"
- **Face Validation** - Comparison of simulation design and outputs (under well defined conditions) with the expectations and opinions of subject matter experts (SMEs) in the simulation area of interest
- **Results Validation** - Comparison of simulation outputs with the results of test measurements made under identical input conditions
- **Sensitivity Analysis** - Determination of variation in simulation outputs for measured changes in inputs, functional operations, or other conditions

(3) The Consequential Effects of This Circumstance

- **Sensitivity Analysis** potentially enables understanding of HITL simulation credibility when "truth" is not available

Where Is AFEWES Today? (6 of 7)

V&V Measures of Success

- IR V&V – Support of Large Aircraft Infrared Countermeasure (LAIRCM) Program
  - AFEWES supported LAIRCM by conducting over 9000 HITL simulated missile engagements in FY02
  - AF Operational Test and Evaluation Center (AFOTEC) personnel spent 500+ manhours working with AFEWES to address more than 250 issues related to AFEWES IR HITL V&V
  - AFOTEC advocated accreditation of AFEWES IR HITL simulations for combined Developmental/ Operational Testing for LAIRCM
- RF V&V – Seeker Aided Ground Guidance Design of Experiments
  - AFOTEC led, tri-Service funded, highly successful Sensitivity Analysis effort to determine RF SAM simulation dependence on input fidelity

Where Is AFEWES Today? (7 of 7)

Synopsis / Summary

- AFEWES investment in V&V (time and funds) - highest level in years
- Continued emphasis for foreseeable future due to recent fundamental changes in AFEWES capability i.e. transition from Intel assessment-based simulators to two clear focus areas:
  - High-fidelity HITL simulation of RF semi-active threats vs. RFCM
  - High fidelity HITL simulation of passive IR threat missiles vs. IRCM
- Initiated multi-service, multi-agency, IPT-based V&V approach
  - VERIFICATION METHODS
    - Rigorous Configuration Mgt
    - Review by SME IPT
  - VALIDATION METHODS
    - Benchmarking
    - Face Validation
    - Results Validation
    - Sensitivity Analysis

Where Is AFEWES Going? (1 of 3)

Intensions and Rationale

- Sensitivity Analysis Approach
  - Evaluation of required fidelity of RF simulation inputs:
    - Radar Cross Section (RCS)
    - Clutter
    - Jet Engine Modulation lines
    - Multipath
    - Antenna patterns
    - Electronic countermeasure (ECM)
  - Evaluation of required fidelity of IR simulation inputs:
    - Target Signature
    - IR Source Extension
    - Spectral Content
    - Atmospheric Attenuation
    - IR Background and Clutter
    - Fly-out Model Characteristics

Where Is AFEWES Going? (2 of 3)

How We Are Going To Get There

- Sensitivity Analysis is key to our success
- Truth may not be knowable but the knowledge of exact truth may not be necessary
- Design of Experiments (DoE) rigorous methodology
  - Seeker Aided Ground Guidance (SAGG) is first effort
    - Evaluates impact of fidelity and magnitude variance in inputs to an Advanced RF SAM HITL simulation
    - First screen completed, reporting in FY03
  - IR DoE efforts are planned for FY03
    - Evaluates impact of fidelity variance in inputs to IR threat missile vs. IRCM HITL evaluations
    - Effort funded by tri-Service working group

US Air Force Electronic Warfare Evaluation Simulation Test Facility

Where Is AFEWES Going? (3 of 3)

Expectations

- Sensitivity Analysis along with Benchmarking, Face Validation, and Results Validation are sufficiently potent tools to enable Accreditation

Why Do We Want to Get There?

- HITL Test Facility credibility is vital to enable appropriate program decisions and to support Developmental and Operational Test objectives
  - Particularly important for EW system effectiveness evaluations

What Do We Gain By Getting There?

- Test customers confidence and accreditation for specific program use
- DoD-wide understanding of ECM effectiveness against threat missiles

There can be no greater reward than that a US aircrew member returns safely home from a mission because of what we learned about the effectiveness (or lack thereof) of Electronic Warfare equipment and tactics in HITL testing.

Agenda

I. Introduction

II. HWIL and Distributed Simulation Systems VV&A Processes, Techniques and Technologies

III. VV&A Issues Facing HWIL and Distributed Simulation Systems

- 3.1 Issues Identification
- 3.2 Major Cross Domain Issues: Technical and Enterprise Complexity
- 3.3 HWIL & Distributed Simulation Issues Impacting M&S VV&A

IV. Major VV&A Research Areas for HWIL and Distributed Simulation Systems

V. Conclusions

VV&A Issues Facing HWIL and Distributed Simulation Systems

Issue Identification

- Focus on identification of major issues related to the HWIL and distributed simulation systems that are largely independent of the particular domains of application that have been discussed.
- Concern with the following forms of *technical complexity* for HWIL and distributed simulation systems:
  - Structural (kinds of parts; numbers (cardinality) of parts)
  - Types of relationships among parts
  - Numbers of relationships among parts
  - Kinds of informational interfaces
  - Numbers of informational interfaces
  - Location of components
  - Time- or circumstantial-variability of composition; etc.
  - Behavioral (kinds of simulation executive operations / processes / methods, kinds of representation, numbers of representations, semantic variety and consistency of representations including 'time'; etc. …)

Major Cross Domain Issues

Management of Technical Complexity (1 of 3)

Description

Implications Upon VV&A of Technical Complexity of HWIL and Distributed Simulation Systems.

