Raytheon’s Modeling and Simulation
Supporting all phases of system development, test and training
Modeling and simulation is everywhere today: in schools and universities, to help teach as well as guide research in science, technology, engineering and math; in industry, to aid product design and perform preliminary testing; and in government, to help characterize, develop and manage our nation’s critical systems from weather forecasting to defense applications and national security.

Raytheon has been deeply involved with all phases of modeling and simulation, from the design and development of models and simulation systems to their use in real-world, mission-critical applications. Raytheon develops, operates and maintains many of the highest fidelity models and simulations for our nation’s defense and intelligence organizations.

Our simulation capabilities support everything from initial conceptual development activities, to product designs, to system testing, to training for fielded systems. In the area of field test planning and pre-test assessment, simulations play a central role in optimizing the value of what are typically expensive field tests, and in some cases simulations actually reduce the amount of field testing needed. The features in this issue highlight the technical innovations and creativity of our simulation engineers and how their simulations add value to our products and services.

In our Leaders Corner, Dan Dechant discusses his role and objectives as the new vice president of Corporate Engineering. Also, Chief Software Engineer Danielle Curcio examines the future of software development and the ongoing integration of simulations and software, including a discussion of the Raytheon Cyber Operations and Development Evaluation (CODE) center — a development, simulation and test facility for cybersystems.

Our Eye on Technology section includes papers on advanced manufacturing and software development innovations — both focused on improving performance while also meeting our customers’ cost requirements.

Finally, our Events section showcases our 2012 Excellence in Engineering and Technology Award winners and Raytheon’s MathMovesU® participation at the annual meeting of the American Association for the Advancement of Science.

Best regards,
Mark E. Russell
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Modeling and Simulation: Its Growing Importance

Modeling and Simulation (M&S) is a critical capability employed in developing and using complex systems. M&S supports the entire product life cycle, from initial concept development to design, integration, test and evaluation, deployment and sustainment, and future evolution. Since there is substantial variation in the purpose, type, fidelity and complexity of analyses performed across the program life cycle, Raytheon’s M&S portfolio offers a wide spectrum of tools, from spreadsheet-level to detailed high-fidelity simulations.

The ultimate objective of an M&S activity is to provide the basis for making technical and programmatic decisions. From early concept studies (Is the idea feasible?), through test and evaluation (Does the system meet its requirements in real world environments?), the system development process is all about making sound data-driven decisions. Obtaining this information by testing the actual system is generally impractical because the data are usually needed before the system has been built, and is too expensive because the range of threat and environmental parameters would necessitate an enormous quantity of testing. Thus, a strong M&S capability is needed to provide the data to inform the system development process.

The fidelity and pedigree of simulations and their associated models must be appropriate for the depth and breadth of the studies being done. Figure 1 illustrates the range of tool fidelities and how they are applied to programs based upon the system maturity (or Technology Readiness Level [TRL]) and analysis objectives. Several of the simulation analytical tools discussed in this issue are represented here. Lower-fidelity analytical tools, such as the Operations Analysis Toolkit (OpsTool) shown in Figure 2, are generally preferred for initial system conceptual or architectural studies because they permit a broad range of alternatives to be studied relatively quickly and because the system parameters are not yet known to a precision that would justify a higher-fidelity simulation. As the system design matures, higher-fidelity, forward-time digital simulations replace analytical tools and more generic simulations to support algorithm development and detailed performance predictions. The all-digital simulations are eventually supplemented by software/hardware-in-the-loop (SIL/HWIL) simulations.

1 TRL is a measure used to assess the maturity of evolving technologies.
to support system verification and validation and pre-flight preparation (Figure 3). At all stages of development, immersive virtual simulation provides a realistic environment for concept of operations (CONOPS) definition and evaluation, operator training, and tactics, techniques and procedures (TTP) development and refinement.

Traditionally, distinct simulation tools were used for different parts of the development process. Early analyses using low-fidelity desktop tools would give way to detailed simulations as the design progressed. Eventually SIL and HWIL environments would be created, which might or might not have some commonality with the digital simulation. All of these were often custom tools created specifically for each program. This resulted in duplication of effort, high cost and potential difficulty in reconciling results from different simulations. Also, simulation efforts often involved a tradeoff of fidelity and breadth; individual systems used very high-fidelity simulations, but that fidelity was often reduced when applied to the analyses of more complicated systems (SoS). Today, we apply a more integrated approach that is based on rapidly configurable simulations that can grow in fidelity as a system design matures from initial trade studies through SIL/HWIL testing. An additional benefit of this approach is the ability to integrate multiple simulations into high-fidelity SoS testbeds. Additionally, Raytheon exploits the explosion of computing technology to support high-fidelity target and environment simulations as well as immersive visualization environments to facilitate concept of operations (CONOPS) development and training. In this issue of Technology Today we illustrate these trends by highlighting some of the M&S tools and initiatives currently ongoing at Raytheon.

**Rapidly Configurable, Modular Simulation Environments**

To minimize systems engineering cost as well as to speed the development process, we need to avoid starting from scratch when developing system simulations. genSIM, discussed in the article “Using the genSim Family of Simulations for System Design,” provides a framework for rapid, low cost, low risk simulation development. genSIM supports the entire life cycle, permitting increased fidelity as a design matures from initial concept studies through HWIL testing. Two examples of simulation environments tailored to specific technology areas are described in the articles “Interoperability Analysis of RF Systems” and “Cyber Analysis Modeling Evaluation for Operations (CAMEO) — Countering the Cyberthreat.” The former discusses the Communication System Engineering Toolset (CoMSET), which provides a simulation environment and process that facilitates the analyses of RF systems in complex spectral environments. CoMSET supports single system performance evaluation and interoperability analysis of multiple RF systems located on the same or separate platforms. CAMEO is a toolset for analyzing cyberthreats and the efficacy of countermeasures. Recognizing the dynamic nature of today’s cyberthreat, CAMEO allows active defense measures such as cyber maneuver and random reconstitution to be assessed.

**Full Life-Cycle Simulation Support**

As previously mentioned, simulation fidelity typically grows as the system matures. While initial studies often rely on analytical tools, forward-time simulations are necessary for assessing complex interactions (such as the scheduling and resource loading of a multifunction radar). These simulations will rely on lower-fidelity representations of the system since the detailed design is not

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**Figure 3. Hardware-in-the-Loop (HWIL) simulations provide a high-fidelity assessment of missile seeker performance under dynamic engagement conditions.**

CARCO Rate table supplied by Ideal Aerosmith, LLC.
complete and thus high-fidelity representations are not necessarily appropriate. As the system development progresses, the simulation fidelity can and must increase. That said, it is undesirable to throw away the initial low-fidelity simulation and start all over with a higher-fidelity one later in the process. What is needed are tools that support system simulation efforts and can keep pace with the product development, by increasing simulation fidelity as the system matures. One such tool is described in the article “Raytheon Air and Missile Simulation: A Selectable Fidelity Tool for Radar and Systems Analysis.” RAMS, employed for the analysis of radar performance and algorithm development, uses a modular architecture that permits the replacement of generic modules with higher-fidelity system-specific ones as the design matures. RAMS supports a range of simulation needs — from early concept evaluation through system-level end-to-end performance assessments and detailed waveform and processing development — simply by plugging in the appropriate models.

System of Systems (SoS) Testbeds
The ability to integrate multiple system simulations, either co-located or distributed, to explore and evaluate the capability of higher-level systems of systems is a critical enabler for exploiting the breadth of Raytheon’s products and maximizing value for our customers. This ability optimizes collaboration both among Raytheon’s global businesses and with government and industry partners. The article “System-of-Systems Testbeds” highlights three examples of SoS testbed environments currently in use at Raytheon. These include the Aerospace-Ground Integration (AGI) Testbed that supports analyses of airborne and space platforms, the Joint Force Interoperability and Requirements Evaluation SupraCenter (JFIREs) that supports the integration of air and missile defense systems (Figure 4), and the Air Dominance Test Bed (ADTB) used for weapon system kill-chain analyses.

Visualization and Training
The ability to integrate the user into a simulation environment is valuable during the development and evaluation of operational concepts and for providing immersive training for the operator. “Virtual Environments: Creating Immersive Simulations and Trainers” describes how Raytheon is leveraging video gaming technology to provide realistic 3-D visualization of modern warfare. This not only supports operator training, but allows the effects of actual human behavior to be included in the evaluation of real systems. “Embedded Training in the Modern Command and Control Environment” discusses Sculpt™, a powerful tool for designing, controlling and modifying training scenarios in order to maximize training flexibility and effectiveness. Sculpt enables the trainers to create realistic and relevant scenarios, and to modify them in real time in response to the operators’ actions.

Enablers
Simulation fidelity (both all-digital and HWIL) is only as good as the simulated threats and environments being used. As processing algorithms become more sophisticated, sensitivity to the subtle characteristics of a target and environment increases.

Paul Bailey
Chief Systems Engineer
Engineering, Technology and Mission Assurance (ET&MA)

Paul Bailey is chief systems engineer for Raytheon Company’s Engineering, Technology and Mission Assurance (ET&MA) organization. In this role, Bailey provides oversight and guidance to system engineering efforts across Raytheon’s businesses. He leverages a broad range of architectures and technologies to address business system challenges and user needs, generating synergy within the systems engineering development organizations. He also leads enterprise reviews of system engineering practices and system engineering aspects of designated watch programs and strategic business captures.

Bailey directs the efforts of Raytheon’s Systems Engineering and Technology Council, interfaces with government personnel for program performance improvements, leads proposal evaluations and assesses system architectures. “I’m continually amazed by the technology being developed across the company and the ability of our engineers to apply it to new and evolving systems,” he states.

For more than 30 years, Bailey has filled a variety of roles, working a wide range of programs. Prior to becoming chief systems engineer, he was technical director of analysis and modeling, responsible for coordinating and expanding operational analysis capabilities enterprise-wide to improve Raytheon’s ability to provide system solutions for evolving customer requirements. Prior to corporate ET&MA, he was chief engineer for Integrated Defense Systems’ National and Theater Security Programs (NTSP), where he was responsible for customer satisfaction by delivering technical performance within budget and on schedule and for fostering commonality and cooperation among NTSP and across Raytheon.

Bailey is the first to tell you that he’s “been very fortunate to have worked for and with some truly outstanding engineers during my career.” He served as chief engineer for the Ballistic Missile Defense System Radar program with overall technical responsibility for all aspects of radar development, including architecture definition, system and software requirements and design, ground and flight test, and radar deployment. He represented Raytheon on the U.S. Navy Future Theater Air and Missile Defense working group, defining the requirements for defense systems for the subsequent two decades and charting the course for enabling technology. He started his career as a hardware design engineer with the Missile Guidance Laboratory and continues to provide consulting support to Raytheon missile development and test activities.
Furthermore, the desire to reduce live testing through more extensive use of simulation necessarily requires the highest possible threat and environment modeling fidelity. This puts a premium on the ability to generate, in hard real time, high-fidelity input signals with the precision necessary to adequately exercise advanced processing and algorithms. “Radar Digital Signal Injection System (rDSIS)” describes a simulation driver developed for the X-Band family of radars to inject high-fidelity time domain in-phase and quadrature (I&Q) radar returns into the signal processor, permitting closed-loop evaluation of the entire signal and data processing chain. In addition to stand-alone radar testing and algorithm development, RDSIS is used to drive the radars during Ballistic Missile Defense System level testing.

The generation of complex high-fidelity radio frequency (RF), electro-optical (EO) or infrared (IR) input scenes and sensor images in real-time requires significant computing throughput. “Accelerating Simulations Through the Use of General Purpose Graphical Processing Units,” a sidebar to the genSim article, discusses the use of general purpose graphics processing units (GPUs) for this purpose, exploiting the massively parallel computing approach which these processors excel at.

To best leverage the breadth of its products, Raytheon relies on the collaboration of engineers in geographically disparate locations. In particular, the ability to share system and simulation data at appropriate classification levels between locations in order to facilitate SoS analyses is vitally important. “Enterprise Modeling and Simulation (EMS): Enhancing Cross-company Collaboration to Improve the Quality of Solutions that Raytheon can Offer Our Customers” discusses Raytheon’s EMS efforts which have implemented companywide data sharing networks that allow engineers to collaborate more efficiently.

M&S supports more than system performance evaluation. “Phased Array Availability Modeling and Simulation: Techniques for Efficient and Effective Performance Modeling” illustrates the application of M&S to the life cycle cost arena by integrating the logistics and availability models for X-Band phased array radars. The article describes tools and methods used to estimate and assess system reliability and availability to facilitate tradeoffs between component reliability, maintenance schedules and sparing quantities to most cost effectively meet system availability requirements.

This issue provides a mere sampling of the extensive M&S capabilities Raytheon engineers apply every day to the development, test and evaluation, and operation and sustainment of complex systems. From initial concept development through fielding and sustainment, our M&S technologies provide value to our customers by ensuring our products meet their expectations and by reducing the need for expensive live testing.

Paul Bailey

Figure 4. The JFIRES Testbed provides a system of systems-level evaluation capability primarily focused on integrated air and missile defense.
Designing systems and confirming that they can defend against coordinated raids of ballistic missiles, aircraft and cruise missiles is challenging. How, for example, can enough fidelity be provided to test components and algorithms? Likewise, how can complex interactions between system elements be examined before the system design is complete? Raytheon Air and Missile Simulation (RAMS) addresses these challenges by using collections of threat modeling, radar processing, battle management and interceptor modules with a plug-and-play foundation. RAMS can represent the system elements at low-, medium- or high-fidelity levels, and it supports a range of applications from standalone radar analyses to mission-level performance assessments of the integrated operation of multiple radars with battle management and interceptors.

RAMS has been used for detailed system performance analysis in multimission environments, for radar feature analysis, and for characterizing the performance of advanced discrimination algorithms for new or evolved ballistic missile defense (BMD) radars. Each application that uses RAMS gains efficiencies by leveraging improvements that have been made by prior applications. RAMS supports the incorporation of the new efficiencies by using a common code base for all applications and allowing alternative representations of functionality to be selected using configuration files that are processed at program initialization.

