Modeling and Simulation at APL

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APL has made significant modeling and simulation (M&S) contributions to sponsor programs over many decades. As computer technology has advanced, our ability to model key aspects of a system design before it is built, and to simulate that design's performance over time, has made it possible to significantly improve system performance while diminishing the need to build expensive hardware for test purposes. As the interoperability of both systems and simulations has gained in importance, APL has also applied M&S skills in this emerging area. This article provides an overview of M&S at APL across all program areas and highlights a few of the many M&S projects that have been completed recently or are currently under way.

INTRODUCTION

Modeling and simulation (M&S), in general usage, refers to the process of representing an entity and its behavior. Although there are various definitions of the terms *model* and *simulation*, this article uses those of the DoD[1]:

> *Model*: A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process
> *Simulation*: A method for implementing a model over time

Models and simulations are often classified by DoD into four levels—campaign, mission, engagement, and engineering, usually depicted as an "M&S pyramid" (Fig. 1). M&S applications at APL span all levels of this pyramid, with campaign models and simulations being applied in warfare analysis; mission-level simulations in such areas as air defense, missile defense, and power projection; engagement simulations in most DoD weapon system projects; and engineering-level models and simulations in many of these areas, as well as in strategic systems test and evaluation (T&E), space applications, and defense communications. Underpinning these engineering-level models is a strong base in phenomenology and environmental modeling to support undersea warfare, space science, and radar systems applications.

This article gives a broad overview of M&S at APL. Starting with a brief historical perspective, we then characterize the prevalence and use of M&S across all of the Laboratory's program areas. Next we highlight a number of current and recent efforts and finally provide some perspectives on APL strengths and opportunities in M&S.

HISTORICAL OVERVIEW

M&S has been a key technology area since APL's inception in the early 1940s—we are just using models

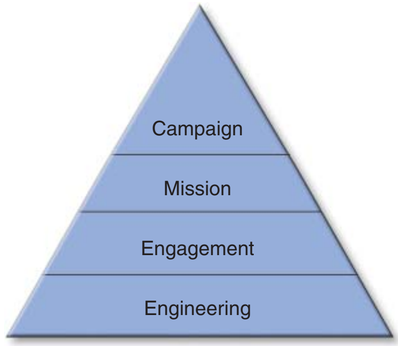

Figure 1. Traditional military modeling and simulation "pyramid."

and simulations differently and more efficiently now, capitalizing on rapid advances in digital computer, display, and networking technologies. Evidence of the early use of M&S can be found in the historical account of APL's first 50 years published in 1993. The following refers to the development of an improved gun director for firing shells carrying the APL-developed VT fuze:

> Because time was short and resources were limited, the first experiments on the new gun director were done at the Laboratory's Silver Spring offices with hastily improvised test equipment, including rocking wooden platforms driven by Ford Model T engines to simulate the pitching motion of a ship's deck. By 1944 the new APL-developed gun director, known as the Mark 57, was ready for action.[2]

By the late 1950s, use of computer-based models had begun, supporting the development and testing of APL's missile programs. In the early 1960s, the Laboratory's developments in satellite navigation were supported by computer-based calculations. To assist in guidance and control development for missiles, a hybrid analog-digital computer was employed for simulations. By the early 1970s, the APL Computing Center housed the IBM 360/91, which was used to run six-degree-of-freedom (6-DOF) simulations of missile flights and simulations of warhead detonation damage among its many other uses.

The evolution and proliferation of computer-based models and simulations at the Laboratory since the 1970s has tracked the evolution of computing equipment. As minicomputers supplemented the earlier mainframes, computer-based models and simulations spread to many laboratories and facilities at APL, supporting analysis, design, engineering, and T&E across many projects, from Fleet defense to space to submarine security applications. After workstations and PCs emerged in the 1980s, the applications of models and simulations grew significantly, as individual engineers and scientists now had the local resources to develop and apply appropriate models and simulations to their daily work. In the 1990s, improved networking capabilities provided the ability to connect different computer systems running different simulations to produce synergistic results, and APL entered the area of advanced distributed, or interoperable, simulation.

The *Johns Hopkins APL Technical Digest* has contained a number of articles on various APL M&S projects going back to the 1980s. Two issues devoted exclusively to M&S in 1995[3,4] provide a sampling of efforts during that time frame.

IMPORTANCE AND STATUS OF M&S

M&S is important to the Laboratory because of our broad involvement across concept development, system design and development, T&E, and, to some extent, training for DoD, NASA, and other programs. In each of these areas, M&S has become increasingly important to our sponsors as systems have become more complex, attention to cost has been heightened, and the consequences of failure during tests or operations have increased. Use of M&S allows exploration of the potential performance of new systems and alternative designs before more costly physical prototypes are built; it provides a cost-effective means of investigating interoperability in a system-of-systems environment before fielding systems or upgrades; and it is sometimes the only feasible way to study a technical problem (e.g., kill probabilities in *M*-on-*N* missile engagements, lethality of kill vehicles against submunition warheads as a function of strike angle).

Because of these and other considerations, M&S is used *pervasively* at APL. Although it is virtually impossible to estimate the resources associated exclusively with M&S, a measure of the potential scope of the use of models and simulations can be found in the database that holds the resumes of over 1800 professional staff members: more than 50% contain variations of the words "model" or "simulation," and the number has grown over the last 5 years.

Models and simulations are employed in every business area at APL to various degrees. Table 1 provides a summary of selected M&S capabilities in each business area and a few examples of M&S applications, along with areas of M&S emphasis (referenced to the military M&S pyramid in Fig. 1).