Forms of Technical Complexity	Influence upon VV&A
Structural Forms:	
Kinds of parts (type variety).	Requires greater variety of V&V techniques.
Numbers of parts (cardinality).	Requires either more effort, or managed investment.
Types of relationships among parts.	Suggests alternative influence dynamics that must be considered and potential greater variety of V&V techniques.
Numbers of relationships among parts.	Requires either more effort or managed investment.
Kinds of informational interfaces.	Requires greater variety of V&V techniques.
Numbers of informational interfaces.	Requires either more effort or managed investment.
Location of components.	Suggests access constraints or need for spatial distribution of consistent operations.
Time- or circumstantial-variability of composition.	Requires careful configuration management and audit traceability of correlation between configuration and V&V determinations and findings

Major Cross Domain Issues

Management of Technical Complexity (2 of 3)

Description

Implications Upon VV&A of Technical Complexity of HWIL and Distributed Simulation Systems.

Forms of Technical Complexity	Influence upon VV&A
Behavioral Forms	
Kinds of simulation executive operations / processes / methods.	Requires effective discrimination between 'executive' and 'representational' function of the simulation asset, thorough identification of elements of the 'conceptual model of the user's space', and greater variety of V&V techniques.
Numbers of executive operations / processes / methods.	Requires either more effort or managed investment.
Kinds of representation.	Requires greater sensitivity to the significance of alternative representational schemas (scope, detail, fidelity, and mechanization) and greater variety of V&V techniques.
Numbers of representations.	Requires either more effort or managed investment
Semantic variety and consistency of representations including 'time'.	Requires extreme sensitivity to confirming not just syntactic consistency in V&V procedures, but to effective evaluation of semantic effect.

Major Cross Domain Issues

Management of Technical Complexity (3 of 3)

Consequences

- Technical complexity that will influence cost, schedule, and product quality risk.

Candidate Solutions

- Scrupulous systems engineering of the HWIL or distributed simulation system should facilitate VV&A and ameliorate some of the difficulties associated with operating in the context of technical complexity.
- Aggressive implementation of the techniques indicated in the introduction of this paper - namely, the use of the Evaluation Kernel, and adherence to the Managed Investment Strategy – should be effective.

Value

- The value of such amelioratives is relatively evident in the area of risk management and control.

Major Cross Domain Issues

Enterprise Complexity Management (1 of 4)

Implications of the Enterprise Complexity Upon VV&A of HWIL and Distributed Simulation Systems.

Form of enterprise complexity	Influence upon VV&A
Structural forms:	
Kinds of individuals, organizations, and roles active in the enterprise.	Multiplicity of role types, especially when executed by different organizations, requires particularly explicit denotation, specification and execution.
Intentions and expectations of stakeholders.	Role holders having diverse intentions and expectations in establishing and executing VV&A programs is untenable.
Relationships among stakeholders and their respective agendas.	Relationships among stakeholders and their respective agendas must at least admit to win-win, non-zero-sum, and certainly non-adversarial consensus appreciation.
Infrastructure investment availability and peculiarity.	Sunk cost in infrastructure for HWIL and distributed simulation development, integration, and consequently VV&A, including facilities and accessories qualification investment will likely strongly influence VV&A programs specification and execution.

Major Cross Domain Issues

Enterprise Complexity Management Page 2 of 4

Implications of the Enterprise Complexity Upon VV&A of HWIL and Distributed Simulation Systems.

Form of enterprise complexity	Influence upon VV&A
Structural forms:	
Cost, value, peculiarity, and rarity attributes of components.	Similarly, cost and availability of distributes simulation assets and HWIL components will constrain VV&A task management – particularly when distributed assets are used for more than one simulation ensemble, or when HWIL assets are in limited supply in the subject program.

Major Cross Domain Issues

Enterprise Complexity Management (3 of 4)

Implications of the Enterprise Complexity Upon VV&A of HWIL and Distributed Simulation Systems.

Form of enterprise complexity	Influence upon VV&A
Behavioral forms	
Custodial management of assets.	Who owns what part of the HWIL / distributed simulation system and how it is controlled necessarily influence how its advocacy as a credible contributor to the larger system is managed – perception of risk in misrepresentation of objective system components and consequent aggressive control of data artifacts is inevitable.
Collaborative planning and program management implementation; etc.	Enterprise-wide participation in VV&A planning and consensus on agreed-upon implementation programs is difficult, but necessary.
Technical developmental and asset employment operational execution.	Expectation of cooperation in developing and using subject HWIL and distributed simulation assets is a powerful incentive to participate liberally and attentively to the VV&A process.

Major Cross Domain Issues

Enterprise Complexity Management (4 of 4)

Consequences

- Overt uncooperativeness in VV&A in complex environments such as HWIL or distributed systems is rare, but the **'load'** on the VV&A program of enterprise class inhibition can be equally deadly.

Candidate Solution

- Deliberate enterprise management with emphasis on consensus-building and Pareto optimal investment of stakeholders' contributions is essential.