Description
RAMS is a modular, plug-and-play framework and set of routines that support development and evaluation of approaches for BMD and air defense, and that can readily be extended to support other missions such as surface or electronic warfare. RAMS can simulate detailed radar data to thoroughly test signal processing and data processing algorithms, or it can rapidly generate lower-fidelity data to support system-level end-to-end performance assessments. In this framework, modules coordinate using well defined interfaces, allowing alternative realizations, i.e., different combinations of modules, to be instantiated at run-time.
Fidelity levels are selectable and range from functional models that represent typical or idealized performance to detailed models that capture every step and dependency of a process. Figure 1 illustrates three fidelity levels for representing scene and radar components, each of which is appropriate for particular analysis questions. During the concept definition stage, operational analysis using simple models (left column) supports system tradeoffs and guides top-level capability definitions. Incrementally, the scene fidelity, signal processor, tracker and discrimination models are replaced with higher-fidelity ones to enable assessments of candidate approaches, prototype designs and even real-time implementations. Because common interfaces are used for these functions, different combinations of signal processing, tracking and planning can be instantiated together to match the analysis goals and design maturity.

Most of RAMS is implemented in Java™, which readily supports modular interfaces and provides mechanisms to quickly identify code and algorithm defects. Some detailed signal processing routines have been re-coded into C to provide more speed, and a few modules have been implemented in Compute Unified Device Architecture (CUDA®) to utilize graphical processing units (GPUs) for additional speed. For cases in which existing algorithms are coded in C, C++ or Fortran, the code can be reused as is, by applying a Java wrapper around the legacy code so that the routine can properly interface with the RAMS simulation infrastructure. Multithreading, where multiple modules or portions of modules are executed simultaneously on a multi-processor computing system, is also used to increase execution speed.

Applications

For detailed BMD analyses, RAMS represents ballistic missile complexes in high fidelity, with operating frequency and angle-dependent, range-resolved signatures of principal objects such as re-entry vehicles (RVs), stages, decoys and debris. All key phenomena that may be exploited by BMD radars have been represented to ensure that algorithms designed for signal processing, tracking and discrimination can be thoroughly tested. Figure 2 shows an example of the range dependence of an object’s RCS (radar cross section) as it is observed with low-, medium- and high-resolution waveforms, each of which is used to perform aircraft and cruise missiles are currently modeled using frequency and angle-dependent signature models. Environmental effects such as attenuation from the atmosphere and rain are modeled to ensure correct radar sensitivity calculations vs. range. Medium- or high-fidelity representations of the terrain and atmospheric refraction effects can be included to enable visibility calculations that determine when low-flying objects, such as terrain-following aircraft, are observable or occluded by the terrain. RAMS currently uses a statistical detection model for air vehicles, together with a functional model of track accuracy based on observed SNR (signal to noise ratio), number of looks, time in track, and time since maneuvers. This level of fidelity has been selected to refine and assess performance of multimission radar resource management algorithms. Higher-fidelity signature models and detailed signal processing and tracking algorithms for air

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vehicles can be implemented to support more detailed air defense system design and analysis.

RAMS currently has a functional model of battle management and interceptor flyout, using a simple set of rules or a script to determine which targets are engaged and when they are engaged; this information defines when firm tracks need to be established and discrimination needs to be complete. The framework is sufficiently flexible to allow higher-fidelity battle management and interceptor flyout models to be incorporated. To demonstrate the potential for sharing information among multiple radars, RAMS was configured with two radars jointly observing a long-range ballistic missile event from different locations, with interceptors launched from a third site. Data from these sensors were fused to highlight the potential benefits of coordinated, multisensor operation.

Summary
By providing a simulated radar system prototype that has the fidelity to represent its operation in detailed scenes, RAMS supports development and refinement of concepts of operations, software architectures and software requirements. RAMS has produced simulated data for studying phenomena, exploring algorithm concepts and maturing algorithm implementations, including:

- Signal processing algorithms for multipulse processing, super-resolution and detection characterization.
- Advanced tracking techniques that provide improved accuracy and continuity in dense scenes.

“Mission-level and operational analyses provide our customers with quantitative data showing the benefit of a weapon system or systems in warfighter terms, not engineering terms,” states Dr. Chapa. “The simulations developed by the OAS Department at different levels of fidelity are delivered to and used by our customers to predict performance in deployed configurations and flight tests.”

Prior to his current assignment, Dr. Chapa served as the technical director for the Global Integrated Sensors and National and Theater Security Programs business areas where he was responsible for technology planning and technical concept development in the areas of air defense, missile defense, space surveillance and control, technical intelligence and battlefield integration. Dr. Chapa began his work at Raytheon in 2005 as a technical director in the Missile Defense business area. Before this, he was a Group Leader at Lincoln Laboratory, where he initiated and led several intelligence, surveillance, and reconnaissance sensor and exploitation technology programs.

Prior to Lincoln Laboratory, Dr. Chapa enjoyed a 20-year career as an engineer and program manager in the United States Air Force, where he served in the Avionics Laboratory, the National Reconnaissance Office, the Airborne Warning and Control System Program Office, and Electronic Systems Center Special Projects. Dr. Chapa received a bachelor’s degree in mathematics from Illinois College, a bachelor’s degree in electrical engineering from Auburn University, a master’s degree in electrical engineering (optics and imaging), and a Ph.D. from the Rochester Institute of Technology in Imaging Science.

Dr. Chapa understands that insights into new solutions or concepts come from understanding the details. “At Raytheon, operational analysis and simulation is essential to our capture process, providing hard data to our capture managers and technical directors that can be used to shape and win key pursuits.”
• Advanced BMD discrimination techniques that identify lethal and non-lethal objects.
• Multimission pulse scheduling algorithms that develop schedules for all radar transmit and receive actions.

As a development program progresses, the RAMS representation of the radar can be verified, validated and accredited (VV&A), and then used to demonstrate that the system requirements are achieved. The VV&A version of RAMS can also provide pre-mission predictions of flight tests.

RAMS provides a set of capabilities that can be leveraged and further extended to address the needs of future programs. Selectable fidelity via configuration files readily supports spiral evolution of a design, in which functional modules are incrementally replaced with more detailed modules and performance predictions are updated iteratively. Its flexible framework maximizes the use of common modules while still allowing system tailoring, via specialized plug-in modules, to accurately represent specific radar systems.

David Cebula, Ph.D.

Jason Shelton
Section Manager, Sensors and Processing, Integrated Defense Systems

Jason Shelton is section manager for the Sensors and Processing section of Maritime Domain Systems, part of the Systems Architecture, Design and Integration Directorate of Engineering in the Integrated Defense Systems (IDS) business. In this role, Shelton supports a number of programs involved in mine and anti-submarine warfare. He also serves as deputy integrated product team lead on the Measure of Effectiveness Testbed (MOETB) for the DDG 1000 program. MOETB is a high-fidelity, real-time simulation environment used to evaluate the Zumwalt-class Destroyer’s performance against a variety of threats, including cruise missiles, aircraft, patrol boats and torpedoes.

“As budgets tighten,” Shelton states, “our Navy customer has come to rely on modeling and simulation techniques to augment expensive live-fire testing of the system, where it is not cost effective to test every type of scenario possible.”

In 2010, Shelton was elected chair of the Modeling, Simulation and Analysis (MS&A) Technical Interest Group (TIG) within the Mission Systems Integration Technology Network. “As MS&A TIG chair, I have the opportunity to interact with modeling and simulation leaders and practitioners from across the company. Oftentimes, when a question arises regarding Raytheon M&S for a particular mission, the MS&A TIG provides an answer, a point of contact, past experience and more.”

Shelton also spent a number of years with the company’s Enterprise Modeling and Simulation (EMS) team, allowing him the opportunity to work with talented people from across the company on a variety of mission areas (e.g., missile defense, cyber, and intelligence, surveillance and reconnaissance). He notes the following: “[EMS] gave me my first experience as a team lead developing a testbed for networked cruise and ballistic missile defense. The EMS leadership team was committed not just to integrating the company’s various M&S capabilities, but also to growing our people, something I hope to carry forward in my new role as a manager.”

Figure 3. RAMS screen close-up
In operational environments, it is imperative that wireless systems maintain performance even in the presence of extreme noise interference originated by other radio frequency (RF) sources in near proximity. To ensure system performance and mission effectiveness, today’s RF engineers must design-for-interoperability and conduct system engineering analyses that will help identify, prevent and mitigate performance shortfalls. A team of Raytheon engineers has developed the Communication System Engineering Toolset (CoMSET) simulation environment to facilitate the process of designing for interference and for assessing the interoperability performance of RF systems in dense and complex spectral environments.

CoMSET is a simulation environment originally focused on analyzing communication system architectures and their performance in complex environments. The CoMSET suite of simulation tools and their associated processes have evolved to address the interoperability needs of RF systems in general, including radar and electronic warfare (EW) systems. While the main benefits of CoMSET reside in RF interoperability analysis, the tools are used for diverse purposes, including the prediction of jamming effectiveness on targets and quantifying the impact of new technologies introduced into system architectures.

The Concept of CoSite Interference

During the last three decades, military operations have benefitted from the proliferation of wireless technologies, electromagnetic sensors, and non-kinetic effectors like jammers. Conventional military systems operate in frequencies ranging from HF bands (3-30 MHz) to W-band (75-110 GHz) and in many cases co-exist with civil and commercial wireless services. Global Positioning System (GPS) devices, navigation systems, radar and surveillance sensors, electronic support and electronic attack measures, and communication networks are examples of RF capabilities commonly found in many military platforms. Due to the constraints on some platforms, antennas often must be located in close proximity to each other. When two antennas are near each other, the probability of electromagnetic interactions, or coupling, among RF systems increases. The closer the antennas, the higher the electromagnetic interactions among them can be. This type of electromagnetic interaction is best known as cosite interference. This type of interference is often unintentional and can easily degrade the performance of receiver systems to the point where signals cannot be processed as they get shadowed or buried in the noise. The intentional use of electromagnetic energy to degrade a receiver’s performance is known as jamming. In this case, the energy directed to the receiver is intended to deny the receiver the ability to process any incoming signal or support any kind of service.

To address issues inherent with cosite interference, designing-for-interoperability requires a good understanding of RF system architectures, electromagnetic scattering, signal propagation while traveling through space (better known as signal in space), and electromagnetic phenomenology. Additionally, the designer must understand that during the design process the platform and other nearby RF systems will contribute to signal interactions and receiver degradation. Predicting potential cosite interference interactions up front is important to minimize the need for future design modifications or mitigation measures that may be non-compliant with system specifications.

Communication Systems Engineering Toolset (COMSET)

Raytheon has developed COMSET to facilitate the interoperability analysis of RF systems in operational environments and to predict a system’s effectiveness.
throughout its lifecycle. Initially, COMSET was developed to fulfill specific needs in the military community by predicting the performance of communication systems operating in complex tactical environments. Since its original conception, the COMSET tools have evolved to support the broader need across Raytheon with regard to modules and processes capable of supporting the analysis of other types of multifunction RF systems in operational scenarios, including EW and radars.

The COMSET simulation environment is MATLAB®-based and includes commercial and customized simulation packages, descriptive system models, graphical user interfaces (GUIs), and visualization tools. COMSET enables the user to (1) derive performance specifications for a given system based on notional concepts of operations; (2) verify and validate component, subsystem, and/or system-level requirements; (3) support the development of platform RF footprints; (4) conduct system interoperability analyses; and (5) apply statistics and probabilistic methods to estimate system performance effectiveness.

While various methods can be used to predict RF interference, most provide only marginal estimates due to the utilization of low-fidelity models. Unlike other interference prediction environments, COMSET is grounded in physics-based models with simulations taking into account the actual system architecture, the in-band and out-of-band RF performance of nearby systems, the physical structure and features of the platform, and the propagation environment.

The analysis engine of the COMSET simulation environment was built on the principles of cost interference. The concept of signal-to-noise and distortion (SINAD) was implemented as a carrier- (i.e., signal) to-noise (i.e., interference) ratio (CNR) that takes into consideration intrinsic and extrinsic contributions acting independently to degrade the receiver performance — better known as susceptibility to interference.

To accurately estimate the system performance, validated radio models describing the in- and out-of-band transmitter and receiver characteristics are required. External noise sources are estimated or characterized. Estimation of the receiver susceptibility to noise and interference provides insight into how well the system can support services under a set of assumed constraints.

**COMSET Architecture and Simulation Environment**

Five major sub-applications, or modules, are embedded in the COMSET environment: (1) model generation and RF analysis; (2) propagation analysis; (3) antenna coupling and placement; (4) statistical operational analysis; and (5) GUIs. Figure 1 illustrates the COMSET simulation environment architecture, application and modeling capabilities. An extensive library of radio models is maintained and is easily accessible, facilitating model re-use for analysis. The RF models are created in Agilent’s Advanced Design System® (ADS) environment, and it is relatively easy to import/export models from/to other commercial or customized environments.

Within the RF analysis module, the component and system models describe the physical layer of a radio. The transmitter model describes the linear and nonlinear characteristics generated by the RF transmitter distribution subsystem, the exciter and waveforms. High-order intermodulation products provide insight into the non-linear performance of the transmitter. The receiver model, on the other hand, includes a detailed description of the RF receiver distribution subsystems and its components up to the analog-to-digital converter. In the receiver analysis, non-linear effects such as reciprocal mixing products are considered noise contributors. An important output of the RF analysis is the estimation of the receiver susceptibility to interference. Typically, the receiver susceptibility can only be estimated by characterizing the receiver system in a controlled environment. COMSET, on the other hand, provides a virtual laboratory to characterize the receiver’s susceptibility to interference and noise over a wide range of simulated conditions.

A comprehensive library of propagation models is currently available in the COMSET simulation environment.

*Continued on page 14*
Computational electromagnetic (CEM) techniques are used to estimate coupling coefficients and scattering products, to support near- and far-field analyses, and to produce 2D and 3D antenna patterns. Statistical methods are also implemented to estimate system performance and operational effectiveness.