CURRENT EFFORTS

Only a few examples of M&S activities at APL can be cited in this short treatment. Some of these examples provide insight into the types of work being performed in two traditional APL business areas—air and missile defense, and undersea warfare. To highlight a few emerging areas, examples are also provided in training, where advances in PC technology, coupled with APL systems engineering skills and subject matter expertise, have enabled a number of innovations. Finally, the emerging area of interoperable simulation

Table 1. Characterization of M&S use in APL business areas.

Business area (and M&S areas of emphasis)	Selected M&S capability areas	Sample M&S projects/models and simulations used
Air and missile defense (engagement, engineering, mission)	Radar and other sensor systems	AN/SPY-1 FirmTrack simulation
	Missile and other weapon systems	Standard Missile 6-DOF simulations Ship Self-Defense System simulation
	Guidance, control, navigation, and fuzing	Guidance System Evaluation Laboratory System component (e.g., IR, RF) models
	Command and control systems	Wrap-Around Simulation Program Area Air Defense Commander simulations
Strategic systems T&E (engineering)	Test requirements and design	Submarine-Launched Ballistic Missile 6-DOF trajectory simulation
	Analysis of Submarine-Launched Ballistic Missile reliability, performance, and accuracy	Navigation error covariance simulator Ballistic reentry vehicle trajectory reconstruction program
Strike (engagement, engineering, mission)	Guidance, navigation, and control	GPS/Inertial Navigation System hardware in the loop
	Flight vehicle dynamics	Tomahawk missile simulations
	Mission effectiveness	Joint Integrated Mission Model
Defense communications (engineering)	Modulation and coding	Turbo-coded Software Radio Digital Signal Processor simulation
	Signal jamming and interception	EHF low-probability intercept investigator
	Architecture and traffic modeling	OPNET
Undersea warfare (engineering, engagement)	Acoustic, electromagnetic, and signal modeling	APL Normal Mode acoustic model
	Ocean, atmospheric, and environmental modeling	Master Environmental Library
	Operations assessment	Tactical Evaluation Support System
Military space (engineering)	Ballistic missile defense target and background phenomenology	Signature (e.g., optical) codes Custom-built plume models
	Environmental impacts on systems	Radar propagation codes
Civilian space (engineering)	Environmental modeling (e.g., atmospheres, fields, insolation)	Custom-built special-purpose models (e.g., optical attenuation)
	Spacecraft design	Custom-built attitude control models NASTRAN
Warfare analysis (mission, campaign)	Theater protection analysis	Extended Air Defense simulation Surface Anti-Air Warfare Multi-ship simulation
	Assured access analysis	Battle Force Engagement Model
	Effects-based operations analysis	FireSim XXI
	Affordability and risk assessment	Parametric Review of Information for Costing and Evaluation
Information operations (engineering)	Network attack modeling	OPNET-based models for denial-of-service attack and instrusion detection system design/test
Biomedicine (engineering)	Corneal modeling	Cornea model for birefringence
	Biomechanics/finite element modeling	3-D femur model Hip and brain finite element models
	Cardiac/cardiovascular simulation	Distributed cardiac/cardiovascular simulation for space biomedicine
Counterproliferation (engineering, mission)	Biological/chemical cloud transport and dispersion	Indoor vapor and particulate modeling
	Biosensor performance modeling	Time-of-flight mini-mass spectrometer simulation
	Biosurveillance	Biosurveillance model for disease outbreak using multiple data sources
Science and technology (engineering)	Object-oriented design applications	High Level Architecture development
	Multiresolution modeling	Multiresolution acoustic propagation modeling
	Knowledge-based systems	Virtual spacecraft design tool
Emerging business areas (engagement, mission)	PC-based training applications	Ship Control Training Program FBI interview training software Advanced SEAL Delivery System trainer
	M&S architecture development	Army Future Combat Systems M&S architecture definition

is highlighted by APL's leadership role in the development of the DoD High Level Architecture and a current APL application of that technology.

Air and Missile Defense

The Standard Missile Family of Simulations

APL serves as the Technical Direction Agent to the Navy for the Standard Missile (SM) Program. To support systems engineering analysis and test activities in this role, an extensive family of 15 Standard Missile simulations has been developed over the past 30 years. Although the simulation versions relating to the earlier missile configurations (i.e., SM-1 Blocks V and VI and SM-2 Block I variants) are not currently being used for analysis efforts, all of the simulations are maintained on a classified network of UNIX-based workstations under rigorous configuration management procedures.

Except for those earliest versions, all of the simulations include 6-DOF missile kinematic representations based on nonlinear, coupled, three-dimensional, wind tunnel–derived aerodynamics. For later simulation versions, the missile guidance, navigation, control, and (where applicable) fuzing algorithms are based on detailed flight software requirements. The more recent versions model not only the missile system, but also related Aegis Weapon Control System (WCS) missile/ship interface functions (e.g., missile launch scheduling, missile and target track filtering, uplink processing, midcourse guidance, and handover processing). Most of the simulations have been verified against models independently developed by the missile contractor and validated against ground and flight test data. In addition, the SM-2 Block IVA and SM-3 simulations have been integrated into the APL Guidance System Evaluation Laboratory, where they provide the capability of closing the guidance loop around actual missile guidance section hardware and software to evaluate the integrated flight software design.