Value

- The value of such amelioratives is relatively evident in the area of risk management control

HWIL & Distributed Simulation Issues Impacting M&S VV&A

- For purposes of discussion and ease of treatment, those issues which bear on successful accomplishment of HWIL and distributed simulation V&V and, ultimately, M&S accreditation and acceptance, have been sorted (imperfectly) and aggregated into several functional categories:
  - ***Systems Engineering*** - related issues
    - Communications
    - Timing and synchronization
    - Interfaces
  - ***High Performance Computing & Software Engineering*** - related issues
  - ***Validation Process*** - related issues
    - General V&V Processes
    - Hardware Validation
    - Digital Model Validation
  - ***Operations*** - related issues
    - Technical Operations
    - Enterprise Operations
    - Expectation Management

HWIL & Distributed Simulation Issues Impacting M&S VV&A

System Engineering Related Issues (1 of 5)

Residual Systems Engineering-Related VV&A Issues On Communications

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
SYSTEMS ENGINEERING			
Communications Issues			
Bandwidth Requirements	Bandwidth requirements and limitations potentially affect HWIL validity. HWIL and SWIL used in simulations must interface / interact within the synthetic simulation environment.	This requirement imposes significant bandwidth requirements on the simulation system.	Enable new approaches for HWIL and distributed simulation operations through additional investment in infrastructure to promote information sharing, and collaboration.
Encryption Constraints	Integration of tactical hardware, software, and C3 systems often bring with them issues associated with providing a secure information environment.	This may impose a requirement on the simulation to address encryption, and the need to V&V encryption mechanisms.	Development of V&V practices for encryption schemas used in HWIL and distributed simulations.
Distributed Operations	Distributed simulation operations potentially introduces additional challenges associated with meeting the real-time, bandwidth, and encryption constraints previously discussed.	Actual feasibility of executing distributed operations (distributed simulation).	Investments in Network Centric Warfare-related research and technologies to provide the necessary understanding and tools to support V&V of HWIL and distributed simulations. Training of individual, team, organizations on the V&V activities used in HWIL and distributed simulation programs will accelerate progress.

HWIL & Distributed Simulation Issues Impacting M&S VV&A

System Engineering Related Issues (2 of 5)

Residual Systems Engineering-Related VV&A Issues On Communications

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
SYSTEMS ENGINEERING			
Communications Issues			
Limitations of Commercial Telecom-munications Technology	Commercial telecommunications technology and computer communications protocols used by JADS (as well as DIS and HLA) do not support the transmission of native spectrum environment data.	Analog waveforms can be captured digitally and transmitted over commercial telecommunications lines using computer communications protocols.	Development and documentation of efficient V&V methods that facilitate the evaluation of native spectrum environmental data against the analog (and digital) representations used in HWIL and distributed simulation systems is needed.
Transmission of Native Spectrum Environment Data	Techniques currently used for transmitting analog and electromagnetic waves such as RF waveguide and fiber optic links are not affordable for geographically separated facilities.	If entire digitized waveforms are being transmitted, bandwidth quickly becomes an issue.	Tools to evaluate bandwidth requirements are needed to enable early trades regarding simulation fidelity versus detail.
Handling Data Loss	Event data cannot be predicted. Data loss must be addressed in simulation experiment and test design. JADS EW Test showed that the lowest latency computer communications protocol consistently showed the highest data loss.	Event data must be sent using reliable but higher latency communications protocols, or transmitted multiple times, or transmitted with periodic data from the same player, or event data losses must be accepted.	Development and documentation of efficient V&V methods and tools to capture rates of data loss, and latencies provides quantitative means of evaluating the robustness of communications within HWIL and distributed simulation systems.

HWIL & Distributed Simulation Issues Impacting M&S VV&A

System Engineering Related Issues (3 of 5)

Residual Systems Engineering-Related VV&A Issues On Timing and Synchronization

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
SYSTEMS ENGINEERING			
Timing & Synchronization Issues			
Real-Time Constraints	Real world system software used in HWIL simulations generally executes on the real-world system's processors.	This requires the simulation environment to meet the run-time (execution rates) of the processors-in-the-loop. If the simulation cannot meet the processors' run-time, then the simulation may fail.	Development and documentation of efficient V&V methods and tools to capture data rates and latencies will provide a quantitative means of evaluating the robustness of communications within HWIL and distributed simulation systems.
Digital Simulation Model Constraints Impacting Distributed Testing	Digital simulation models (DSMs) must work in real time to usefully link with hardware- and software- in-the loop simulations, manned simulators, threat simulators, manned operator stations, and other real-time simulations of blue or red players. Inability of DSMs to meet run-time requirements of the processors and SWIL will result in failure of the HWIL simulation to operate reliably.	Oftentimes, these models are executed off-line (like a pre-processor) to generate the inputs data needed.	The consequences of using pre-processed data in a dynamic simulation must be evaluated in terms of discrete event management. The development of V&V techniques to capture and compare differences associated with operating in this manner is needed.

HWIL & Distributed Simulation Issues Impacting M&S VV&A

System Engineering Related Issues (4 of 5)

Residual Systems Engineering-Related VV&A Issues On Timing and Synchronization

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
SYSTEMS ENGINEERING			
Timing & Synchronization Issues			
Latency in Distributed Simulations	Latency is a limitation on how tightly two players can be coupled. For example, the distributed simulation architectures used in JADS EW testing were capable of average round-trip transmission latency for HLA "reliable" (transmission control protocol [TCP]/Internet protocol [IP]) interactions of 254 and 167 milliseconds respectively.	Inability to meet run-time requirements may result in failure of the distributed simulation to operate reliably.	A standard means to measure and establish the "tolerable" latency in HWIL and distributed simulations is needed.
Handling Out-of-Sequence Data	Out-of-order (out-of-sequence) data are a distributed simulation effect that must be addressed in experiment design.	Differences in transmission methods, distance, and the one-device-at-a-time nature of some computer communications protocols are all contributing factors that diminish the ability to effectively execute distributed simulations	V&V agents need to be aware of these sources and deal with them in the design of V&V Plan, V&V data collection, and V&V data analysis