The COMSET GUIs allow easy access to the various application modules within the tool. All GUIs were created using the Matlab Graphical User Interface Development Environment (GUIDE) and are written in Matlab. Pull-down menus provide the user with options to import and export data, invoke models and applications, execute analyses and create reports. Other sub-applications in the COMSET tool can be accessed from the main COMSET GUI application. These include model creation applications, the analysis applications, the propagation model applications, and the multipath scenario application.

COMSET Analysis Methodology

The COMSET interoperability analysis methodology is a well structured process supported by menu-driven GUIs that enable the user to proceed through a set of intuitive steps. This process is illustrated in Figure 2. For most cases, the process is a top-down analysis approach with the starting point being the concept of operations (CONOPS) requirements. However, the COMSET environment also offers the user flexibility to conduct bottom-up sensitivity analyses.

The process starts with the identification of operational and performance requirements for a given capability. The user then develops the platform-level model that provides the physical description of the platform (i.e., airplane, ground vehicle, maritime ship, etc.) in which the RF systems resides. This model includes detailed descriptions of the placement of the antenna ports. Each RF system within the platform is then represented by a radio model that describes the electrical and electromagnetic performance of the system. Each radio model has three main components: (1) antenna, (2) RF distribution system for both transmitter and receiver chains, and (3) the analog receiver and exciter subsystems.

Creating the Radio System Models (Step 4) has two parts. The first is to create the communication model, which provides the linkage between the radio transmitter and the receivers. The second set is to develop a model description of the signal propagation and its interactions with the physical environment. The system performance in a non-interfering environment is estimated (Steps 5 and 6), providing a rough order of magnitude assessment of the validity of the system requirements. The second part of the analysis takes into account coupling and interference sources and potential electromagnetic interactions among systems in a given platform. During this step (7A), the analyst estimates the contributions to the expected system degradation as a result of non-intentional interference from other systems on the platform and within the operational environment.

The COMSET modeling approach links the radio, platform and propagation models to perform the interference analysis. The radio model includes a full description of transmit and receive functions and the antenna patterns of a given RF system. At the platform level, antenna coupling models are used to describe the potential electromagnetic interference (cosite interference) between close-proximity antennas. Multiple communication channels are established to describe the linkage between remote radios and platforms in a complex operational scenario. Finally, propagation models are implemented to describe signal propagation and attenuation due to the physical environment. The propagation models take into account...
consideration environmental variables such as weather conditions, platform altitude, reflection and scattering phenomena, and obstruction density (e.g., urban canyons, heavy vegetation).

This process is repeated for every system and every platform under consideration in the analysis until an operational picture of the RF environment is fully synthesized.

Each receiver channel responds differently to interference. The susceptibility of a receiver is a combination of the receiver’s response to all active emitters, antenna coupling and environmental noise. An important step in the interference analysis is to estimate the antenna coupling. Figure 3 illustrates an antenna coupling analysis in which seven antenna ports were considered on a platform under evaluation. In this case, 15 primary interference pairs needed to be considered to determine the net receiver performance degradation due to antenna coupling (Figure 3, left side). The next step in the process is to estimate the overall receiver susceptibility to interference on a platform or in an operational environment. CNR is used as a measure of the receiver susceptibility. CNR is frequency dependent and will vary from system to system in a given platform. Figure 3 right side illustrates a result of a receiver susceptibility analysis. In this case, a system pair is analyzed and the receiver degradation is estimated when both systems are fully operational in the platform. The CNR estimates are used in a link analysis to estimate the quality of service of a communication channel in a highly dense spectral environment. Methodical analyses are conducted by reviewing all possible interfering mechanisms until performance estimates show acceptable link margins consistent with the operational requirements. During the process, the user has the flexibility to isolate specific cases and apply design of experiments methodologies to perform further analysis as needed.

COMSET Utility
COMSET capabilities have been effective in simulation and analysis of RF interoperability in complex operational scenarios. COMSET enables engineers to (1) derive performance specifications for a given system based on candidate concepts of operation; (2) verify and validate component, sub-system, and/or system-level requirements; (3) support development of a platform’s RF footprint; (4) conduct system interoperability analyses; and (5) apply statistics and probabilistic methods to estimate system performance effectiveness. The COMSET analysis methods, when used up front during the design phase, allow the user to design for interoperability. In addition, the interoperability and operational effectiveness analyses have proven to be a powerful tool for preventing, identifying and/or resolving issues in systems operating in a complex environments throughout the life-cycle of a program. COMSET has been used in support of multiple efforts across Raytheon, and has received multiple accreditations and awards.

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Joanne Wood
Sr. Engineering Fellow, Space and Airborne Systems

Joanne Wood is currently a Senior Engineering Fellow within the Systems Development Center in Raytheon Space and Airborne Systems. Working with the Raytheon Corporate team, she leads the Enterprise Modeling and Simulation Core Research project to enable simulation and analysis based collaboration on crosscompany initiatives. She also is the lead investigator and manager for two study activities in the Advanced Concepts and Technology business area.

In 2011, Wood completed a 14-month rotation as the Mission Systems Integration, Corporate Technology Area Director. She has more than twenty-five years of experience as a systems engineer, performing mission analysis and modeling future systems and systems of systems. Her expertise includes systems and operational analysis, customer/user requirements and technical management.

One aspect of Wood’s work is to bring customer focus to Raytheon product engineering. Through the use of a comprehensive toolset, Wood and her team demonstrate to the warfighter what exactly Raytheon products do and how they can fill capability gaps that can improve mission execution.

“‘There is nothing better than getting postbriefing comments from customers who come up to me and say, Hey, you guys really get what it is that we are trying to do!’” Wood exclaims. Fundamentally, Wood and her team help facilitate the translation of requirements to operational utility. As the program matures, her team’s mission analyses help both the customer and Raytheon understand the value of system upgrades that can help solve near-term mission performance gaps without having to wait for a new system to be fielded.

“Being able to translate engineering solutions to operational benefit gives me direct exposure to the warfighter, which provides me with valuable experience at understanding what they [the customers] care about,” states Wood. “Being on the front end of the business puts me and my team in a position to help shape programs by ensuring performance requirements are communicated to warfighters in their mission terms, and not just by dB, power, detection ranges and timing.”
Today’s cyberthreat is real, pervasive and potentially devastating to information networks and systems that are the core of defense and commercial infrastructures. All information systems are under the shadow of cyberattack, and the developers and users of these systems must evolve and apply cyber countermeasures and resiliency techniques that enable secure operation in this hostile environment to ensure mission survival.

Essential to the evolution, evaluation and application of cyber countermeasures and resiliency techniques is the ability to visualize the cyberthreat and analyze the prospective effectiveness of countermeasures during all phases of networked system development, deployment and use. Common cyberthreat analysis tools provide only a static examination of cyber vulnerabilities. This is similar to examining a wall for integrity against an outside force (e.g., are there any cracks or weaknesses?). A true understanding of the cyberthreat must consider the dynamic aspect of the cyberattack as it moves into and through an information system; just as gauging a wall’s defensive effectiveness must include a consideration of the dynamic forces applied from breaching attacks (e.g., wind, water, explosives or projectiles). The effectiveness of new defenses such as cyber maneuver, random reconstitution and other active defense mechanisms must be evaluated against the dynamic nature of today’s threats. Additionally, “what-if” scenarios and zero-day attacks covering many combinations of cyberattack need to be considered, including those as yet unobserved but viable future threats.

Dynamic Cyber Modeling and Simulation Framework

Raytheon’s Cyber Analysis Modeling Evaluation for Operations (CAMEO) modeling and simulation toolkit addresses the need for a dynamic cyber modeling and simulation framework. This framework specifically supports “what-if” scenario simulation and analysis, enabling the selection and configuration of the most effective active defenses and attack-detection mechanisms during the planning and operations phases of an information system’s lifecycle (Figure 1).

The CAMEO modeling and simulation analysis process is shown in Figure 2. It starts with ingestion of target network node data that may be scanned by a vulnerability scanning tool or be entered directly by the cyberanalyst. The CAMEO ingest service provides a single common interface for disparate authoritative sources of device, application, hardware, vulnerability and weakness data, and it automates the enrichment, correlation and verification of that data.

Once the network and vulnerability data have been ingested, the network...
visualization component of the CAMEO toolset enables the analyst/user to visualize, manipulate and verify various aspects of the target network and to conduct operations on its component tree and interconnections.

Once the cyberanalyst verifies the network data model, the CAMEO discrete simulation (DSIM) begins. DSIM launches analyst-defined simulated threat attacks that seek to reach the final attack phase of exploitation (e.g., pilfer) on a target node in the modeled network. CAMEO-modeled defenses can then be applied independently or in combination against these attacks to ascertain optimal cyberdefense employment as illustrated in Figure 3. Also, analyst-defined-and-verified alternate network configurations can be substituted into DSIM to study parametric designs and operational alternatives being considered.

Parametric Evaluation
CAMEO provides several cyberattack metrics, including the number of threats visited on the target network, the number of threats defeated, the number of threats successful in reaching exploitation objectives and the lifetime of threats. These metrics enable the comparative evaluation of parametric alternatives for target network resiliency techniques, configuration, design and/or defense employment versus threat attack characteristics (e.g., number of simultaneous attacks, type and combination of attacks, timing of attacks), as shown in Figure 4. This figure illustrates the improvement gained as the interval between proactive defensive maneuvers decreases (faster proactive defenses). This increases the time cyberattacks spend in reconnaissance phases (footprint, scan and enumerate) and decreases the time available for pilfering (exfiltrating) data.

Large-scale parametric evaluation is greatly enhanced by an analytic technique and adjunct feature to CAMEO called data farming. Data farming enables quick examination of pre-run simulation data across a wide range of parameters of interest for different design and operational sensitivity studies without having to rerun the simulation. The data farming process and the enabling CAMEO functionality culminates in the generation and assimilation of results from many different scenarios for the investigation of a large number of variables across a wide range of values and multiple time factors. This process generates a farm of data from which a harvest of meaningful anti-cyber design and employment strategies can be realized, including results that may lead to non-intuitive findings.
At various stages in the CAMEo data farming workflow, data can be post-processed to enable a narrowed grouping around the data of interest. This post-processing is based upon evaluation and visualization to expose metric inflection break points for applying optimal design and operational anti-cyber techniques. In Figure 4, one break point for the application of preemptive defenses appears between 24 hours and two days, where the latter interval is the last time the final pilfer stage of cyber-attack appears. The result of this CAMEo analysis then forms the basis for a course of action to apply preemptive defenses every 24 hours in order to counter “pilfer” by the envisioned and simulated attack.

The CAMEo framework toolkit enables the cyber engineer and analyst to appraise a network concept design or existing system for cyber implications against single and multiple attack scenarios. The toolkit has a wide range of capabilities that can be used throughout network system design, development and deployment for the enhancement of network resilience and the application of cyber countermeasures.

Jane Orsulak
Solution Architecture and Analysis (SA&A) Lead

Jane Orsulak currently leads the Solution Architecture and Analysis department for Intelligence, Information and Services (IIS). Her department is charged with developing winning solutions for strategic pursuits. Concurrent with this assignment, Orsulak was also appointed Mission Analysis Technical Center (MATC) director. In this role, she is responsible for leveraging mission analysis and modeling and simulation capabilities across IIS.

“We are responsible for providing solutions for our strategic pursuits, and we are heavily engaged up-front with our customers, understanding their mission, and identifying cost-effective solutions,” Orsulak states. “These activities are bolstered by our Mission Analysis Tech Center, charged with developing the tools, skills and resources within IIS to support that early stage analysis through execution of key IRAD [Independent Research and Development], CRAD [Contract Research and Development] and pursuit-related analysis projects.”

Prior to her department manager role, Orsulak served as the Mission System Integration Technology Area Director (TAD) for Raytheon Company. In this role, she provided technology leadership across the Raytheon businesses with a focus on model based system engineering and architecture technologies. Along with other TADs, Orsulak managed the Raytheon Innovation Challenge and Identify-Develop-Expose-Action (IDEA) programs during her tenure as TAD.

During her tenure as technical lead for the systems, architecture and software engineering disciplines, Orsulak provided support for a wide variety of programs, including intelligence, surveillance and reconnaissance technologies, command and control applications, and commercial industrial engineering applications.

A Raytheon Certified Architect since 2007, Orsulak is accomplished in the unmanned air vehicle (UAV) domain where she has provided significant contributions to national and international architecture standardization activities through participation in government/industry consortiums and the NATO Standard Agreement (STANAG) custodian support team for the STANAG 4586 Unmanned Air Vehicle Interoperability standard.
System-of-Systems Testbeds

Raytheon’s customers often demand innovative, low-cost, minimal-risk solutions with high technical readiness levels (TRLs\(^1\)). Many new program pursuits require TRLs of 6 or greater just to compete. This is driving an industry trend toward greater reliance on early prototyping in high fidelity simulation testbeds to demonstrate technology maturity during the proposal and concept design phases.

Raytheon operates several rapidly configurable system-of-systems (SoS\(^2\)) testbeds. They consist of commercial-off-the-shelf (COTS), government-off-the-shelf (GOTS) and Raytheon-developed models that are used to validate integrated system solutions at the mission level. These testbeds are used as software-, processor-, hardware-, and/or operator-in-the-loop simulation environments used to demonstrate how Raytheon’s solutions meet the needs of the warfighter and have the maturity needed to proceed to the next phase of development. The testbeds also provide an excellent early system development capability to rapidly find and fix system and system of systems integration issues.

Three Raytheon testbeds are highlighted in this article:
- The Aerospace-Ground Integration (AGI) Testbed, supporting airborne and space platforms.
- The Joint Force Interoperability and Requirements Evaluation SupraCenter (JFiRES), supporting integrated air and missile defense.
- The Air Dominance TestBed (ADTB), supporting the weapon system kill chain.

As U.S. Department of Defense (DoD) mission areas begin to overlap and their assets perform multimission roles, there is a need for integrating these mission-area-focused testbeds to provide a broader battlefield-wide simulation capability. Under a corporate Enterprise Modeling and Simulation (EMS) initiative, the first steps toward a more integrated capability where taken by creating the necessary network connectivity between sites; see article “Enterprise Modeling and Simulation (EMS): Enhancing Cross-Company Collaboration to Improve the Quality of Solutions that Raytheon can Offer Our Customers,” for more information on this topic.