APL uses the Standard Missile simulations as part of systems engineering activities in support of the missile design and test process. Early in a missile development program, we use the simulation to perform system trade studies. These studies determine the underlying requirements for the missile design (such as missile response time, guidance sensor acquisition range and track accuracy, fuzing sensor accuracy, etc.). With such requirements established through simulation trade studies, the simulation is then used as the primary tool for developing and evaluating candidate functional design options for both the missile and the Aegis interface. As the missile and ship contractors develop detailed designs based on the identified options, APL implements the contractor designs into the simulation, identifies any deficiencies, and recommends improvements. When the development program progresses into the flight testing phase, the simulation is used to define and evaluate candidate flight test scenarios and provide missile performance predictions for preflight mission control panel meetings conducted by the Navy.

In addition, following each development flight test, the flight telemetry data are compared to simulation predictions to identify areas where simulation model updates are required or where the flight round did not perform in accordance with its requirements. Once credibility in the simulation has been established through comparisons to flight test data, the simulation is used to evaluate system performance throughout the missile engagement envelope. This last activity is especially critical given that budgetary constraints typically preclude the conduct of an extensive flight test program. Through this use of detailed 6-DOF simulation models as part of the APL systems engineering process, confidence is provided to the Navy that the evolving Standard Missile design meets its overall performance requirements.

The AN/SPY-1 Radar FirmTrack Simulation

The APL AN/SPY-1 radar FirmTrack simulation is a high-fidelity Monte Carlo simulation of the Aegis AN/SPY-1 series of multifunction phased array radars—a subsystem of the Navy's Aegis Weapon System (AWS)—that are fielded on Aegis cruisers and destroyers. FirmTrack has been used since 1980 on many Aegis-related tasks and is designed for many purposes including engineering trade studies, system design (forward-fit and back-fit), test planning (e.g., scenario certification), mission planning, post-test reconstruction, and *in situ* performance assessment (e.g., in a shipboard decision aid). FirmTrack has been constructed through algorithmic interpretation of the AN/SPY-1B/B(V)/D specifications for the AWS. It has undergone continual development to keep pace with (and in many cases to anticipate) the new missions and functionality that have been added to the AWS over the years. Specific versions of FirmTrack have been accredited to support the Cooperative Engagement Capability (CEC) Operational Evaluation and Live Fire T&E tests.

FirmTrack can be used to characterize AN/SPY-1 performance in an almost unlimited variety of scenarios (dependent on input data). As a high-fidelity model, virtually any information that the AN/SPY-1 radar supplies to the AWS can be extracted from the FirmTrack simulation. This information may be examined directly to evaluate radar performance using various graphical or statistical output data products. Output data files may also be used as input to other models. When combined with models of other parts of the AWS, the system's end-to-end performance can be evaluated. FirmTrack is also being configured to run as part of an online end-to-end AWS simulation.

FirmTrack is a one-on-many simulation, i.e., it represents one radar observing and tracking as many targets as are input for that model run. In an end-to-end simulation, multiple copies of FirmTrack can be used to represent multiple Aegis ships simultaneously observing a common air picture. A high-level block diagram of the simulation is shown in Fig. 2. Within FirmTrack, all important aspects of radar functionality are accounted for on a dwell-by-dwell basis. Environmental and target data are read in as input files. The simulation then performs the search function using either internally generated search doctrine (for Anti-Air Warfare [AAW] or Theater Ballistic Missile Defense [TBMD]) or by accepting Resource Planning and Assessment search sectors (for TBMD). Detection processing, including monopulse angle estimation and cross-gating (correlation) of search detections with currently held tracks, is simulated. Both clutter and clutter rejection processing, including Track Initiation Processor transition-to-track and Moving Target Indicator track processing, are modeled. SM-2 missile acquisition and tracking are also modeled, along with both AAW- and TBM-specific track filtering and processing, including redundant track processing.

For TBMD, the AN/SPY-1 radar performs both characterization and warhead discrimination functions, which select reentry vehicles for engagement and simultaneously reject debris. These functions are modeled in FirmTrack and the results can be examined directly and/or sent to the SM-2/SM-3 6-DOF simulation for end-to-end analysis. Many lower-level functions are also simulated to support the more visible functions listed here. One critical underlying function is the radar scheduler, which prioritizes and queues up all radar dwells (search, track, missile, etc.) for all missions (AAW, TBMD). This function is modeled in detail to produce realistic performance results and track radar resource use. In summary, FirmTrack is an extremely capable simulation that can be used by radar engineers to obtain detailed insight into AN/SPY-1 radar performance under a multitude of real-world conditions.

The Cooperative Engagement Processor Wrap-Around Simulation Program

CEC[5] is a system that enables multiple ships, aircraft, and land-based platforms in a battle force to operate as a single entity by sharing precision sensor and weapon