HWIL & Distributed Simulation Issues Impacting M&S VV&A

System Engineering Related Issues (5 of 5)

Residual Systems Engineering VV&A Issues Relating to System Interfaces

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
SYSTEMS ENGINEERING			
System Interfaces Issues			
HWIL Interfaces	Difficulties may exist in meeting HWIL interfaces between simulation hardware and software, and the tactical (prototype) hardware and software integrated into the simulation.	Simulation and tactical systems may not be interoperable.	Development of standards relating to interfaces between tactical systems and simulations are needed to facilitate the incorporation of tactical hardware (and software) as players within HWIL and distributed simulation systems.
Specifications For Linking Threat And Environmental Simulators	The specifications for linking threat and environmental simulators activities must provide for additional types of quality assurance instrumentation to monitor the environmental and threat representations at each location.	Subtle differences in the waveform representations among locations have the potential to change how each player behaves in the scenario and may impact the distributed simulation results.	Development of standards relating to interfaces linking threat and environmental simulations and simulators are needed to facilitate simulation interoperability and re-use.

HWIL & Distributed Simulation Issues Impacting M&S VV&A

HPC & Software Engineering Related Issues

HPC and Software Engineering-Related VV&A Issues

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
HPC / SW ENGINEERING ISSUES			
Parallel Processing	Many HWIL simulations are intended to be deterministic. However, parallel processors and software increasingly are *used in the simulation* to generate the synthetic natural environment. This contributes to run-to-run variability in the simulation results.	Analysis results and findings can be confounded due to the increased variability due to the use of parallel simulation processors in simulations.	V&V methods and techniques that address the multiple paths, and associated run-to-run variability, found in complex, parallel processor simulations need to be established, documented and promulgated to the community.
	Many HWIL simulations are intended to be deterministic. However, massively parallel processors and software are increasingly being *used in tactical systems* and these systems are being integrated as players in HWIL simulations, distributed simulation systems and test beds.	Analysis results and findings can be confounded due to the increased variability due to the use of parallel simulation processors in tactical systems.	V&V methods and techniques that address the multiple paths, and associated run-to-run variability, found in complex, parallel processors used in tactical systems need to be established, documented and promulgated to the community.

HWIL & Distributed Simulation Issues Impacting M&S VV&A

Validation Process Related Issues (1 of 3)

Validation Process-Related VV&A Issues

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
VALIDATION PROCESS ISSUES			
General			
Conceptual Models	Relationship of a unary conceptual model of the *mission-space* (real world of the operating objective system) to the unary conceptual models of the *simulation representation domains*	Class inheritance within conceptual models and associations to system functions whose representation are subject to V&V.	
Identification of UUT	There must be an unambiguous identification and denotation of the Unit-Under-Test. (UUT) to ensure V&V evaluation activities are properly focused.	Without identification of the UUT, V&V activities may not be properly focused, and as a consequence not provide data needed for an accreditation decision.	Uniform means of explicitly identifying the unit under test are needed.

HWIL & Distributed Simulation Issues Impacting M&S VV&A

Validation Process Related Issues (2 of 3)

Validation Process-Related VV&A Issues Relating to Hardware

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
VALIDATION PROCESS ISSUES			
Hardware-Related			
Serial Number To Serial Number Variability.	There may be significant serial number-to-serial number variability of hardware used in HWIL simulations.	Significant serial-number to-serial number variability of hardware used in HWIL simulations can confound HWIL results.	Studies to evaluate the consequence of serial number variability and the implications of drawing conclusions about a population based on a single sample would be beneficial.
Validation Of HWIL Used In Simulations	Is validation of HWIL integrated into the simulation within the scope of the HWIL VV&A program, or just I to i ?	How do you know you have representative hardware in the HWIL si ulati n	Specification of the scope of the VV&A effort across DoD HWIL M&S would be helpful in
	sy m. The risk of committing pe I Error is high ulation results are rejected ugh in fact they are ible].	Committing this type of error unnecessarily increases the cost of M&S development and M&S V&V as even more extensive V&V activities may be executed to obtain a favorable accreditation decision.	Application requirements must be very clear, and the simulation results must be carefully considered against these requirements.

Validation Process Related Issues (3 of 3)

Validation Process-Related VV&A Issues Relating to Digital Models

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
VALIDATION PROCESS ISSUES			
Digital Model-Related			
Synthetic Environment Fidelity	While advanced distributed simulation (ADS) provides the ability to use resources across facilities, the fidelity of the resulting environment is limited by the fidelity of the test infrastructure to create (represent) each piece of the environment.	Fidelity of the synthetically generated signals is limited to the capability of the simulator / stimulator connected to the unit-under-test, threat, or other players in the scenario.	This is not unique to distributed simulation test environments. The fidelity of the environment is always a constraint and must be addressed in the V&V program design as well as the V&V data analysis and assessment of results.