Aerospace-Ground Integration (AGI) Testbed

The AGI Testbed was designed to support airborne platform program pursuits for a large customer base. It is currently being used to explore advanced concepts in the area of unmanned airborne systems (UAS). AGI Testbed capabilities are derived from targeted key capabilities across Raytheon; these include weapon models, sensor models, entity generators, communication models, fusion models and command and control algorithms. Raytheon has an eye toward adding immersive simulation expertise in the future.

Raytheon utilizes the AGI Testbed to show its customers how the integrated system solution meets the warfighter’s need. Such demonstrations are conducted at the appropriate security levels so that the effectiveness of system-of-systems solutions can be evaluated within their true context. Raytheon has multiple modeling and simulation (M&S) demonstration facilities where the customer is invited to observe and participate. Raytheon’s Mission Modeling Aerospace Ground Integration Center (RM2AGIC) is one such facility.

The RM2AGIC facility has two main areas for audience observation and participation with regard to live virtual demonstration. The first is the white room theater (Figure 1 main) where the audience can simultaneously view, on three digitally projected screens, operator displays, truth data and engineering displays. As such, the audience can simultaneously observe a) what has been “sensed or detected,” and subsequently shown on the operator’s display; b) what entities are present in the entire virtual scenario; and c) what is occurring at the detailed algorithm level. As the audience members listen and observe the live virtual exercise, they can change the conditions of the exercise at any given time unbeknownst to the blue force operators, who are physically isolated in a separate room. This allows the audience to observe an operator’s behavior as well as the effectiveness of the system when pop-up threats or other sudden changes are made to the environment.

Operators conduct the mission in the blue (friendly) force room (Figure 1 inset). Operators can only view data that has been “sensed” and is displayed in the common relevant operating picture (CROP). Because this is a non-scripted, real-time simulation, the scenario outcomes are not predetermined. Outcomes, therefore, vary depending on the skill of the operators, the tactics employed and the weapons systems available to both the blue and red (opposition) forces.

Continued on page 20

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1. TRL is a measure used to assess the maturity of evolving technologies.
2. A SoS is defined as a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities [DoD Defense Acquisition Guidebook 2008].
The ability to execute a live virtual demonstration has frequently resulted in follow-up demonstrations per customer request. In one instance, a customer wanted a better understanding of the advantages of employing multisensor and multiplatform sensor fusion algorithms in the context of his mission. A live demonstration was set up where sensors and platforms were added in real-time, under the control of the customer, enabling him to observe how fused track accuracies improved as the sensor/platform asset mix was changed.

Once an airborne system solution has been verified in RM2AgIC, it is ready for hardware/software integration and testing in flight. Traditionally, the transition between the virtual environment and real hardware has been both time consuming and expensive. This transition is minimized by the advances of faster CoTS hardware, the use of experimental test aircraft and the use of a prototype system that is encapsulated within the AGI testbed and employs the same hardware interface definitions as those used within the flight test asset. Following integration lab tests, the prototype system is typically exported to an experimental flight test asset such as the Raytheon Multiprogram Testbed (RMT, Figure 2). The RMT aircraft is equipped with multiple sensing systems and multiple computer racks, allowing Raytheon to demonstrate to the customer the effectiveness of its solutions in flight at TRL 6.

Joint Force Interoperability and Requirements Evaluation SupraCenter (JFIRES)
JFIRES is a multiservice, multitheater, multimission prototyping, evaluation and analysis environment with a focus on integrated air and missile defense (IAMD). High-fidelity, real-time, integrated digital simulations complement hardware- and software-in-the-loop (HWIL/SIL) capabilities, providing an ideal testbed for SoS-, system-, and component-level evaluation. The scalability and flexibility of the JFIRES open architecture meet Raytheon’s rapid prototyping needs in bringing critical IAMD capabilities to the warfighter.

At the center of JFIRES infrastructure is a highly scalable distributed simulation layer consisting of low- to high-fidelity simulation models and HWIL/SIL elements capable of sharing common, operationally relevant scenarios. Simulated scenario data are exchanged in real time between models by using a COTS implementation of the Object Management Group (OMG®) Data Distribution Service (DDS). Built from this foundation of distributed data, simulated and actual tactical system software and hardware exchange information over simulated tactical data links. This flexibility, illustrated in Figure 3, allows for the rapid configuration and testing of sensors, weapon systems and command and control (C2).

This configuration and test process highlight specific functionality of interest and have often been used to demonstrate new concepts for sensor, weapon and engagement resource management, joint track management and integrated fire control.

An example of the JFIRES testbed’s flexibility is a recent adaptation in support of space situation awareness program. On this program, the JFIRES environment was used to perform a set of experiments to assess the potential contribution of Missile Defense Agency (MDA) radars to space situational awareness, and to evaluate architecture alternatives for multimission sensor use.

The first of these JFIRES experiments (iterations) evaluated opportunities for using the basic coverage capabilities of radars to contribute to space situation awareness. The next experiment, using higher-fidelity radar models that included sensor slew and dwell dynamics, investigated radar resource management requirements. Finally, the last of these iterations evaluated multiple prototypes of a sensor resource manager (SRM). The SRM operates within a predefined concept of operations (CONOPS) and other constraints and maximizes sensor utilization efficiency in the gathering of both missile defense and space object data.

By leveraging the existing JFIRES simulation capability, the program rapidly completed the initial set of experiments and provided the customer with needed analysis data to assess the desirability of the SRM concept.
Without an existing simulation framework to build upon, excess funding and time would have been spent developing tools instead of producing analysis results. The study was one of over 20 rapid-response projects that JFIRES completed over the last five years, allowing studies like this one to focus more on the experiment and analysis phases and less on developing new simulation capabilities.

Air Dominance TestBed
A kill chain is the sequence of actions performed by a defense system to destroy an incoming threat. The events that define the kill chain include detection, location, tracking, targeting, engaging, and post-engagement assessment. Flight testing is the standard method used for making technology development and insertion decisions for airborne weapon systems. Although flight testing can potentially provide the most convincing validation, it is usually the most expensive method, especially if it involves multiple elements of the kill chain. M&S is often a cost-effective alternative to live fire exercises. Scenarios involving kill chain elements can be extremely complex and may include intricate system details; thus, it is advantageous to utilize simulation testbeds comprised of high-fidelity kill chain models.

The Air Dominance TestBed (ADTB) is one such simulation environment. Developed, maintained and operated by Raytheon, the ADBT is a national asset that has been supporting customers for over 20 years. The ADBT simulates the entire kill chain at the highest fidelity necessary in order to demonstrate performance to requirements and perform design of experiments and data-intensive analyses.

As shown in Figure 4, the ADBT includes a toolbox containing multiple simulation models that are integrated with tactically representative information processing and exchanges between models. Each model represents a tactical system, key function or key technology in the kill chain. A typical kill chain is implemented by integrating models for a surveillance asset, models for a manned tactical fighter aircraft, models for a weapon associated with the manned tactical fighter, and models for threats of interest. Additionally, warfighter tactics, kill chain interoperability and environmental factors are also implemented as models. Simulation control, data logging, tactical information exchange and entity kinematics are provided by Raytheon’s Air Combat Evaluation Model (ACEM).

Most of the models included in the ADBT toolbox are derivatives of the stand-alone models used by subject matter experts to validate requirements and predict flight test performance for their associated kill chain elements. When detailed models of specific kill chain assets are not available, or when high-fidelity is not necessary, the analyst can employ the lower-fidelity engagement-level models embedded within ACEM. These models are sufficient for quickly performing “what if” analyses. As questions of interest tend to vary from customer to customer, it is not uncommon to use a combination of lower- and higher-fidelity models in the course of an ADBT analysis effort.

Because each phase of the kill chain is modeled in the testbed, ADBT provides its customers with detailed and credible data. This helps customers make the right decisions on weapon system deployment, tactics and system upgrades. The ADBT has been used to assess cooperative engagement techniques in air-to-air engagements. The analysis uncovered potential limitations in the tactical code of one of the kill chain elements and eventually resulted in upgrades to the tactical software of the missile. In a similar instance, ADBT was used to generate performance predictions for an upcoming flight test. The preliminary analysis indicated that the desired test shot had a lower than expected chance of successful intercept. Upon further investigation of the testbed output, it was determined that some of the targeting data used by the launch platform was suboptimal for the intended test. Additional analyses were performed with the ADBT, which subsequently led to proposed modifications to the launch platform’s estimation of the target data. The probability of successful intercept improved and the eventual flight test was a success.

Data generated from the kill chain analysis process enables Raytheon and its customers to view the mission from a complete engagement-chain perspective. This, in turn, enables more informed decisions concerning technology development and program upgrades.

Steve Baba, Tony Curreri, Russell W Lai, Yuxiang Liu, Stelios Pispitsos and Tony Sabatino
Phased Array Availability Modeling and Simulation: Techniques for Efficient and Effective Performance Modeling

Introduction and Availability Overview
Raytheon has a legacy of delivering high-availability phased array radars on ground, sea and airborne platforms. A sample of our 30+ year history of phased array systems is illustrated in Table 1. This broad range of experience has allowed Raytheon to develop sophisticated availability modeling and simulation techniques, which are continually refined to assess performance for evolving and varied mission and support environments.

While we typically think of system “reliability,” or the probability of failure-free mission performance, as the common measure of system dependability, it is the system “operational availability” that has gained recent visibility in terms of mission readiness and system support costs. Availability is the probability of being able to accept a mission with full capability given that the mission may be requested at any random time. The joint probability of being able to accept a mission (availability) and then complete the mission (reliability) is a common measure used in system effectiveness models.

Due to the thousands of elements in a typical phased array, the rate of single item failure is relatively high (daily in certain very large arrays). Therefore, performing immediate maintenance on a single failed item is often not practical or cost effective. Phased arrays typically operate in accordance with periodic scheduled maintenance, whereby a system will deploy for weeks or months with no array face maintenance. To accommodate this support approach, Raytheon designs arrays such that when failures inevitably occur, performance degrades gracefully while maintaining specified levels of performance until scheduled

Table 1. Raytheon is experienced in developing and delivering high-availability phased array radars for a broad set of platforms, missions and environments.
maintenance can be performed. The challenge for reliability and availability engineers is to ensure and verify that the array design has sufficient margin to successfully complete "maintenance-free" missions, and that sufficient support is provided (e.g., spares and personnel are made available) to restore the array to full health prior to the next deployment.

High Availability Phased Array Radar Antenna Architectures

The high availability of active phased array radars is made possible by the antenna architecture’s ability to degrade gracefully. The architecture is designed to efficiently distribute waveforms, power and control to an array of hundreds or thousands of individual transmit (Tx) and receive (Rx) elements. Because transmit and receive elements are distributed on an array in large numbers, individual elements make a relatively small contribution to system performance; thus, failures are very tolerable. Transitioning upstream from the transmit and receive elements, the antenna’s power, radio frequency (RF) and control line replaceable units (LRUs) support dedicated groups of Tx/Rx elements and therefore make a larger contribution to system performance and decreasing tolerability of failures. The degree of performance degradation from any individual LRU failure increases as the failures occur farther upstream within the distribution chain. Figure 1 summarizes the reliability architecture of a gracefully degrading phased array antenna and the associated failure effect and maintenance concepts linked to primary antenna functions.

In addition to high availability, a well distributed, fault tolerant, phased array radar architecture offers attractive and flexible maintenance and support options. For example, if projected array failures during a deployment are tolerable, there is no need for costly on-board spares; nor is there a need for the associated on-board maintenance manpower. The resulting ability to defer maintenance and centralize spares significantly reduces the logistics footprint. It is interesting to note that deferred maintenance does not improve costs by reducing the number of overall repairs. Rather, it

Continued on page 24
improves costs by way of efficient batching of repairs without impact to mission operations.

While the performance of our phased array antennas degrades gracefully as failures gradually accrue, Raytheon’s continuous health assessment function provides status on all failures, regardless of criticality. This health monitoring of arrays provides the status and data to allow commanders to monitor degradation, and it enables fix-or-fight decisions prior to mission.

Phased Array Radar Availability Performance Simulation & Modeling
Raytheon employs a variety of modeling and simulation techniques to accurately evaluate array availability performance. Tools that focus on inherent availability are implemented during architecture and preliminary design trades. Inherent availability assumes an ideal support (maintenance and spares) environment. The Raytheon-developed Phased Array Combinatorial Reliability Analysis Tool (PACRAT) is a Monte Carlo simulation tool that allows rapid assessment of all possible projected failure combinations during a specified deployment or mission period. PACRAT computes the probability of mission success and availability where success is defined as performance above specified thresholds. Typical array performance thresholds include antenna sensitivity (which is expressed in the availability simulation as the maximum number of failed Tx/Rx modules), and antenna pattern degradation (which is expressed in the simulation as both the maximum number of failed Tx/Rx modules and the maximum number of Tx/Rx module groupings). These groupings are specific to the architecture and relate to failures of upstream assemblies. Before tools like PACRAT were available, phased array availability calculations required time consuming individual calculations for the thousands of possible failure combinations that could occur during a mission. Using a 16 element array example, Figure 2 illustrates how PACRAT significantly reduces the analysis and computational effort. PACRAT also provides an effective approach for conducting design trades involving array module density (e.g., elements per field replaceable assembly, assemblies per upstream assembly, etc.).

In addition to inherent availability, an operational availability assessment is required to optimize radar support concepts and to verify array compliance to reliability and availability specifications in an operational environment. The additional maintenance and support inputs required to compute operational availability include spares provisioning, system corrective and preventive maintenance, depot repair factors, transportation, and maintenance manpower. Raytheon uses a variety of powerful operational availability simulation tools to support these types of analyses and to develop a

![Figure 2: The PACRAT simulation tool significantly reduces the effort to perform array availability analysis and support design trades.](image)

**EXAMPLE:** Consider a 16-element, four-stage array that allows no more than nine element failures to maintain required performance levels.