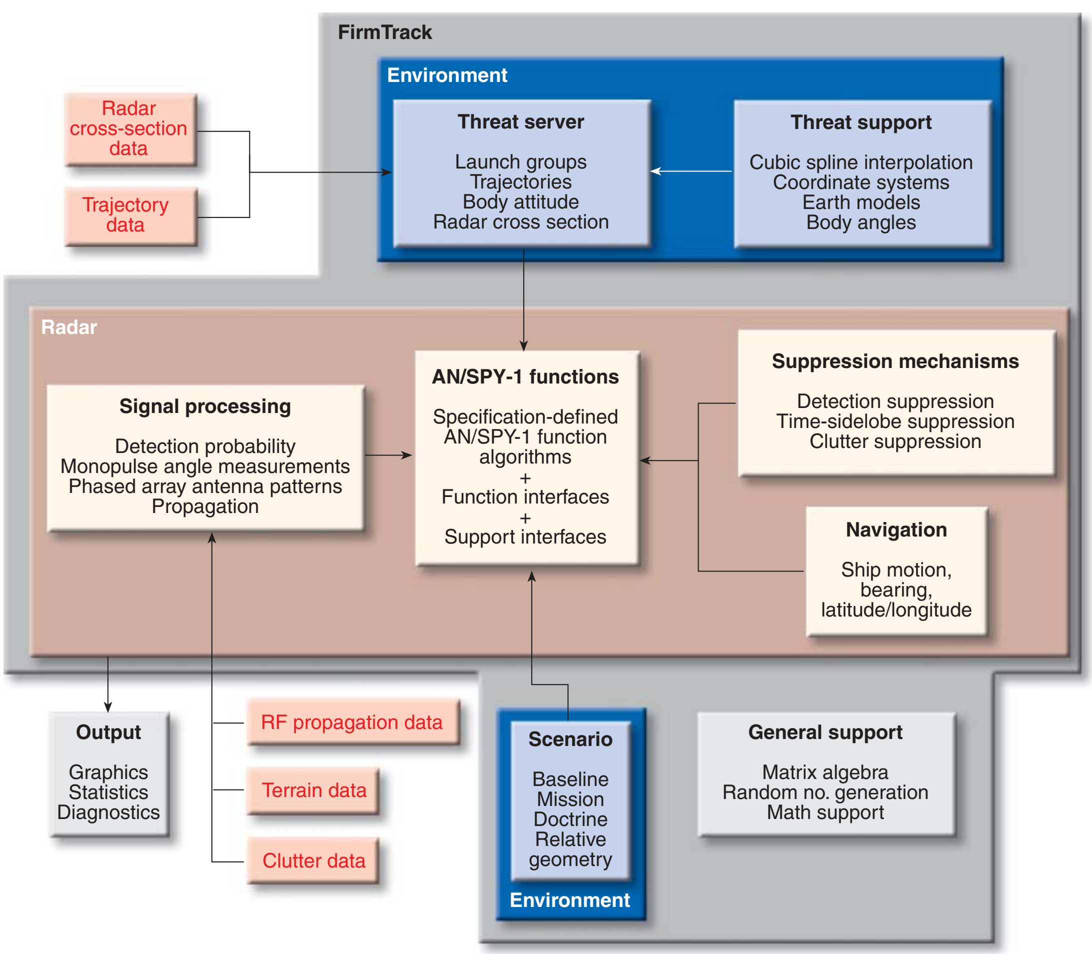

Figure 2. A high-level block diagram of the AN/SPY-1 FirmTrack simulation (external inputs shown in red).

data via a radio-based communications network. To participate in a CEC network, a unit must be equipped with a Cooperative Engagement Processor (CEP) for data processing and a Data Distribution System (DDS) to provide the communications links necessary for data exchange with other CEC units. The CEP Wrap-Around Simulation Program (WASP) was developed to allow an end user to perform unit tests, system integration tests, and system validation tests of tactical CEP hardware and software in hardware-in-the-loop and software-in-the-loop environments.

The CEP WASP provides the ability to test up to 10 CEP units in a single test bed—both within a single laboratory where test assets are co-located and in a physically distributed test environment. It consists of a sophisticated scripting capability as well as real-time target generation and medium-fidelity sensor, combat system, ship's motion, and communications simulations that can operate in a stand-alone, locally networked, or geographically distributed simulation environment. Figure 3 presents a typical CEP WASP simulation environment.

The CEP WASP has been integrated with several different DoD and contractor test beds, using the IEEE standard 1278.1 Distributed Interactive Simulation (DIS) interface, to provide enhanced testing capabilities. It has also been formally accredited and subsequently used by the Navy to support key CEC developmental and operational tests.

Undersea Warfare: Acoustic Propagation Modeling

The effects of the natural environment on sensors, platforms, and weapons are an essential component of DoD advanced distributed computer simulations that support training, acquisition, and analysis. APL has developed a methodology, now in use by the Navy (e.g., Naval Warfare Development Command Anti-Submarine Warfare simulation in the Global 2001 war game; Fig. 4), for significantly enhancing the representation of environmental effects in complex computer simulations.[6] This methodology, termed Multiresolution Interaction Validity (MIV), essentially provides a means of capturing the complex dependence of a given environmental effects model on its input parameters and a means of using that knowledge to better employ the model to accomplish the objectives of the desired computer simulation.