HWIL & Distributed Simulation Issues Impacting M&S VV&A

Operational Related Issues (1 of 5)

Operational Issues Impacting VV&A Relating to Technical Operations

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
OPERATIONAL ISSUES			
Technical Operations			
Simulation Reliability	The expected reliability of a distributed architecture is the product of the expected reliability of each component, resource, and facility. The reliability of each simulation component, resource, or facility has to be factored into the distributed simulation design.	As such, reliability can generally be expected to decrease as the number of components or players increase.	
Unique Skill Set Needed To Support Distributed Simulation Development, Integration, Test and VV&A	Distributed simulation experiments require skills not found in traditional simulation and test.	Lack of requisite skills will hinder and potentially prevent successful distributed simulation operations.	Training in nontraditional M&S VV&A skills including: wide area computer network design, integration, test, and operation; local area computer network/wide area computer network integration and optimization; computer / simulation interface design, integration, optimization, and test; and if HLA is used, then Run Time Infrastructure experience, and local area network (LAN) and wide area network (WAN) installation, optimization, and operation

HWIL & Distributed Simulation Issues Impacting M&S VV&A

Operational Related Issues (2 of 5)

Operational Issues Impacting VV&A Relating to Technical Operations

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
OPERATIONAL ISSUES			
Technical Operations			
Early Testing Against HWIL Threats	Early testing against HWIL threats is likely to increase test program costs over the current DoD test process design.	However, early testing against HWIL threats should uncover problems earlier in the weapon system development cycle.	Ultimately, increased costs will have to be weighed against the improved test realism benefit, the potential improvements in test capability through the networking of existing facilities, and the potential of cost avoidance.
Systems Integration	There are non-standard processes associated with the integration of HWIL simulations and distributed simulations. Efficiency in operations and technical operations mandate a formal integration and execution process.	The absence of formal specifications for simulation integration and execution require each simulation enterprise to invent (and re-invent) their own practices.	Development of best practices associated with simulation integration and execution for HWIL and distributed simulations potentially would reduce costs, and increase efficiency and effectiveness.

HWIL & Distributed Simulation Issues Impacting M&S VV&A

Operational Related Issues (3 of 5)

Operational Issues Impacting VV&A Relating to Enterprise Operations

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
OPERATIONAL ISSUES			
Enterprise Operations			
Resource And Facility Limitations	Understanding resource and facility limitations is critical to experiment (test) design. Connecting facilities for distributed simulation operations tend to highlight these limitations. Each resource or facility brings its inherent errors, limitations, and assumptions into the test architecture.	V&V of the players and the architecture are essential. Again, this is not unique to distributed simulation experiment designs. However, it is important that limitations be known up front to ensure the best quality environment is created.	These errors, limitations, and assumptions must be identified and managed in the experiment design to avoid problems with increased data variance and/or decreased test validity.
Limited Availability / Number of Distributed Simulations	Executing distributed simulation operations is limited by the availability of suitable simulators and environment representations in HWIL and ISTFs.		

HWIL & Distributed Simulation Issues Impacting M&S VV&A

Operational Related Issues (4 of 5)

Operational Issues Impacting VV&A Relating to Enterprise Operations

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
OPERATIONAL ISSUES			
Enterprise Operations			
Limitations of Existing HWIL Facilities to Support Distributed Tests	Existing EW and HWIL facilities are challenged in implementing advanced distributed simulation-based tests. Most existing facilities were designed to perform stand-alone tests.	Facility details such as the ability to time synchronize the entire facility and internal latencies that are not a factor in traditional tests are critical in distributed simulation experiments.	Facilities will have to investigate and document design details that may have been made decades earlier, and it forces facilities to reveal more of their internal workings than they are accustomed to revealing.
Additional Costs Associated With Distributed Simulation Systems	There are significant costs associated with the implementation of distributed simulation systems. For example, JADS found the single largest cost for implementing distributed simulation experiments to be the cost of modifications to existing EW and HWIL facilities to allow them to inter-connect.	Cost associated with implementation of distributed simulations may be significant and an inhibitor to the utilization of distributed simulations.	

HWIL & Distributed Simulation Issues Impacting M&S VV&A

Operational Related Issues (5 of 5)

Operational Issues Impacting VV&A Relating to Expectation Management

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
OPERATIONAL ISSUES			
Expectation Management Issues			
Preferential Use of HWIL Simulations	Certain agencies have a pre-disposition to "accept" HWIL simulation data since the simulation incorporates elements of the "Real-world" system. These agencies are not sensitive to the issues that arise with HWIL M&S. False expectations of simulation validity because they incorporate HWIL are established. An increased risk of committing a Type II Error [invalid simulation results are accepted, even though they are not sufficiently credible].	Committing this type of error can be catastrophic. This is especially true if key decisions are based on the M&S results.	Like the Type I Error, the Type II Error is best avoided by completely understanding the application requirements and carefully considering simulation results.
Simulation Is Easier Than Physical Testing	While advancing the use of M&S, some proponents express the notion that simulation is easier and less expensive than physical tests.	False expectations of what simulations can do and at what cost may be established.	

Agenda

I. Introduction

II. HWIL and Distributed Simulation Systems VV&A Processes, Techniques and Technologies

III. VV&A Issues Facing HWIL and Distributed Simulation Systems

IV. Major VV&A Research Areas for HWIL and Distributed Simulation Systems

V. Conclusions

Major VV&A Research Areas for HWIL and Distributed Simulations Systems

- Research topics derived from the forgoing analysis of HWIL and distributed simulation systems VV&A are roughly categorized as pertaining to one or another sets of issues from which their consideration arose.
- The identification of candidate research topic and the selection of preferred candidates followed relatively systematically from the proceeding review. Each issue identified was considered to see what research or new knowledge was required for its resolution.
- Research topics were consolidated, as several research interests pertained to more than one issue topic.
- Finally, the research topics themselves were prioritized according to the following criteria:
  - Need for investigation of the topic *(How original was the topic – how much work already has been done in this area?).*
  - Tractability as a topic of investigation *(How hard is the topic to pursue? How likely were significant findings?).*
  - Focused relevance to HWIL and distributed simulation systems' VV&A *(To what degree is the topic pertinent to HWIL and distributed simulation AND to VV&A in particular?).*