**Prior to PACRAT** - Perform many individual computations to compute the probability of item combinations that cause array failure. Use results to compute array-level calculation.

<table>
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<tr>
<th>Allowable Failure Combinations During Mission</th>
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**With PACRAT** - Failure maps are automatically generated via Monte Carlo simulation. Failure maps can be easily assessed against the array failure definition to determine the desired array reliability and availability statistics.

**Analysis inputs:**
- Total number of array elements: 16
- Stages of the distributed array: 4
- No. of elements affected by failure in each stage: 16, 8, 4, 1
- Failure rate for each stage item (FR1, FR2, FR3, FR4)
- Mission duration: X hours

**Figure 2:** Continued from page 23
cost-effective system support structure.

While tools like PACRAT provide rapid inherent availability calculations for “maintenance free” portions of operation, operational availability requires more complex calculations and tools. This complexity is driven by:
- Multiple maintenance strategies (e.g., replace some array items more frequently while deployed and defer others until end of deployment).
- Multiphase mission profiles with phase-dependant allowances for maintenance and varying operational tempo.
- Complex failure dependencies.
- Limited support resources (spares, personnel, funding).
- Time-dependent failure rates (e.g., “wear out”).
- Need for optimization analysis (e.g., spares cost, maintenance personnel).

To assess operational availability, more complex Monte Carlo Reliability Block Diagram (RBD) simulation techniques are used. First, a RBD model must be constructed to accurately capture the array’s fault tolerance. Next, all the blocks must be populated with the required attributes (e.g., failure rate and distribution, repair rate, etc.), and the spares and maintenance resource pools must be defined and/or assigned. Finally, a model comprising the mission phases that define the RBD operational environment is employed. Once the models and resource pools are established, a Monte Carlo simulation of system operation is executed for the defined missions and the entire system service life. Figure 3 summarizes the failure and support flows of this modeling and simulation approach.

Raytheon relies on commercially available simulation capabilities such as Windchill® Quality Solutions™ Reliability Block Diagram to develop the specific RBD models and to simulate system availability performance. When required, Raytheon also employs customer-specified simulation tools to support modeling and simulation (M&S) integration with a user’s higher-level “system of systems” model. Regardless of the M&S tool used, results are only valid if populated with valid data inputs. Raytheon’s decades of field reliability analysis, operations and sustainment (O&S) and depot repair operations provide a wealth of real-world operational data required for accurate Ao forecasts.

Raytheon also uses its M&S capability to help customers determine the additional support required to “dial up” availability. For instance, an additional user investment in on-board spares can significantly reduce the probability of system down-time due to insufficient provisions, and thus provide much higher operational availability for extremely critical missions.

Operational availability (Ao) modeling and simulation is not just a technique to support Ao requirements verification. Raytheon routinely extends Ao M&S into the O&S phase. Raytheon’s models can easily transition from “predicted” inputs to “field-observed” inputs that are obtained from the mission environment. The integration of models with the Failure Reporting Analysis and Corrective Action System (FRACAS) and Reliability Centered Maintenance (RCM) activities provides a powerful feedback loop, which includes field failure rates, repair cycle times and wash-out rates. This living availability model enables accurate system availability performance assessments, helps identify candidates for technology refresh, optimizes scheduled maintenance, and serves to measure and prioritize reliability growth initiatives throughout operations and sustainment.

Philip Bedard
Radar Digital Signal Injection System (RDSIS)

System Description
RDSIS is a radar signal processor injection driver developed by Raytheon along with Dynetics and TecMasters Inc. (TMI). RDSIS provides a real-time, high-fidelity test capability for the AN/TPY-2 Radar. The RDSIS simulates the in-phase and quadrature (I&Q) output from the receiver/exciter (rEX) and injects these radar returns into the AN/TPY-2 Radar Signal and Data Processor (SDP). This unique approach provides a test capability to exercise the complete signal and data processing functionality in a real-time, tactical configuration. The RDSIS simulates radar return data for targets, associated objects, launch and separation debris, and man-made and natural environments. Simulated radar return data are injected into the SDP at the appropriate time instants, and are packaged in the required formats to support AN/TPY-2 radar operations. Figure 2 shows the current RDSIS configuration.

The Ballistic Missile Defense System (BMDS), developed and tested by the Missile Defense Agency (MDA), is a globally distributed multibillion dollar system made up of complex elements (Figure 1) that have different communications protocols and interfaces developed by multiple contractors, and that are owned and operated by different branches of the government and military. The BMDS requires continuous upgrades to meet evolving threats, putting a heavy burden on the development and sustainment community. This development includes the need to test and validate new system capabilities on a wide range of threat scenarios. Flight tests provide a reliable venue for testing out the new capabilities, but such tests can also be prohibitively expensive and provide only a small sample of the required data. This necessitates system-level testing through the use of high-fidelity models and simulations of individual elements and validation by flight testing. As more and more BMDS elements are deployed and brought on-line, models and simulations become more important. Simulations provide a cost-effective test and assessment capability that can emulate a near-infinite number of scenario variations that affect critical system performance.

Figure 1. The BMDS is a globally distributed system of sensors and shooters that provides a tiered missile defense architecture.
RDSIS Applications
RDSIS has evolved from a system engineering integration and test tool to an X-Band Simulator Tester (XST), a deliverable product that integrates with multiple radar systems (forward and terminal modes of AN/TPY-2, along with the X-Band Radar [XBR]). Initially RDSIS development focused on providing a high-fidelity threat modeling capability to stimulate radar discrimination algorithms for verification of radar requirements. Successful demonstrations of the RDSIS throughput capability led to additional investment to provide pre-flight risk reduction simulation testing and to integrate RDSIS as part of the BMDS Single Stimulation Framework (SSF) for participation in integrated system test events with multiple BMDS elements.

For element integration, RDSIS is used for requirements verification at the prime item development specification (PIDS) level for the radar (specifically for requirements that need high-fidelity threat representation and the tactical signal and data processor). For flight test pre-test analysis, RDSIS is used for HWIL performance analysis within the lab environment in support of test event milestones (e.g., scenario certification). RDSIS is also used for post-flight reconstruction to recreate the performance observed on the test day and to anchor data with live mission results to provide evidence for simulation validation and accreditation. Finally, the ground test use cases integrate RDSIS into the SSF with other elements to support BMDS HWIL system performance testing.

RDSIS, when integrated with a Radar Interface Unit (RIU), also supports virtual-over-live signal injection. The RIU is modified commercial-off-the-shelf hardware that merges the simulated I&Q from the RDSIS with the live output of the tactical REX. This application of RDSIS provides a greater threat complexity by enabling the tactical software to be exercised with outputs from natural and simulated radar environments.

RDSIS Verification and Validation
RDSIS undergoes thorough integration and testing prior to its use within the radar laboratory environment. This includes verification testing of new requirements and regression testing with each formal release. Test cases are used to test RDSIS functionality; radar interfaces; threat models; and antenna pattern models, receiver characterization (e.g., signal-to-noise ratio, range accuracy and angle accuracy), processing throughput, and SSF interfaces.

RDSIS has been validated through comparison with live radar data including measurements from radar cross section (RCS) signature satellites and high accuracy ephemeris (HAE) satellites, as well as radar data collected during flight tests. Results from these validation activities resulted in initial accreditation of RDSIS by the Operational Test Agency (OTA) in 2011.

Recently, RDSIS has added the capability to interface with the XBR and to model and inject unresolved fuel debris chuff to test new radar capabilities and reduce risk associated with future missile defense flight test events. The Cobra Judy Replacement (CJR) program is leveraging RDSIS to provide an X-band stimulation capability to reduce the risk associated with an upcoming demonstration. RDSIS is also re-hosting the RDSIS Signal Injection (RSI) software item from the Mercury 3200 to an x86 platform with a Linux® operating system. This re-host reduces the overall RDSIS cost and provides a platform-independent solution aligned with the AN/TPY-2 radar signal and data processor hardware migration.

As systems and threat complexity continue to evolve, HWIL simulators, including RDSIS, will develop in parallel to meet simulation and test needs within the laboratory environment. Software architecture studies for RDSIS have already been completed and provide a long-term incremental roadmap for improvements in system throughput, increased scalability and platform independence.

Gregory Hoppa and Rich Powers

Figure 2. Functional block diagram of the AN/TPY-2 Signal and Data Processor along with the RDSIS.
Embedded Training in the Modern Command and Control Environment

Raytheon Solipsys produces tactical display and command and control (C2) software for domestic and international customers. The C2 implementations run from single-user expeditionary systems, such as the Marine Common Aviation Command and Control System (CAC2S), to continental defense (where many dozens of operators work simultaneously), such as the Air Force Battlespace Command and Control Center (BC3). The modern C2 system places great power in the hands of the individual operator. The same human machine interface (HMI) can be used for surveillance, command, control, planning and maintenance activities.

While this density of capability has considerable advantages for experienced operators, it does present a challenge for training. Operators are best trained on the tactical C2 system, yet the environment is necessarily isolated from the Internet. The solution is to provide an embedded training capability that can reside with and stimulate the C2 system so operators can train the way they fight in a live virtual constructive (LVC) environment as mandated in DoD Directive 1322.18.

The importance of embedded training will likely grow as DoD fiscal budgets become constrained, reducing the number of live training exercises. Real assets are not only costly to operate, but training with them increases the potential for injury. While embedded training cannot fully replace live actors, it does offer an environment where the operators can exercise their tactics, techniques and procedures (TTPs). Operators within the C2 system can develop the muscle memory and tool familiarity that are essential for responsiveness in the tactical situation.

Further advantages of embedded training include the consistency and flexibility of application. The embedded trainer application will typically execute a scenario that was developed in advance to subject the operators to a particular test condition such as, in the case of a C2 system, a particular enemy attack formation that threatens a friendly base. The scenario will play back in real time and the operators can be observed to determine their timeliness and accuracy while responding to the stimulus. The same scenario can be played identically each time — which is not the case with real assets involved in an exercise. The embedded trainer should be sufficiently easy to use that a new scenario can be generated quickly to vary the stimulation of the system under test; ease of use and flexibility are paramount in embedded trainer design.

Sculpt

Raytheon Solipsys’ Sculpt is a powerful scenario generator for training, testing and simulation environments. Sculpt facilitates the rapid creation of scenarios of varying size, length and complexity through its intuitive, easy-to-use interface. With a few clicks of the mouse, operators can create detailed scenarios combining air, surface, and undersea platforms. Platform behavior can be customized using Sculpt’s extensive point-and-click editing capabilities, from minor adjustments to altitude and speed to major changes involving platform waypoints and paths.

During scenario playback, the trainer can elect to let the scenario play as planned or interact dynamically with vehicles to introduce real-time changes to tracks. In addition, operator-controlled vehicles can be dynamically injected at any time during playback. The freedom to introduce unscripted, unexpected events gives event supervisors the tools to evaluate operator response to an array of mission variables. Scenarios can be played locally or output to any Distributed Interactive Simulation (DIS)-compliant C2 visualization system.

Figure 1. Sculpt operator interface
Sculpt maximizes force readiness by giving operational organizations the power to generate timely, realistic and relevant training scenarios. In addition, Sculpt’s ease of use assists training organizations in reducing the learning curve required for training personnel to gain proficiency in planning and generating effective scenarios.

Users orient themselves quickly to Sculpt, as they are already familiar with the layout of menu locations, dashboard widgets, filtering buttons, display personalization and the map behavior itself. Sculpt is the same as the Raytheon Solipsys’ C2 systems that they operate; an example screenshot is displayed in Figure 1. This familiarity extends to real-time execution as collaboration features such as chat and alerts also match those of the C2 system.

Features
When developing the simulated scenario for a particular training lesson, the user selects what type of entity to produce and then draws the path of travel for that object directly on the map (Figure 1, locations 1,2,3). To replicate two- or four-ship flight formations, subsequent entities can be defined as following the leader with a defined standoff (Figure 1, location 4). In a test environment the realism of the background air picture is important, so Sculpt has the ability to record time histories of actual air and surface tracks, in a generic data format, and subsequently play a track back simultaneously with the simulated scenario tracks developed as part of the training lesson.

Being compatible with the C2 display, Sculpt can communicate with central display services to obtain shared shapes such as association control measures, which define where the C2 has allocated space for refueling, safe corridors, transit routes, missile engagement zones, etc. (Figure 1, locations 5,6). For simulations to be realistic they should adhere to these conventions. The trainer can utilize a timeline slider bar to review how all the tracks will behave during the scenario playback (Figure 1, location 7).

During execution the tracks will all follow their planned paths. The Sculpt trainer can, however, take control of a specific track in real time and divert it. This functionality, commonly referred to as a “pseudo pilot,” is very useful while training the C2 operator in fighter control.

Sculpt can also support more general simulation and modeling tasks by defining and providing “ground truth” position and velocities of air and surface objects to other applications via its DIS interface. For instance, radar simulators can take the Sculpt-generated DIS truth data and determine if the system being evaluated should be able to observe each track and, if so, the simulator converts the data to the specific interface protocols of the system under test. In such a configuration, Sculpt is merely acting as a component of a larger test scenario and ensuring that the tracks are presented to the system under test. Non-Raytheon customers are currently evaluating Sculpt as an enhancement to their test environments.

Application
Sculpt’s software architecture flexibility allows it to be rapidly adapted to support new or emerging mission areas. One example of this was when a customer was investigating the use of Raytheon Solipsys’ Multi-Source Correlator Tracker (MSCT) and Tactical Display Framework (TDF) software products for a Counter Rocket, Artillery, and Mortar (CRAM) C2 solution. Sculpt was needed to support the demonstration of the C2 solution and, if the C2 solution were selected, provide operator training, which in this case is a very time-critical function due to the short flight time of the RAM threats. Sculpt already had capability to simulate tactical ballistic missiles (TBMs), but did not support the simulation of short-range ballistic weapons. However, over the course of a couple of weeks, representative RAM trajectories were extracted from public domain sources and the software team reprogrammed the existing TBM scenario creator to include mortar and short-range rocket threat trajectory generation as well. As Sculpt utilizes industry-standard models such as ColladaTM, it was possible to purchase an 81-mm mortar shell model for less than six dollars off the Internet.