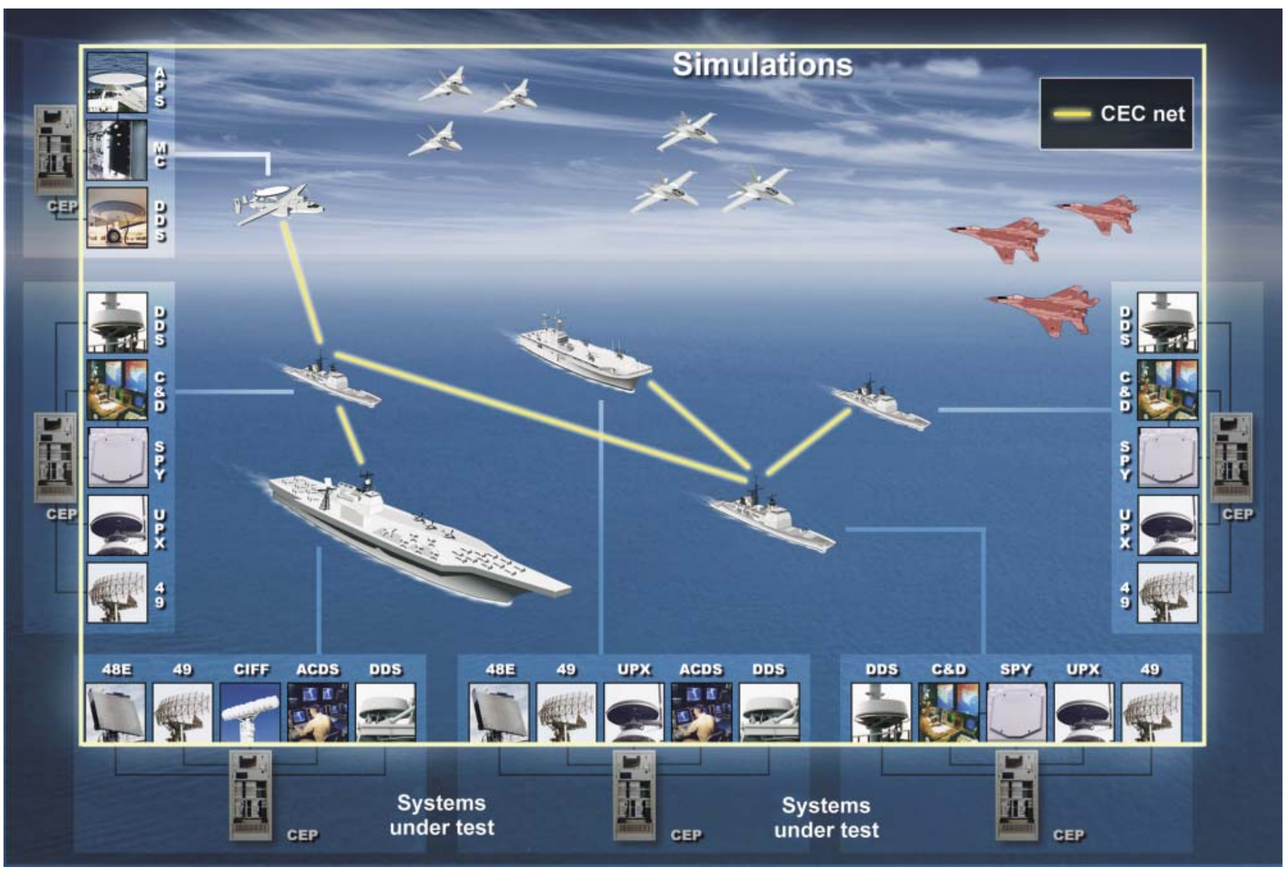

Figure 3. Typical Cooperative Engagement Processor (CEP) Wrap-Around Simulation Program (WASP) simulation environment. (48E = AN/SPS-48E radar, 49 = AN/SPS-49 radar, ACDS = Advanced Combat Direction System, APS = AN/APS-145 radar, C&D = Aegis command and decision, CIFF = central identification, friend or foe, DDS = Data Distribution System, MC = E2C mission computer, SPY = AN/SPY-1 radar, UPX = AN/UPX-29 identification, friend or foe.)

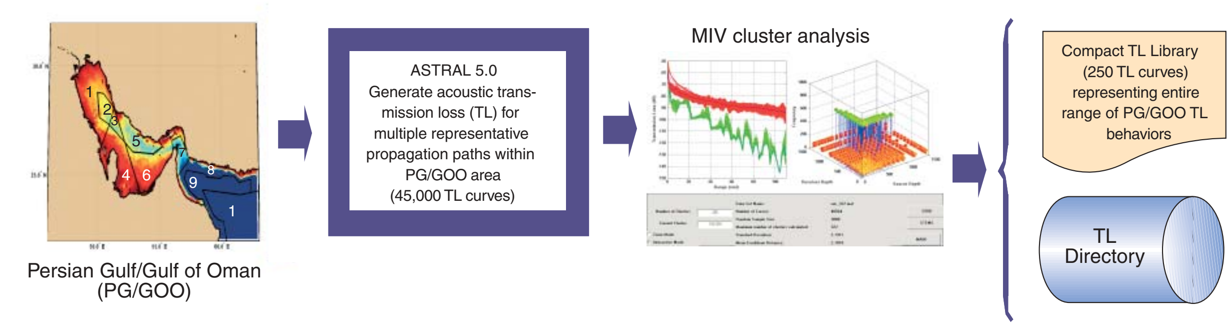

Figure 4. Development of Global 2001 war game acoustic transmission loss library using Multiresolution Interaction Validity (MIV).

Because the representation of environmental effects often requires computationally intensive physics-based computer models, it is often not feasible (owing to limited available CPU cycles and/or requirements on simulation clock speed) to include a highly detailed representation of these effects in computer simulations. MIV can be used to identify and develop (in advance of the simulation) a compact set of model calculations that can be used as a fast-access library to represent accurately the entire spectrum of effects required of that model during the simulation. If the simulation requires greater accuracy than is feasible using the fast-access library and simulation clock-speed requirements will allow, MIV can support the development of a strategy for determining when a real-time model calculation is necessary. In addition, MIV can support a simulation run-time selection between use of the fast-access library or a real-time model calculation. MIV can also be used in a networked simulation application to provide a rapid assessment of the consistency between two or more environmental models employed in the simulation exercise.

Briefly, the MIV methodology uses cluster analysis to categorize the range of environmental effects model outputs over the input parameter space of interest. The number of categories is determined by the user and depends on the level of accuracy required by the simulation exercise. One Navy application of MIV requires the simulation of acoustic sensor systems. This is accomplished by performing numerous acoustic transmission loss model calculations, which are made to encompass the range of environmental conditions encountered in the geographic region of interest and then categorized using cluster analysis. The representative transmission loss calculations are then identified and collected to form the fast-access library, which supplies the data to the sensor model(s) used in the simulation.