Major VV&A Research Areas for HWIL and Distributed Simulations Systems

Simulation System Architecture Specification

Topic Title:	Simulation System Architecture Specification
Research Need:	Need exists to regularize the practice of specifying the compositional architecture of simulation systems to facilitate the identification and appreciation of structural features of the complex simulation system and their associated architectural relationships and behaviors. No such generally recognized practice exists, inhibiting VV&A of technically complex simulation systems.
Research Activity:	Review techniques and supporting tools for specification of (HWIL distributed simulation) systems architectures. Evaluate alternative approaches for establishing the compositional architecture of HWIL and distributed simulation systems in particular. Draft recommended practice.
Desired Results:	Standards, tools (notations and COTS products), and techniques necessary and sufficient to systematically document the compositional architectures of complex HWIL / distributed simulation systems.

Major VV&A Research Areas for HWIL and Distributed Simulations Systems

Conceptual Model Specification

Topic Title:	Conceptual Model Specification
Research Need:	Need exists to document conceptual models of components of HWIL and distributed simulation systems, particularly in regard to model detail and semantic consistency. No such generally recognized practice exists, inhibiting VV&A of technically complex simulation systems.
Research Activity:	Review techniques and supporting tools for specification of HWIL / distributed simulation systems component conceptual models. Evaluate alternative approaches for establishing the specification of conceptual model detail and consistency of semantic significance between simulation system components. Draft recommended practice.
Desired Results:	Standards, tools (notations and COTS products), and techniques necessary and sufficient to systematically document the conceptual models of components and ensembles of complex HWIL / distributed simulation systems.

Major VV&A Research Areas for HWIL and Distributed Simulations Systems

Encryption Implementation V&V

Topic Title:	Encryption Implementation V&V
Research Need:	HWIL and distributed simulations frequently require encryption functions. These simulation executive functions need to be verified in accordance with relevant informational security policies and procedures as well as with respect to simulation implementation correctness and operational credibility. No generally satisfactory and widely appreciated practices exist to meet these requirements for encryption component / function verification.
Research Activity:	Review verification requirements for encryption components and functionality in HWIL and distributed simulation systems. Evaluate alternative approaches for establishing the acceptability of these components and functions from both the information security and simulation credibility perspectives. Draft recommended practice.
Desired Results:	Establishment and general acceptance of processes, procedures and techniques necessary and sufficient to establish the correctness of implementation of encryption in simulation systems.

Major VV&A Research Areas for HWIL and Distributed Simulations Systems

Communications Latency Management

Topic Title:	Communications Latency Management
Research Need:	The need exists to manage communications latency among components of HWIL / distributed simulation systems. Latency management includes: a) Evaluation of acceptable / tolerable data transport latencies, b) Prediction of likely latencies in simulation systems and their likely effects, c) Observation / measurement of actual latencies and their consequent causal effects as they impact verification and validation evaluation, and d) Amelioration of data latency induced effects on V&V vis-à-vis control of observed simulation behaviors relative to V&V criteria.
Research Activity:	Some research is imagined possible for each area of latency management indicated, although some are ostensibly more relevant to VV&A than others. To support estimation of acceptable / tolerable data transport latencies, two elements of research are necessary. 1. Establishing reliable forms of prediction of transport latencies among diverse types of components, communicating across diverse communications infrastructure under control for diverse executive mechanisms is desired. Tools that can be tailored to the circumstances of distributed and HWIL simulation and can predict node-specific latencies of message instances or types is necessary. 2. Establishing generally appreciated and relevant latency tolerance criteria is necessary.

Major VV&A Research Areas for HWIL and Distributed Simulations Systems

Native-Spectrum Environmental Data

Topic Title:	Management of Native-Spectrum Environmental Data
Research Need:	Environmental data is relatively dense, and is provided in a variety of formats, including time- and frequency-domain and in context of spatially and parametrically distributed manifolds. The systematic management of such high-volume and particularly formulated information is often challenging in HWIL simulations where the HWIL article is frequently sensitively dependent upon access to appropriately representative data in 'effective real time'.
Research Activity:	Investigate the data types and formats necessary for representation of environmental data in typical HWIL simulations, and establish processes, techniques and tools to support the management of such data - including its delivery to the HWIL article - in forms that will meet to within well-defined criteria requirements for data integrity appropriate for the several classes of HWIL artifact.
Desired Results:	Systematic best practice, processes and accompanying tools necessary and sufficient to pro-actively manage Environmental Data Management and control the effects on environmental data manipulation on simulation predictive credibility.

Major VV&A Research Areas for HWIL and Distributed Simulations Systems

Parallel Processing

Topic Title:	Parallel Processing Implications
Research Need:	While, many HWIL and distributed simulations are intended to be deterministic to within constraint of non-deterministic components (e.g. MIL), there are frequently parallel computational elements whose effects on repeatability and causal correctness may be relatively unappreciated or uncontrolled. Such computational elements - some in the simulation-representation domain, and some in the simulation-executive domain - may include: a) parallel processing used to generate synthetic environments, b) parallel processors used within the objective system components that may be used as HWIL / SWIL components, c) parallel processing within the simulation executive to facilitate evaluate of digital representations, and d) the parallelism intrinsic in distributed simulation architectures.
Research Activity:	Investigate the kinds of effects on predictive credibility that can result from the variety of parallel processes likely to be relevant to HWIL and distributed simulations. For each, establish the range of contingency circumstances wherein such effects can arise, identify indicators of such pathologies, educe possible consequences, and provide indications of possible amelioratives along with their applicability and effectiveness.
Desired Results:	Best practices guidance for managing the implication of parallel processes in HWIL and distributed simulation systems.