Using Sculpt, a simulated RAM attack on a defended base can be defined and displayed in both two- and three-dimensional views. In the two-dimensional viewing window, the trainer selects the ballistic vehicle pointer and then draws on the map the desired launch and impact point locations. The flight trajectory is automatically computed, where the range triggers the appropriate algorithm choice (among TBM, short-range missile and mortar) so the geometry is immediately visible in Sculpt’s three-dimensional viewing window. The trainer can pre-view the scenario by using the time slider to review the fly-out. While this is a simple example, it does reflect one of the tenets of the Sculpt product; namely, it is not necessary to provide fidelity in simulation beyond its intended purpose. If the focus is to train C2 operators, then the fidelity must pass their credibility test. Too often programs attempt a “one size fits all” approach to simulation, resulting in the development of a large, complicated infrastructure where the costs of adding functionality are prohibitive.

Sculpt Looking Forward
Embedded training techniques continue to improve, providing increased simulation realism and breadth of scenarios to the operators, and Sculpt continues to expand its capabilities in both these areas. A particular challenge is the integration of tactical data link functionality within the simulation. Increasingly, tactics, techniques and procedures are relying on these digital data link methods to execute the C2 mission, where it had previously been dominated by voice interaction. Sculpt’s flexible development architecture and its compatibility with Raytheon Solipsys’s MSCT product, which already has an extensive tactical data link capability, ensures that Sculpt can meet this emerging need.

Richard Harman
The increasing complexity and scope of operations conducted by today’s warfighter have created a corresponding need for increasingly complex modeling, simulation and analysis methods to represent and assess these missions. For example, U.S. ground forces operating in urban areas may suddenly encounter an ambush that requires them to quickly adapt to and gain greater situational awareness of their immediate surroundings.

Conventional constructive simulations used for mission analysis are limited in the realism with which they can capture mission dynamics because constructive simulations use simulated people, systems, and environments. During combat, real soldiers are inundated with stimuli and information that must be quickly translated into decisions. The use of simulated people in constructive simulations requires that human factors such as situational awareness and decision making be simplified or altogether ignored due to the complexity of human behavior. Because human behavior is such an important part of a simulation’s realism and effectiveness, this was a shortcoming of these conventional simulations.

The availability and maturity of commercial off-the-shelf (COTS) tools — such as Virtual Battlespace 2™ (VBS2, Figure 1), Virtual Reality Scene Generator™ (VrSG), and Unity™ — have brought immersive 3-D visualization of modern warfare to military simulations. The use of videogame engines with simulation is officially called “serious gaming.”

The use of videogames for simulation experiments at Raytheon dates as far back as the use of Fleet Command™ for naval traffic in the year 2000. In addition to major advances in visual detail, vendors also provide software such as LVC-Game™ with VBS2 to simplify integration with Raytheon simulations by providing interfaces based on standard defense industry distributed simulation protocols such as Distributed Interactive Simulation (DIS) and High-Level Architecture (HLA).

Serious gaming has provided a means to address much of the realism gap by inserting real people using simulated systems into simulated environments. In industry standard parlance, these operator-in-the-loop simulations are called “virtual simulations” or “virtual environments” (VEs). Some COTS visual tools originated as popular game engines, but others were purpose-built as simulation tools to represent a sensor’s view of the battlefield. One important distinction that stems from this difference is that game engines such as VBS2 generally only represent passive sensors (e.g., infrared) whereas some real-time scene generators such as VRSG can simulate active sensors (e.g., radar). The modeling priorities of the genres also differ. In general, the videogame community heavily emphasizes the visual experience more than the physics, but the simulation community values physics more than visual detail. This is why the linkage of technologies from the two communities is so powerful; their respective strengths are complementary.

VEs are not a modeling panacea, but they have enjoyed tremendous popularity and use within the U.S. Department of Defense and defense industry because they can capture much of the complex and nonlinear dynamics of today’s missions. The most common uses of VEs include training, mission rehearsal, experimentation, mission analysis and wargaming. For instance, the ground forces in the ambush scenario mentioned at the start of this article could participate in a simulation experiment where they are inserted into vehicles in a convoy in...
the Middle East and forced to fight through the ambush using current technologies and tactics. The mission can then be repeated using systems with proposed new capabilities such as a wide area sensor whose video simultaneously covers an entire urban area as shown in Figure 2. Qualitative and quantitative assessments can be made of the impact of these new technologies on mission effectiveness. The increased realism provided by VEs translates into deeper insights into whether new concepts or technologies can change battle outcomes in spite of the fog of war.

Some of the benefits of using Virtual Environments based on commercial, government and Raytheon off-the-shelf tools include:

- Better representation of the fog of war.
- Deeper insights into whether concepts or technologies can improve battle outcomes.
- Easier experimentation with varied tactics, techniques, and procedures (TTPs).
- Greater focus on modeling military systems instead of tedious reproduction of the mission environment (terrain, buildings, people, vehicles, weather, etc.).
- More immersive scenarios and environments for improved training.
- Faster progression of concepts from PowerPoint® to evaluation in virtual missions.

The latest generation of warfighters has grown up with realistic video games and smart phones, which have made them comfortable interacting with virtual environments and avatars. The U.S. Army has recognized this ease with technology and has been actively enhancing their training curricula to exploit the warfighter’s ability to learn through this new and interactive medium. The Army is moving toward a new model of training that mixes traditional live training with virtual, constructive and gaming simulations, creating a seamless, blended environment that allows soldiers to train as they fight (Figure 3). This new model, called blended training, is continuously available, cost effective and flexible, giving soldiers the ability to train more often and in scenarios that are difficult to create in live exercises.

Despite all of its advantages, however, there are negative aspects of the new blended training model, stemming primarily from the gaming simulations. These simulations are powerful tools that let an entire unit rehearse missions collectively, but commercial companies often create these simulations by adapting existing, mass-market video games. As a result, the weapon system models included in these simulations, including models of Raytheon products, are only gaming representations of the real system. They are controlled by a mouse and keyboard and typically do not behave like the actual system. For instance, the Javelin system included in a popular Army gaming simulation automatically locks on to targets for the player and simply requires a mouse click to fire the missile. To use this model would not only misrepresent the capabilities of a Raytheon product but also would miss an opportunity to train the player on how to employ the weapon properly.

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Raytheon is working to correct this problem through an innovative new set of products called Virtual Combat Systems (VCSs), which are accurate representations of Raytheon systems within the various gaming simulations (Figure 4). The VCS for each system consists of two parts: the software plug-in for the gaming simulation and a training replica of the weapon hardware that is used to control the software. Providing the warfighter with both of these components ensures that the form, fit and functionality of the tactical weapon system are accurately recreated in the virtual training. With VCS, a warfighter can now gain all of the benefits of blended training while still receiving positive training on the weapon systems.

Raytheon engineers and graphic artists collaborate to construct each Virtual Combat System. First, graphic artists collaborate to take detailed engineering drawings of the weapon system and use them to create an in-game model of the weapon. This process is different for each gaming engine. Currently, VCS efforts have been based on the VBS2 commercial gaming engine. Once the weapon has been recreated within VBS2, engineers begin coding the functionality of the weapon system. Engineers ensure that the virtual system and its graphical user interface (GUI) look and behave like the real system: facsimile buttons trigger the appropriate action, munitions fly accurately, optical capability is correctly represented, error messages are displayed, etc.

The final step is to integrate or construct the replica hardware that controls the software. This is done by remapping the controls of an existing training device or creating entirely new hardware with movement-recording technology (such as gyros and accelerometers) similar to what is embedded in most modern smartphones. The movement information is combined with information from the various buttons and switches on the system and sent back to the software, which then translates the information into the appropriate commands for the gaming simulation. When a soldier moves the hardware or presses a button, his virtual avatar matches his actions.

An example VCS for Javelin shown in Figure 5. The user looks through the viewport on the hardware controller (lower right inset) and sees the weapon system’s GUI (lower left inset). All movement and button presses are then translated to the avatar in VBS2, and the GUI updates to the new state. The power of using VCSs for training is enormous. One day a soldier can be learning the basic skills of the weapon system on a virtual representation of a familiar firing range, and the next day he or she can be rehearsing a virtual mission in Afghanistan with their unit. VCS adds requisite fidelity to the gaming representation of Raytheon products, ensuring that the warfighter has the best training tools possible. This not only provides better training for the warfighter, but also helps ensure that Raytheon products are being used to their full potential.

Aside from the military training application, VCSs have also proven to be powerful tools during earlier program phases for visualizing and test-driving new technologies and capabilities with customers. This ability has proven invaluable for the growing International market. With a VCS, not only can you provide the customer with a solid understanding of the weapon system, but you can easily do it in a scenario that demonstrates your understanding of the customer’s problem space. With a virtual representation of the weapon, demonstration is easier in any language and scenario.

To date, Virtual Combat Systems have been created for the four programs shown in Figure 6: Javelin, Serpent, Tube-launched, Optically-tracked, Wire-guided (ToW) missile, and Stinger. Raytheon is considering extension to other products and is exploring how this technology can be applied elsewhere, including light-weight mobile applications.

As new hardware and software technologies mature, future virtual environments will continue to expand into many more markets than simulation and training. Although virtual reality (VR) has been touted as transformational, visions of the future such as the holo-deck in “Star Trek®” have given many people an expectation of VR that goes beyond the limits of today’s technol-
However, the gap between simulation and reality is continually shrinking due to advances in animation software, computing resources and new human interfaces that promise greater operator immersion.

One example of a new interface technology was developed by VirtuSphere, Inc. and is akin to a “hamster wheel” for humans. It breaks down one of the big barriers to realism: the lack of physical movement to induce fatigue when “running around” in a VE. The ability to physically run within a VE can reveal secondary effects of proposed systems such as the impact of carried weight on mission tempo and operator effectiveness.

Another area of much needed improvement is virtual reality goggles that allow a user to see their virtual environment in any direction they look. Unfortunately, most goggles available today offer a field of view (FOV) similar to looking at the world through a tunnel. However, things are improving and new goggles are beginning to offer horizontal FOVs roughly equal to the full human FOV.

Although Hollywood’s latest blockbuster movie visuals can raise expectations of simulated reality to unrealistic levels, it does give a compelling glimpse into future VEs. The video games of yesteryear now easily run on an average smartphone. Similarly, the major difference between the computer graphics in movies today, which are almost indistinguishable from reality, and future virtual environments is just the date on the calendar.

Patrick V. Lewis and Jon Peoble

Aside from the military training application, VCSs have also proven to be powerful tools during earlier program phases for visualizing and test-driving new technologies and capabilities with customers.
For more than a decade, Raytheon has been working on an integrated suite of tools geared to support simulation development through the entire product life cycle. These tools are genSim™, genIr and genRF, and they offer users and customers a flexible, reliable, cost-effective and proven solution to their simulation and modeling needs. Each of these tools incorporates “gen” in their names to reflect the design goal of being a “general-purpose” simulation capability that is adaptable to programs across many product lines. The use of genSim, genRF and genIr has helped reduce the risk and number of expensive field tests by allowing system components and software, such as today’s cutting-edge signal processing algorithms, to be matured and extensively tested in simulated environments prior to field testing.

**genSim Provides the Simulation Infrastructure**

At Raytheon, program simulation development usually begins with an infrastructure and a set of core tools that can be leveraged to quickly develop simulations at low cost and risk. For nearly ten years, programs have used genSim (Figure 1) as the base simulation architecture to provide the infrastructure and tools required for rapid weapon system digital simulation development.

As an advanced, off-the-shelf simulation framework solution, genSim supports the complete life cycle, from simulations that perform initial trade studies through hardware-in-the-loop simulations that support program flight tests. To provide such a range of capabilities, genSim combines a complete six-degrees-of-freedom (6-DOF) simulation with a rich development environment. Using the genSim architecture, engineers can quickly and efficiently stand up simulation capabilities, add program-specific modules and/or increase fidelity by expanding existing modules. An existing collaborative user base and multiple model

**Accelerating Simulations Through the Use of General Purpose Graphical Processing Units (GPGPUs)**

Computer processors known as graphical processing units (GPUs) are massively parallel processors that outperform multi-core processors in solving computing problems that can be broken down into a large number of less complex, independent processing tasks. These computing problems, commonly known as embarrassingly parallel problems, arise naturally in physics-based modeling and simulation (M&S). While modern multi-core processors contain a handful of central processing units (CPUs or cores), GPUs contain hundreds; though GPU cores are specialized, and are not exactly equivalent in versatility or complexity to the modern CPU.

Traditionally, GPUs were designed to handle computer graphics algorithms, which are described in the form of highly parallel mathematical operations. Once the industry realized that GPUs could be used for general purpose computing, programmers were required to configure their computing tasks as a series of graphics operations. This became cumbersome and time consuming. Over time, standardized software Application Programming Interfaces (APIs) were developed, creating the field known as General Purpose Computing using Graphical Processing Units (GPGPUs). Current APIs include the open standard OpenCL, from the Khronos Group consortium, and the NVIDIA proprietary CUDA® (Computer Unified Device Architecture).

Rapid advances in semiconductor manufacturing and a high demand for the devices, have made GPGPU-capable commercial off-the-shelf (COTS) graphics boards affordable and easily available. The latest generation cards are peak-capable of hundreds of gigaflops (10^9 floating point operations per second).
Raytheon employs GPGPU technology as a cost-effective way to accelerate simulation and computation, and to increase computing power (Figure 1). The technology has been used in air warfare, land combat, and air and missile defense simulations to accelerate computationally intensive models and enable high-fidelity testing of real-time software. In particular, it has been applied to electro-optic (EO) scene generation and sensor modeling, radar beam forming, signal decoding, and general purpose scattering-based scene generation. It has enabled new capabilities, such as the ability to test embedded real-time signal processing algorithms in a computer-in-the-loop (CIL) configuration that uses high-fidelity, dynamic real-time scene generation (RTSG).