Emerging Business Areas: Training

PC-Based Training Simulations

A recent study conducted by a Defense Science Board Task Force[7] determined that—although the United States enjoys a clear superiority in military training—a new training revolution is afoot due to advances in information technology, through which adversaries are closing this superiority gap. The Task Force recommended that, to prevent the erosion of this superiority and avoid a "training surprise" by other nations, the DoD should fully use emerging technologies and, among other things, develop more self-paced, just-in-time training tools. The Laboratory's PC-based simulator development, the first application of which is described in Ref. 8, falls directly in line with this recommendation, effectively bringing a system to the students and enabling them to train whenever they can and wherever they are.

APL's PC-based simulator effort has thus far addressed training for submarine systems (Fig. 5). Work began with a series of ship control simulators built to replicate the systems and instrumentation in submarine control centers. These simulators have been developed for U.S. and U.K. submarine classes and provide a means for learning how to operate ship control systems. A high-fidelity, 6-DOF hydrodynamic simulation is at the heart of the product and is linked to on-screen replicas of the submarine's control panels, as well as to a three-dimensional visualization of the ship in its submerged environment. The simulators are well suited for self-paced training because they can run on a laptop and include a "virtual instructor" that identifies trainee errors during a training scenario. These products are being used in training centers and aboard ship to supplement the pipeline for submarine driver qualification. They have provided training when access to full-scale simulators and instructors is limited.

APL has also been developing a family of PC-based simulators for the Navy's Trident submarine missile system. One of these products, the Trident launcher simulator, trains a 12-person crew to coordinate the rapid-fire launching of these missiles. Although a large-scale team trainer facility is available for this purpose, crews cannot access it as often as is necessary for qualification and refresher training. The PC-based launcher simulator has addressed this problem by

Figure 5. PC-based simulators developed for submarine systems.

operating in multiplayer mode in an electronic classroom of networked PCs. Here members of an entire Trident launcher crew can interact with each other and with their launcher systems in an extremely realistic manner.

APL continues to apply PC-based simulation design to other training arenas, particularly for the Navy SEALs' newest combatant submersible (Fig. 6). In this application, the Laboratory is building a full-scale cockpit replica simulator, driven by PCs, and a complementary single-PC simulator that operates with identical software. The single-PC version will be used for mission planning and rehearsal.

The FBI Training Simulation

APL has developed a unique PC-based training tool that emulates human behavior using a computer-simulated subject in a realistic scenario. The first training simulation was created for the FBI to teach investigators to detect deception.[9,10] The self-paced multimedia courseware provides a meaningful interview experience.

In the training scenario, the FBI student/agent interviews a bank loan officer about a crime to determine his involvement. Sometimes he committed the crime and at other times he did not. The interview is conducted by selecting from an extensive pre-scripted list of possible questions and observing the subject's responses, both verbal and nonverbal. A stochastic model of the subject produces responses to the interviewer and his questions based on logical and emotional factors associated with human behavior. Because most questions have many possible responses and the simulated subject may or may not be guilty, the interview proceeds differently each time it is conducted. While the subject's behavior and responses are determined by a computer model of his brain, the visual and audible responses are presented by video sequences using an actor, as shown in Fig. 7. This allows for a realistic, two-way conversational interview. Like a real interview, a complete interview is expected to take over an hour.

The simulation gives the trainee experience in asking proper questions and distinguishing between deceptive and truthful responses. It also provides a critique of the interview along with a numerical score. The benefit of this type of training tool is that it gives a student an interactive experience to supplement and reinforce traditional classroom instruction. The PC platform permits multiple replications at low cost. As skills develop, students can see their critique improve and their scores rise. The simulation was designed to enhance classroom training at the FBI Academy, but now has more than 15,000 users in law enforcement agencies throughout the United States and in more than 20 foreign countries.

The Emerging Area of Interoperable Simulation

A current critical challenge in the U.S. defense community is improving the interoperability of models and simulations. DoD defines *M&S interoperability* as "the ability of a model or simulation to provide services to, and accept services from, other models and simulations, and to use the services so exchanged to enable them to operate effectively together."[11] The DoD's effort in this area began in the late 1980s with the Defense Advanced Research Projects Agency (DARPA) SIMNET, and gained more prominence in the early 1990s, particularly

Figure 6. Navy SEAL combatant submersible simulator.

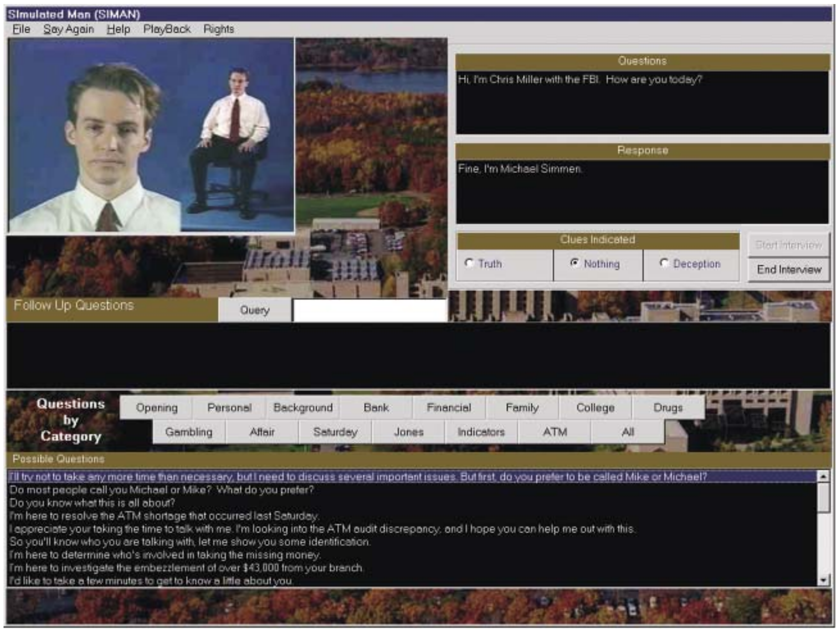

Figure 7. Typical screen view from the FBI interview training simulation.