Major VV&A Research Areas for HWIL and Distributed Simulations Systems

Simulation & Systems integration Process

Topic Title:	Simulation-Systems Integration Process
Research Need:	Developmental integration of HWIL simulation systems strongly influences system developmental cost, efficiency and effectiveness. While processes have been established particularly to support the development of distributed simulation systems – that is the Federation Execution Development Process (FEDEP) – no similar guide to practice / process exists for HWIL simulation development.
Research Activity:	Explore the development life-cycle of HWIL simulation systems, and identify components of the developmental process that are particularly sensitive to the use of HWIL components and that may materially influence the cost-effectiveness of HWIL simulation development. Analyze these operational elements and develop guidance suitable to either: a) the modification / qualification of the FEDEP, or b) the establishment of a similar tailored process guidance for developmental integration of HWIL simulations.
Desired Results:	Best practices guidance for integrating HWIL simulation systems.

Major VV&A Research Areas for HWIL and Distributed Simulations Systems

Cost Benefit Analysis

Topic Title:	Cost benefit-analysis and HWIL / Distributed Simulation Investment Criteria
Research Need:	The determination of cost-benefit of HWIL and distributed simulation systems and their associated VV&A and the establishment of "best-practices" for investment in those systems and VV&A process deserve particular attention due to the considerable cost typical of such systems. Identification of the cost (and utility) factors of HWIL and distributed simulations and the establishment of generally accepted accounting practices for reporting both the cost and benefit is subject to research and analysis. Guidance on how best to account for prospective cost and utility in making investment decisions likewise admits to systematic attention.
Research Activity:	Analyze the economics of HWIL and distributed simulation systems and their associated VV&A processes. Particularly identify dependencies on factors that differentiate HWIL and distributed simulation, and within that set of factors, address those for which cost / benefit sensitivity is high. Account for the extended life cycle of HWIL and distributed simulation assets and the incremental but sometimes disjoint investment and recovery timeframes. Identify cost and utility factors. Establish best practices for cost and benefit accounting and procedural guidance for investment and investment recovery decision-making.
Desired Results:	Operational guidance for financial management-of and investment-in HWIL and distributed simulation assets and their VV&A.

Major VV&A Research Areas for HWIL and Distributed Simulations Systems

Enterprise Management

Topic Title:	Enterprise Management
Research Need:	HWIL and distributed simulation requires generally more overt attention to 'enterprise' aspects than forms of simulation that have smaller constituencies, fewer roles, and lesser extent in sites, assets, and operations. In particular, the establishment of enterprise environments wherein all the significant participating agents can interoperate efficiently on terms that are generally appreciated as being win-win and risk-controlled is extremely important.
Research Activity:	Investigate and document the institutional dynamics of HWIL and distributed simulation operations, identifying the significant roles and relationships among participating agents and establishing criteria for successful collaborative participation among role-holders. Identify the dependencies of enterprise success on formal and informal roles and relationships, and indicate the forms of administrative and management control that are suitable for such operations.
Desired Results:	Operational guidance for enterprise establishment and operations in support of HWIL / distributed simulation systems development and operations.

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- 5.1 The Challenge
- 5.2 Discovery
- 5.3 Determination and Findings

Conclusions

The Challenge

- The challenge of this effort was to determine what processes, techniques, and tools, beyond those that are normally available for VV&A are necessary for support of HWIL and distributed simulation assets. We have:
  - Addressed some very powerful strategies common to M&S VV&A practice:
    - Accreditation-Requirements-Driven V&V Planning.
    - Concept of the V&V Evaluation Space.
    - Concept of the V&V Evaluation Kernel.
    - The business strategy of Managed Investment.
  - Identified how they apply to HWIL and distributed simulation systems.
  - Surveyed a few characteristic HWIL and distributed VV&A loci in order to disclose a representative sample of particular tools, techniques and practices.
  - Attempted to identify issues characteristic of V&V of HWIL, distributed simulations, and simulation frameworks and then propose ameliorative strategies.
  - Addressed potential research topics and technologies to advance the state-of-the-art for validation of HWIL and distributed simulations.

Conclusions

The Discovery

- Discovery of the nature of VV&A for HWIL and distributed simulation systems occurred in the context of the contributors' particular operational emphasis.
  - The Army AMRDEC contributors emphasize:
    - The extreme variety of HWIL and distributed simulation systems requiring VV&A.
    - Indicating that complete formality in defining and executing V&V is difficult but that tailoring to the needs of individual VV&A programs is tenable.
    - The need for deliberate financial management of VV&A activities over the extended lifetime typical of many HWIL and distributed simulation systems operation.
  - The Navy contributors, representing both the particular perspective of NUWC WAF and the broadly general perspective of NAVMSMO, emphasize:
    - The implications of organizational culture.
    - Attending to the interfaces between complex simulation system components.
    - The need to 'build-in' V&V to the simulation system development process.
  - The Air Force, AFEWES, emphasizes:
    - Diligent configuration management.
    - The use of Subject Matter Expert IPTs.
    - Application of an appropriate mix of validation tools (Benchmarking, Face Validation, Results Validation, Sensitivity Analysis) to achieve necessary credibility for users to accredit HITL test methods for evaluating EW system effectiveness.