Complex simulations producing sensor images can be accelerated up to 100 times without a major compromise in scene content fidelity and numerical equivalence. This capability allows modelers to architect their designs in ways that accelerate computations while still maximizing code reuse, i.e., not requiring development of separate streamlined lower-fidelity models to support real-time simulation testing.

Vendors and original equipment manufacturers are partnering with Raytheon to explore GPU implementations in harsh, rugged environments and low-power situations to provide the same level of performance for applications in an operational environment as well.

Anibal Morales

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Figure 1. Raytheon’s use of general purpose graphical processing unit (GPGPU) technology to accelerate a computer simulation in a real-time computer-in-the-loop (CIL) environment. From the left, a requirement must be met to generate each sensor image frame within a given time budget. The genSim 6-DOF “flies” the sensor package, providing the sensor information via a high-speed interface to a workstation equipped with GPUs. The image formation software in this workstation (e.g., genIR) has been accelerated with GPGPU techniques to deliver an image stream at faster-than-real-time rates to the electronics unit stack of an actual built sensor. The sensor stack electronics cannot tell the difference between real or simulated flights, allowing engineers and algorithm designers unprecedented testing and performance evaluation capabilities in a laboratory setup.

Repositories enable model reuse and agile support.

genSim uses an object-oriented, module-interchangeable framework, which provides a means to test multiple levels of fidelity for individual modules or entire systems. It supports integration with third-party models, operational flight software interoperability via genSoft™ and distributed simulation implementations for multicore processing environments. genSim also provides real-time synchronization and timing analysis capabilities that are required for computer-in-the-loop and hardware-in-the-loop simulation environments.

Leveraging capability originating since 2002 from successful genSim simulations developed for the Mid-Range Munition (MRM) and the Miniature Air Launched Decoy (MALD), the Small Diameter Bomb (SDB) program has generated a series of genSim-based simulations for multiple purposes, from the all-software Integrated Flight Simulation to the real-time Computer-in-the-Loop simulation that employs selected flight test hardware. SDB also incorporates form-factored flight software in the simulation using genSoft™. This genSim/genSoft-based approach allows for seamless integration of the embedded flight software during missile buildup, which will have significant utility as SDB embarks on its flight test program to demonstrate the capability of the tactical design.

genRF Models Radio Frequency (RF) Systems

The General-Purpose Radio Frequency Signal Generator (genRF) is a signal generation model that represents the performance and characteristics of an RF system in a simulated environment. genRF provides a common set of modules and capabilities so that users can configure the model environment to match a particular radar system (Figure 2).
By allowing for variable configurations and fidelity modes, genRF is capable of supporting scene generation and sensor modeling throughout the product development lifecycle. Users are able to simulate a variety of scenarios and effects, including self-defined waveforms, geometries of interest, electronic warfare environments and specific hardware components.

genRF provides a multitude of RF simulation and analysis capabilities, enabling users to develop and assess performance on a variety of different RF system designs and algorithms. Integrated into genSim, genRF provides simulation capabilities ranging from initial trade studies through to system hardware testing.

genRF can provide rapid results using effects-based models, and it can also use time-domain models to supply data that includes pulse-to-pulse motion effects. When simulation run-time becomes a concern, genRF offers a General Purpose Graphical Processing Unit (GPGPU, see inset) accelerated implementation that can reduce data generation times by an order of magnitude or more. Additional configuration parameters allow users to modify their scenario setup, providing the ability to perform system trades on different hardware and software components and to assess performance in different terrain, clutter and countermeasure environments. The tool has been integrated into multiple genSim-based integrated flight simulations, and it can be used in a single-point, stand-alone mode. Users can leverage and extend genRF’s built-in telemetry system and analysis scripts to meet individual processing needs.

Among the recent genRF development efforts are the real-time simulation capabilities used to enhance support for computer and hardware-in-the-loop environments and to improve flight simulation throughput.

Technology demonstrations utilizing genRF and genIR (described in the next section) have proved the capability to simultaneously simulate both RF and infrared (IR) sensor data for multimodal sensor applications. The ability to support stand-alone analysis, integrated flight simulation and system hardware testing makes genRF a perfect fit for Raytheon’s external and internal customer radar analysis needs.

genIR Models Infrared (IR) Systems
The General Purpose Infrared Sensor Model (genIR) is a next-generation imaging sensor model developed for use in closed-loop digital simulations. Using physics-based models in combination with laboratory measurements and/or statistical models, the genIR architecture provides a unified way of modeling infrared cooled and uncooled sensor camera optics and video hardware. genIR exists as a user-configurable package designed by subject matter experts in electro-optics (EO) technology, using best practices of simulation software design. genIR benefits from an active user and developer community continuously adding to its model knowledge base.

genIR consists of object-oriented C++ software modules that model the EO/IR missile seeker and surveillance sensors from programs across Raytheon. As shown in Figure 3 the model architecture contains physics-based modules aggregated into processing pipelines that work together to accurately model imaging infrared seeker optics and the electronics front-end for IR hardware. genIR is a proven technology used today in major programs, independent research and development efforts, signal processing algorithm development, and other modeling applications.

By allowing for variable configurations and fidelity modes, genRF is capable of supporting scene generation and sensor modeling throughout the product development lifecycle. Users are able to simulate a variety of scenarios and effects, including self-defined waveforms, geometries of interest, electronic warfare environments and specific hardware components.

genRF provides a multitude of RF simulation and analysis capabilities, enabling users to develop and assess performance on a variety of different RF system designs and algorithms. Integrated into genSim, genRF provides simulation capabilities ranging from initial trade studies through to system hardware testing.

genRF can provide rapid results using effects-based models, and it can also use time-domain models to supply data that includes pulse-to-pulse motion effects. When simulation run-time becomes a concern, genRF offers a General Purpose Graphical Processing Unit (GPGPU, see inset) accelerated implementation that can reduce data generation times by an order of magnitude or more. Additional configuration parameters allow users to modify their scenario setup, providing the ability to perform system trades on different hardware and software components and to assess performance in different terrain, clutter and countermeasure environments. The tool has been integrated into multiple genSim-based integrated flight simulations, and it can be used in a single-point, stand-alone mode. Users can leverage and extend genRF’s built-in telemetry system and analysis scripts to meet individual processing needs.

Among the recent genRF development efforts are the real-time simulation capabilities used to enhance support for computer and hardware-in-the-loop environments and to improve flight simulation throughput.

Technology demonstrations utilizing genRF and genIR (described in the next section) have proved the capability to simultaneously simulate both RF and infrared (IR) sensor data for multimodal sensor applications. The ability to support stand-alone analysis, integrated flight simulation and system hardware testing makes genRF a perfect fit for Raytheon’s external and internal customer radar analysis needs.

genIR Models Infrared (IR) Systems
The General Purpose Infrared Sensor Model (genIR) is a next-generation imaging sensor model developed for use in closed-loop digital simulations. Using physics-based models in combination with laboratory measurements and/or statistical models, the genIR architecture provides a unified way of modeling infrared cooled and uncooled sensor camera optics and video hardware. genIR exists as a user-configurable package designed by subject matter experts in electro-optics (EO) technology, using best practices of simulation software design. genIR benefits from an active user and developer community continuously adding to its model knowledge base.

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and simulation activities. Its highly configurable modules make it a perfect choice for engineers seeking to model specific EO/IR sensor behavior in their analyses. genIR provides an extensive pedigree through verification and validation efforts performed in multiple programs, which include comparisons with theoretical calculations, captive flight tests and free flight data.

genIR is designed to be compatible with genSim and other simulation frameworks, as well as being capable of running in stand-alone mode. Many programs have substantially lowered their design and development costs by leveraging this technology, and many others are currently investigating its applicability. genIR supports the complete life-cycle process, including sensor pre-design, algorithm development and software- and computer-in-the-loop performance testing (Figure 4).

Future Applications
The genSim family of simulations is poised to expand into additional system design activities, such as cost modeling and reliability, in order to support robust and affordable system solutions. While future developments of genRF and genIR will increase model capability, genSim development will focus on new features requested by the growing user base. We are also looking to apply our software and analysis tools to broader system design challenges in the other Raytheon businesses.

C. Russell Hanson, Anibal Morales, Edward Romic and Juan Carlos Salcedo

ENGINEERING PROFILE

Michael L. Walker
RFuture Project Lead
Missile Systems

Michael L. Walker is currently the lead for the missile system’s RFuture effort. In this role, he is responsible for a business-wide collaboration effort to transform the missile system’s business and culture into an organization that will provide for faster and more effective engineering solutions for our customers. Prior to this assignment, Walker was the deputy center manager for the Modeling Simulation and Analysis (MS&A) Center. He has more than 20 years of experience in commercial and military modeling and simulation with extensive experience in system engineering, network/Internet technology, large-scale simulations and algorithm optimization. He has designed and implemented embedded processing frameworks, along with the High-Level-Architecture-Real-Time-Infrastructure (HLA-RTI) design for embedded and large-scale federations, and numerous simulations for product lines.

While working at the MS&A Center, Walker enjoys leading company activities in simulation networking and security, high-performance computing (HPC) design, and model based engineering initiatives. “I have always gravitated to computer programming and simulations,” he notes. “During my undergraduate studies, I had the opportunity to work in developing simulations that focused on countermeasure performance for the Army. It just seemed natural to continue simulation work after graduation, and continued simulation work when I joined Hughes Missile Systems [later becoming Raytheon Missile Systems].”

Early in his career, Walker was exposed to a wide range of analyses, from test range prediction to operational performance to countermeasure analysis. He developed various models and performed analyses that focused on RF countermeasures and GPS improvements for weapon systems. He worked on the original Theater High Altitude Air Defense (THAAD) proposal where he initiated the development and collection of the tools and models that would later become what we now know as the Interactive Theater Air Defense System (ITADS) simulations suite. Walker led efforts to commomimize the Standard Missile Plate 2 design across all of the missile variants. He also worked on several Defense Advanced Research Projects Agency (DARPA) activities with the University of Southern California. These efforts led to a team lead position in charge of several HLA interface modules that were delivered to the NATO ballistic missile defense testbed. Walker became a department manager in 2007 for the newly formed department within the MS&A Center called Advanced Modeling Concepts (AMC). This department was responsible for the continued development of ITADS, genSim and other simulations.

“Our customers want Raytheon to deliver the best systems that we can build to protect our warfighters,” Walker maintains. “Understanding the customer need and how to turn that need into requirements is critical in producing our products. To help understand what those requirements should be, we work with the customer, using simulations to perform the analysis that will turn those needs into our top-level requirements.”

RAYTHEON TECHNOLOGY TODAY 2013 ISSUE 1
Enterprise Modeling and Simulation (EMS): Enhancing Cross-Company Collaboration to Improve the Quality of Solutions that Raytheon can Offer Our Customers

One of Raytheon’s core strengths is the broad and deep knowledge that exists across the company. Our collective expertise spans a wide range of high tech disciplines, providing a vast fund of knowledge that drives our success. However, knowledge in isolation does not generate solutions to the many complex technical challenges that our customers face. Enterprise Modeling and Simulation (EMS) addresses this problem by providing solutions to enable us to rapidly and effectively distribute our expertise, knowledge and simulation capability from where it resides to where it’s needed. This capability results in quick access to the information needed so our subject matter experts (SMEs) can provide innovative solutions to customer problems.

EMS is an effort that facilitates collaboration by permitting the sharing of data, including classified data, across the Raytheon Enterprise (Figure 1). EMS has partnered with Information Assurance (IA) and Information Technology (IT) specialists across Raytheon to provide governance and processes to facilitate analysis that benefits the government and Raytheon.

EMS has assisted in developing a strong mission analysis capability that supports the needs of our customers. Like a strong house, a strong mission analysis capability needs a good foundation. EMS provides this foundation by providing access to data and models, interacting with the customer modeling community, and enabling collaboration between a geographically dispersed set of SMEs. This work enables system and technology development to be more effective. Instead of starting from scratch, technology development efforts are able to leverage existing work within Raytheon or the customer modeling community. They are able to reach into Raytheon’s breadth of SMEs for support, which leads to more credible analyses. Credible analysis results produce more opportunities for customer engagement, improve investment strategy decisions, and help develop a better technical baseline to meet customer needs.

Architecture
The EMS architecture encompasses a security framework, accreditation model and a secure product work environment that facilitate classified collaboration. Users of the infrastructure have modern tools available to them such as email, instant messenger, screen sharing and video teleconferencing. When users travel to different sites, they are already briefed to the information security plan and therefore they are able to use the same authentication credentials. They no longer have to think about having to “move” data from one site to another; they work in a common project workspace that is available from any deployed location.

Security Framework
Strong EMS governance, processes and procedures are employed to facilitate compliance with security requirements. The Security Framework pillar has responsibility for the creation and management of the governance that maintains compliance while providing a methodology that enables projects to succeed. Beyond collecting project requirements and generating the required security documentation, the most critical part of this pillar is the data co-use agreement. The co-use agreement is our mechanism for evaluating whether a specific set of program data can be moved and used for the specified project. Also included in the co-use agreement is whether the data has special handling requirements. EMS governance then ensures that the requirements stated in the co-use agreement are followed.

Accreditation Model
The second pillar of the EMS architecture is the Accreditation Model. The National Industrial Security Program Operating Manual describes two types of network accreditation: interconnected and unified. An interconnected wide area network (IWAN) comprises separately accredited systems and each site retains control and protects its own resources while a Unified Wide Area Network (UWAN) is a network accredited under a single system security plan. Each offers advantages and disadvantages in the areas of accreditation time, ability to add
and remove hardware at different sites, and security infrastructure support for modern collaboration tools. Coordination with the Defense Security Service (DSS) resulted in the definition of an enhanced IWAN called IWAN 2.0. This approach provides granular control of the security environment at the participating site level, establishes one common active directory infrastructure, and is agile enough to efficiently support the dynamic nature of the WAN. The IWAN 2.0 accreditation model consists of one host site and multiple participant sites. The host site manages the Network Security Plan (NSP) and distributes a common security policy to the other sites, each of which customizes the policy to fit its needs. This accreditation architecture provides the ability to manage the network’s configuration without creating a high level of accreditation overhead, a highly desirable arrangement for both industry and DSS.