During this initial effort, APL was the lead in the development of the Object Model Template component of the architecture, which defines a standard presentation format and syntax for describing HLA object models.

A functional view of the HLA is shown in Fig. 8. The most fundamental construct in an HLA application is known as a *federation*. A federation is a set of software applications interacting together under a common object model and Runtime Infrastructure (RTI) to form a unified simulation environment. Each member of the federation is called a *federate*. A federate serves as a software application with a single point of attachment to the RTI and can represent a simulation, a runtime tool, or an interface application to a live participant in the federation. The RTI is a distributed operating system with services that support and control the exchange of information among federates during execution.[13] In 1997, an Independent Research and Development project[14] was conducted to investigate the use of this new technology, which exploited connectivity among several APL facilities provided by the Laboratory's Secure Communications and Networking Infrastructure.

The HLA has continued to mature and evolve, with the most recent DoD release of the HLA specifications (V1.3) occurring in February 1998. During this maturation process, APL has led the development of several supporting HLA products such as the FEDEP

for real-time training applications, with the development of the DIS protocols. The Laboratory's first DIS effort began in 1993 under DARPA sponsorship. DoD subsequently embarked on a more general architecture effort—known as the High Level Architecture (HLA)—to extend interoperability into other types of simulations.

The High Level Architecture

In October 1995, the U.S. Under Secretary of Defense for Acquisition and Technology (USD(A&T)) published a master plan for the use of M&S in DoD applications.[12] Included in this plan was a set of high-level M&S objectives. The first major objective was the establishment of a Common Technical Framework (CTF) for M&S as a means of facilitating interoperability and reuse. The HLA was identified as the first and most prominent component of the CTF. The need for the HLA was based on the premise that no single simulation system could satisfy the needs of all users, and thus an architecture was required for composing unified simulation environments from multiple, interacting simulation systems. APL has played a prominent role throughout the development of the HLA.

Following an initial definition based on the synthesis of industry inputs and previous DoD architecture efforts and a prototyping phase to test and mature the architecture via active use in several different application areas, the baseline version of the HLA was released in August 1996. A month later, the USD(A&T) formally designated the HLA as the standard technical architecture for all DoD simulations and directed all DoD components to establish plans for transitioning to the HLA.

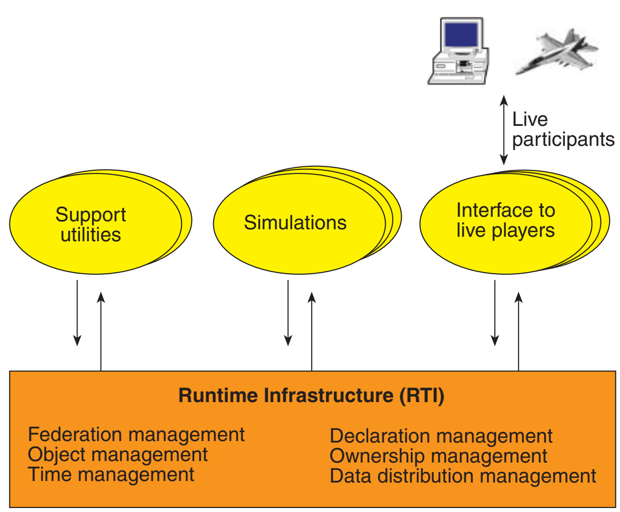

Figure 8. A functional view of the High Level Architecture.

(Federation Development and Execution Process). HLA V1.3 is currently a recognized DoD standard, and in September 2000, the Institute of Electrical and Electronics Engineers (IEEE) formally approved the 1516 series of HLA specifications.[15] DoD transition to IEEE 1516 is expected once supporting tools and other infrastructure components are developed to support the commercial standard. Over the last 2 years, APL has continued to provide technical assistance to several HLA-based initiatives in support of the Defense Modeling and Simulation Office (DMSO) such as Millennium Challenge 2002 (MC '02; being conducted by the Joint Forces Command) and the Environment Federation (EnviroFed).

ARTEMIS: An APL HLA Application

As systems become more complex, they can become increasingly difficult to test under realistic conditions. High-fidelity M&S becomes crucial to understanding system capabilities. Often high-fidelity simulations represent a piece of a larger overall system of systems. The HLA can be useful in bringing these components together to form an integrated end-to-end system simulation. An example of a successful application of the HLA to this type of environment is the ARTEMIS (the APL Remote TBM Engagement Missile/Ship) simulation, a high-fidelity, integrated, end-to-end Navy Ballistic Missile Defense simulation.[16] ARTEMIS uses the HLA to integrate pre-existing high-fidelity simulations with newly developed components to create a comprehensive Navy TBMD environment.