Conclusions

Determination and Findings

Issues

- The variety and emphasis of issues raised in the subject analysis is suggested by the topical classification provided earlier:
  - Systems Engineering
  - High Performance Computing (HPC) and Software Engineering
  - Validation Process
  - Validation Operations
  - Expectation Management
- Consensus on these issues by all the participating contributors testifies to the ubiquitous diversity of VV&A for HWIL and distributed simulation.

Conclusions

Determination and Findings

Research Topics

- Prospective research topics were evaluated with respect to criteria including:
  - Need
  - Tractability
  - Focused relevance to HWIL and distributed simulation systems' VV&A
- It is evident that potential research in VV&A for HWIL and distributed systems is likely to be both diverse and challenging.
- Research opportunities were defined for each of the following:
  - Simulation System Architecture Specification
  - Conceptual Model Specification
  - Encryption Implementation V&V
  - Communications Latency Management
  - Management of Native-Spectrum Environmental Data
  - Parallel Processing Implications
  - Simulation-Systems Integration Process
  - Cost benefit-analysis and HWIL / Distributed Simulation Investment Criteria

Conclusions

Determination and Findings

Implications / Actions

- While the issues and potential research topics educed by this analysis are considered relevant and valuable, the concern persists that without extraordinary effort to pursue the establishment of a viable program of research for M&S VV&A, the net effect of the Foundations 02 will be to document the 'as-is' state of M&S VV&A – admirable, but not all that could be hoped for!

BACK-UPS & SUPPORTING CHARTS

Major Cross Domain Issues

Shortfall in Telecommunications Infrastructure for Distributed Simulations (1 of 4)

Consequences

- Overt uncooperativeness in VV&A in complex environments such as HWIL or distributed systems is rare, but the **'load'** on the VV&A program of enterprise class inhibition can be equally deadly.

Candidate Solution

- Deliberate enterprise management with emphasis on consensus-building and Pareto optimal investment of stakeholders' contributions is essential.

Value

- The value of such ameliorates is relatively evident in the area of risk management control.

Major Cross Domain Issues

Shortfall in Telecommunications Infrastructure for Distributed Simulations (2 of 4)

Description

- In 2001, The RDEC Federation, including the APEX Lab, conducted a CALibration EXperiment (CALEX) to determine the ability of the US Army to perform long-haul HLA experiments of analysis-quality.
- The CALEX identified and experienced the VV&A performance risks associated with long-haul HLA analysis.
- Factors included:
  - The number of sites
  - Number of federates
  - Duration of scenarios
  - Instability of wide-area networks
  - Fragility of federations
  - Federate differences in optimal settings
- These factors were significantly high during the CALEX, to the extent that long-haul record runs were not possible.

Major Cross Domain Issues

Shortfall in Telecommunications Infrastructure for Distributed Simulations (3 of 4)

Consequences

- With the loss of the old DSI, the Army has lost the capability to perform long-haul distributed simulation without purchasing dedicated lines or operating across a general-purpose network such as DREN.
- The current state of performance using HLA and DREN precludes long-haul analysis and experimentation of the scale needed for the RDEC Federation.
- Performance of the RDEC Federation across general-purpose networks is expected to improve, but remain marginal, in the near-term.

Candidate Solution

- The risk factors mentioned must be mitigated to the degree that record runs can be executed.
- Short-term solutions are to revert to co-locating equipment and people.
- Long-term solutions must include building stability and resilience into the architecture elements.

Major Cross Domain Issues

Shortfall in Telecommunications Infrastructure for Distributed Simulations (4 of 4)

Experiment Approach

- Resources have been budgeted starting in FY03 to address RDEC Federation performance and infrastructure and efforts are underway now to streamline DREN connectivity at each site to minimize MAN nodes and bottlenecks.
- HLA RTI fragility has been highlighted to the DMSO and to the Parallel and Distributed Simulation community as a critical issue.
- Near-term solutions may require co-locating critical federates.

Value

- The RDEC Federation, and architectures like it, is critical to the development and assessment of the Army's FCS and the Objective Force.
- Collaborative simulation from integrated facilities is the only way the Army can fully implement the SMART process, and support multiple customers without duplication of resources and expensive travel costs for experimentation.

Army Domain-Specific Issue

US Army - Aviation & Missile Command (1 of 2)

Description

- Assumptions have been made that validation is possible by making (small) adjustments to the simulation models to achieve agreement between measured data and simulation results.
- The possibility exists that a simulation is so unrepresentative that:
  - Validation is not achievable without drastic re-structuring and re-design of the simulation.
  - Changes to the simulation model have been made that produce the desired comparison between measured data and simulation results and satisfy validation criteria for a particular set of measured data but the adjustments are physically and mathematically unrealistic.

Consequences

- Validation may appear to be achieved based on a particular set of measurement data, but the model is not robust enough for results to be credible across a wide range of parameters and scenario variations.
- Considerable time and effort may be spent before the realization of the inadequacy of the simulation becomes apparent.

Army Domain-Specific Issue

US Army - Aviation & Missile Command (1 of 2)

Candidate Solutions

- Solutions to issues described include:
  - M&S and VV&A experience to combat the design of inadequate simulations.
  - Use of as wide a range as possible of measured data for performance of VV&A and the division of the simulation in modules and sub-systems for validation at this level before applying validation processes at the overall system level.

Experiment Approach

- Validation should be considered a continuous process throughout the life of the simulation and applied continually when new data become available.

Value

- With such a continuous process the credibility and utility of the simulation increases as a function of time.