Figure 9 shows the primary components, or federates, of ARTEMIS: threat, ship navigation, SPY radar, command and decision (C&D), WCS, missile guidance, and missile signal processor. The threat federate provides a common threat picture and can generate both major objects and debris for a single threat or raid. Ship navigation provides a common understanding of both true and estimated ship position. The SPY federate is based on the FirmTrack simulation described previously. The simulation performs dwell-by-dwell scheduling, dynamic waveform selection, tracking of threat and missile, and RF discrimination functions. C&D, a newly developed component, computes interceptability, provides track management functions, and gives the engagement order to the WCS federate. The WCS, based on functionality from the APL Standard Missile 6-DOF guidance simulation, computes a fire control solution, launches the missile, and provides midcourse guidance and handover information. The missile guidance federate is also built upon the SM 6-DOF simulation, the government standard for the high-fidelity simulation of Standard Missile, to model missile flight. The missile signal processor federate draws on the BLAST (Ballistic Missile Localization and Selection Tool) simulation, which contains a high-fidelity representation of the IR sensor as well as the tracking, handover, target selection, and aimpoint algorithms. ARTEMIS integrates these federates to capture the closed-loop interactions among them. This function provides a crucial systems engineering tool for overall system performance assessment, design verification, and flight analysis.

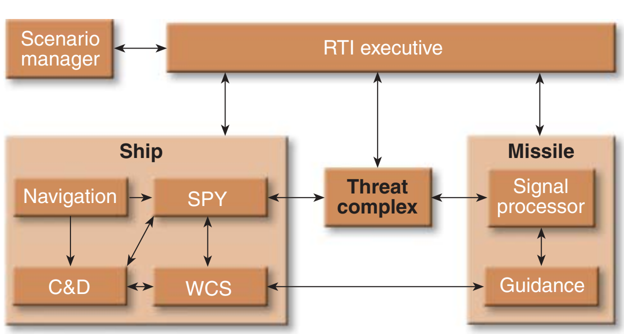

Figure 9. The primary components (federates) of the ARTEMIS simulation.

OPPORTUNITIES BASED ON APL'S M&S STRENGTHS

The Laboratory's greatest strength in M&S is its many knowledgeable technical professionals with M&S experience covering a broad spectrum of application areas. This breadth is apparent across business areas, as already discussed, as well as across the vertical levels of the M&S pyramid, from campaign-level down to engineering- and phenomenology-level models.

APL has externally recognized expertise in a number of specific M&S development and application areas including

- Missile and weapon system engineering-level models and simulations
- System-level weapon engagement simulations
- Force-level simulations in particular mission areas (e.g., missile defense)
- Phenomenology, signatures, and environmental modeling
- Validation of models (i.e., that the model represents the real world accurately)

Several APL staff members are well recognized in the external M&S community in certain emerging M&S areas for their roles in the development of the HLA; establishment of DoD verification, validation, and accreditation (VV&A) policies and practices for DMSO; and contributions to aspects of synthetic natural environment modeling and the emerging acquisition M&S area generally known as Simulation Based Acquisition (SBA). Several staff members have leading roles in different forums of the semi-annual Simulation

Interoperability Workshops sponsored by the Simulation Interoperability Standards Organization, which has gained prominence as a technical interchange vehicle in the military simulation community.

Opportunities for APL contributions to M&S development and application can be expected to continue and grow to some extent in the future. Our experience in M&S associated with system acquisition can be capitalized upon in particular. As emphasis on system-of-systems interoperability increases, the need for models and simulations to represent this complex environment will grow correspondingly. In addition, increasing emphasis on collaborative and integrated use of M&S across acquisition phases (sometimes referred to under the general SBA term) should present opportunities within specific acquisition programs.

Past APL experience in assuring that models and simulations properly represent the real world for their intended applications can also be leveraged. Within this general area of VV&A, the Laboratory's experience in validation of models and in assessing validity for particular applications (i.e., accreditation assessment) can be expanded into new application areas.

APL's experience across several departments and business areas in the general area of modeling the environment (undersea, atmospheric, and space) may also bring opportunities, since representations of the environment are critical to accurately representing system performance in models and simulations. Possibilities could range from applying our expertise at the engineering level to determining appropriate abstractions of environmental effects for higher-level models with demanding execution time requirements.

APL has historically not been involved in training applications of M&S (except for some of the emerging PC-based applications noted earlier). However, training remains the most well-funded area of M&S application in DoD, and the area in which many M&S innovations (e.g., interoperable simulation) have seen their first significant uses. Moreover, the performance of systems is becoming even more dependent on the performance of the systems' human elements. So from a systems engineering perspective, training of system operators requires and deserves attention. The key will be to determine the "niche areas" of the broad training area where APL can make near-term contributions of significance.

With respect to particular areas of M&S application, although APL's M&S strengths tend to be correlated with the more long-standing business areas, some of the newer business areas offer opportunities for expansion. In particular, two application areas—(1) general network modeling (including information operations) and (2) biochemical transport/diffusion and biosurveillance for counterproliferation and homeland security—appear to be fields in which APL can play an important role.

CONCLUSION

Modeling of systems and their components and simulation of their behavior over time have been an important part of APL's work since its inception 60 years ago. As computer and information technology has advanced, the Laboratory's capabilities in M&S have increased accordingly, enhancing the ability to provide significant contributions to many sponsored programs. As the need for interoperability of systems becomes more and more important, the need to assure that these systems will perform correctly together will result in increasing emphasis on models and simulations.

APL's accomplishments in M&S span all business areas. We possess considerable depth and breadth in the traditional areas such as air defense, strategic systems T&E, submarine security, and power projection. Newer areas such as information operations, counterproliferation, and homeland security are expected to be growth areas for APL M&S contributions in the future. Just as emphasis on interoperability of systems is increasing, so is the emphasis on interoperability of models and simulations, and APL is keeping pace with advances in this field. In summary, M&S has been one of APL's key science and technology areas throughout its history, and is expected to continue and to expand in the future.

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