Secure Product Work Environment
The third pillar of the EMS architecture is the Secure Product Work Environment (SPWE). SPWE is the IT solution that meets the accreditation requirements of IWAN 2.0 while giving the users access to modern collaboration tools. The primary building block of the SPWE is named Program-in-a-Box (PnB). PnB is a common set of off-the-shelf hardware that creates a highly virtualized server and desktop infrastructure for streamlining the way we work within secure environments. It benefits users through collaboration services such as email, document sharing and instant messaging. At the same time, the PnB approach eliminates many redundant IT assets and lowers the management burden.

Enterprise Modeling and Simulation
Raytheon’s EMS team has led the development of three operational classified networks connecting six Raytheon locations across the country. Each network has its own unique contract security classification specification for specific technology projects, thus allowing the different sites within Raytheon to conduct collaborative program activities at a classified level. The classified networks allow much more than just the simple exchange of data. Each network contains a SPWE that provides a host of computer network collaboration services, including voice over Internet protocol (VoIP) communications; video teleconferencing (VTC); web-based project management; and numerous automation capabilities for system administrators, including software deployment, inventory and auditing.

Keys to Success
Partnering among IA, IT, and engineering is the key to our success. These relationships facilitate the sharing of best practices along with finding better ways to collaborate, lower operational costs and introduce innovative IT solutions into a complex accreditation environment. As the SPWE build-out continues and connectivity among Raytheon’s businesses expands, our governance, processes and procedures will become increasingly uniform, transparent and efficient across the company. We will continue to ensure protection of sensitive data while increasing the availability of information to people who require access.  

R. Flanagan

Figure 1. Enterprise Modeling and Simulation (EMS) facilitates collaboration across Engineering Development Sites to enable development of new system concepts that span capabilities across Raytheon businesses.
Continuous improvement to drive efficiency and higher development productivity is Raytheon’s priority and our customer’s directive. In a September 2010 memo, Under Secretary of Defense for Acquisition, Technology and Logistics, Dr. Ashton Carter, calls out the need to:

• "Mandate affordability as a requirement."
• "Set shorter program timelines and manage to them."
• "Incentivize productivity and innovation in industry." 1

Software development methods and tools such as Agile and Lean development are used to minimize software cost and reduce software delivery time. The emerging trend to use these methods in the commercial industry is beginning to penetrate the defense industry. Recognizing the opportunities that these methods and tools present, Raytheon’s software community has been challenged to think beyond incremental software development methodology improvements and look for ways to dramatically increase productivity and our competitiveness.

**Pillars of Success**

Raytheon’s Software Innovation for Tomorrow (SWIFT) initiative is helping us meet the challenge of delivering mission solutions faster and more efficiently while meeting or exceeding the software quality levels our customers expect.

Realizing this goal requires a comprehensive approach. SWIFT is organized around four primary focus areas whose foundational objective is customer alignment (Figure 1). This approach is designed to improve productivity, reduce schedule and mitigate risk.

Some major SWIFT pillar components are summarized below.

**People and Environment**

Raytheon-selected methods provide the education, collaboration, workspaces and development tools needed to change the traditional software development culture.

Agile software development — characterized by open communications, iterative requirements and development, and customer collaboration — allows for rapid delivery of incremental working (integrated/tested) software components. Application lifecycle management (ALM)2 tools go beyond the well known integrated

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2 Application Lifecycle Management is “a continuous process of managing the life of an application through governance, development and maintenance.” Wikipedia Foundation, Inc., 2010.
development environment (IDE), providing automation and managed workflow through requirements, design, architecture, release and deployment phases. Virtualization (running multiple operating systems on a single computer) makes efficient use of hardware while introducing agility in supporting multiple development environments. When combined with lean methods, which eliminate waste and increase efficiency, this approach enables Raytheon to develop effective solutions while providing the customer with high-priority capabilities first.

"Scrum is an iterative and incremental agile software development method for managing software projects and the product or application development." A key element of this is a sprint, which is a fixed unit of development generally of a one-to-four-week duration with team-defined tasks and goal(s). Figure 2 (page 43) depicts a typical Raytheon implementation of the Scrum management framework. The Scrum team, comprised of Raytheon and customer team-mates, (A) holds daily time-boxed standup meetings to facilitate communication and (B) utilizes a job list to organize, plan and delegate tasks and subtasks. The Scrum Master captures the sprint progress in electronic form and tracks progress of the work products daily, leading to an incremental release.

As noted in the November 5th, 2012 issue of Aviation Week, the Scrum management framework adopted by IDS’ Zumwalt program had a positive direct impact to the program’s schedule and milestones: “Few ships are more dependent on proper software development than the thinly crewed DDg 1000 Zumwalt-class destroyers, which rely on computer networks to run more automated systems for their operation. Thus far Raytheon Integrated Defense Systems, one of the Zumwalt’s prime contractors developing a major portion of that software, has been able to meet program deadlines and milestones for those systems. One of the keys for that success, says Bill Marcley, Raytheon DDg 1000 program manager and vice president of Total Ship Mission Systems, has been a, ‘new agile software development approach,’ for software development and production."

Automation

Model Driven Software Development (MDSD) is a method of creating models in a high-level, domain-specific language, and these models can subsequently be converted to executable software components through an associated automatic code generation function. These automation techniques decrease the time required to generate deliverable artifacts and raise the quality of the software by minimizing defects throughout software development stages. Task automation focuses on eliminating or reducing repetitive tasks and thereby streamlining development activities, allowing engineers to focus on technical tasks. Finally, the consistent use of parametric cost modeling automates the generation of project estimates, refines the accuracy of each estimate and reduces the cost of capturing estimates.

Integration automation techniques have been deployed widely within Raytheon’s businesses. Automated overnight builds

Continued on page 42
result in savings in configuration management labor, while automated unit tests reduce overall engineering hours. This increased automation and pace of integration helps developers identify defects earlier and quickly implement fixes, leading to reduced manpower requirements. As a result, programs have reduced estimates at completion and have lowered estimates on future efforts.

Structured Reuse

Structured Reuse is the framework, resources and mechanisms for developing reusable software, and it provides governance on how to reuse such software correctly and efficiently. The methods within the Structured Reuse pillar pull together the strategic use of external software sources such as commercial off-the-shelf (COTS) and government off-the-shelf (GOTS) products to leverage mature industry technologies. Software product lines are sets of software-intensive systems sharing a common, managed set of features developed from a common set of core assets, e.g., from a toolkit (see sidebar on toolkits). Satisfying specific needs within a market segment, software product lines help ensure that Raytheon’s delivered systems contain seasoned, well-tested components. Similarly, at a smaller scale, niche reuse solutions are strategically targeted software assets reused across a mission domain as a means to quick and reliable solutions.

Raytheon has focused on broadly deploying structured reuse methods and has received a noticeable benefit from the adoption of software product lines and niche reuse. Usage of Raytheon genSoft (an integrated toolkit of simulation models that supports a common product development methodology) has increased over 100 percent since 2010 and is now standard on all new missile programs. Employing genSoft has saved thousands of labor hours per use.

Advanced Test

Advanced test techniques play a major role in both software development and function verification. Test driven development is an iterative process by which both test software and the functionality are continually advanced in short, repeating cycles until the functional software component and associated test harness are completed. Test optimization is a parametric-based approach to statistically determine an optimized test.

Significant focus today is placed on applying software reuse and software design patterns to improve software development efficiencies, reduce costs and increase overall product quality. While this concept is conceptually understood, successfully implementing it is highly dependent on the individual solution (target platform, language, application domain, etc.) and oftentimes requires a manual effort with subject matter expert (SME) input. To minimize solution dependencies while maximizing software reuse and SME effectiveness, Raytheon uses a toolkit approach.

A toolkit is a self-contained, documented solution to a particular common software function and incorporates well-defined interfaces for ease of integration. The use of toolkits drives down software implementation cost by capturing domain-specific patterns from SMEs in a tool, and then enabling non-SMEs to reuse that tool repeatedly. This approach enables reuse and multiplies the value of the SME’s expertise.

Toolkits utilize tightly integrated elements such as pattern construction process flow; contextualized guidance to describe the processes why, what and how; pattern models and user-focused variability points; domain-specific languages (DSL) to raise the abstraction level; automation to generate code, documentation and other artifacts; and code generation validation. These elements work together to produce a valid, high-quality result every time. Because toolkits incorporate high-level pattern knowledge and failure-resistant processes, they help developers to focus on what to change and then enable them to validate and quickly generate the change. This means that toolkits make reuse much easier and therefore more likely to be done.

Applications

Raytheon uses toolkits to increase efficiencies and reduce errors during the software development cycle. One toolkit application that has been widely used by programs is a message handler. In this context, a message handler is an application used to mediate messages between two different systems or subsystems (e.g., receiving messages from a Tactical Data Link [Figure 1] such as Link16 and converting them to an Internet Protocol [IP] based message protocol such as Data Distribution Service [DDS]). Traditionally, message handlers are developed individually to provide a single, particular solution. As a toolkit, however, a generic message handler is developed containing user-configurable message sets, rules for mapping fields between messages, workflows that define message processing priorities, and transport layers (e.g., Tactical Auto Data Information Link [TADIL], Ethernet, satellite communications [SATCOM]) that support connection to the appropriate external data sources. Ultimately, subsequent implementations that were once significant development efforts for SMEs on multiple application platforms become much more efficient and reliable configuration/integration tasks.

Consider a C++-based radar system broadcasting bit packed track messages over Transmission Control Protocol/Internet Protocol (TCP/IP) and a Java-based intelligence application utilizing Web services for Extensible Markup Language (XML) encoded data exchange. These are very different domains with a need to exchange data using their own network protocol in a format each will understand. The toolkit integration provides a high-level interface for message definition to identify the fields to be changed and also furnishes the conversion process, the validation process and finally the cyber hardened network transport functionality. This extreme reuse example demonstrates how the toolkit approach broadens opportunities for reuse across functions and domains. It promotes efficiencies in both software design and development while ensuring the highest possible reliability through reuse of proven software.

Terri Potts and John Slaby

Toolkits Enable Efficient Software Development

SWIFT: Challenging Software Productivity Limits

Continued from page 41
suite that meets all testing requirements. These methods are combined to focus and streamline the component-level software development and test effort. As the software is developed, code analysis tools are employed to identify defects prior to beginning unit test. The continuous integration (CI) infrastructure provides a cycle of automated product software builds, automated unit test execution, and continuous automated testing of the software; and these collectively lead to continuous automated formal qualification testing (FQT). With this integrated solution set, the software is always in a fully tested configuration. System/software test optimization leverages tests prepared during software unit-level testing for use in validation and verification during system-level testing. The resulting collaboration among system and software engineers increases the quality of system testing while reducing the test time and effort required.

These advanced test methods have been implemented on several programs with measurable results. For example, one program used the continuous integration method, which resulted in most defects being detected very early in the development cycle, and far fewer than expected found in the field.

Customer Alignment
Raytheon’s SWIFT ensures that customer needs are a foundational focus by making the customer a key stakeholder in each step of the software development process. The goal of Customer Alignment is to reduce, through close customer partnerships, the cost, schedule and effort required to achieve technical and management milestones. This pillar is the foundation for maturing the methods associated with the other pillars.

The Rewards
The SWIFT Agile project management framework provides a method to incrementally develop and field customer solutions quickly and reliably. The methods adopted by SWIFT reduce development and lifecycle costs by providing predictable, stable processes based on the latest technology. Raytheon programs that have adopted agile management frameworks have realized substantial cost and schedule productivity improvements over programs developing software using a traditional management structure.

Jennifer Walker, Robert Boardman and Shirley Hendrick

Link 16 is a type of military tactical data exchange network used by the North Atlantic Treaty Organization (NATO). It is a time domain multiple access (TDMA) based secure, jam-resistant high-speed digital data link that operates in the ultra-high frequency (UHF) radio band. DDS is networking middleware that simplifies complex network programming.
Metal injection molding (MIM) is a powder metallurgy (PM) fabrication process employed by Raytheon to produce metal structures both simple and sophisticated. With MIM, metal or alloy parts can be formed in the same manner as plastic or ceramic parts at a fraction of the cost of machined parts, but with the same properties as wrought (hammered) materials. MIM also facilitates tailoring of alloy composition to satisfy unique performance requirements.

Although the defense industry has studied these processes since the 1980s, Raytheon leads the industry by successfully incorporating structural components and flight control surfaces produced using PM and MIM manufacturing methods into mature weapon systems.

The MIM Process

First, fine (≤ 44 µm) metal powder is mixed with plastic and organic binders into raw material (feedstock) that behaves like a plastic. This is injection molded using standard techniques into a partially processed (green) part. The binder is then removed and the part is densified by sintering at temperatures of up to 2,300°F (1,260°C), depending on the alloy. Secondary operations such as coining (stamping) and final heat treating are completed to produce the strength, shape and surface quality required. Heat treating and secondary operations are standard wrought processes. Complex and sophisticated parts — some that would be difficult if not impossible to form using other methods — can be formed using the MIM process. The following are some examples of Raytheon’s use of MIM.

Use of MIM to Manufacture Control Fins

Excalibur is a guided artillery projectile that provides precision fire at extended ranges for all current and future 155 mm howitzers. The original Excalibur control fin (Figure 3A) was composed of 17-4PH precipitation hardened stainless steel. Machining was extremely time consuming, requiring tens of passes with a tool bit on both sides of the fin to create its complex shape. Each pass proceeded slowly to ensure accurate tracking of the tool. Machining of precisely located mounting bosses required numerous setups on sophisticated machine tools. Tolerances were difficult to maintain from part to part.

With the use of MIM manufacturing, the airfoil shape is molded in one piece (Figure 3B). The airfoil shape is injection molded in the green (unsintered) part. Because the hardened steel die cavity in the mold does not change from shot to shot of injected material and maintains its shape for a minimum of a quarter of a million shots, tolerances are easily achieved. In some cases, die cavities are not changed for over 10 million parts. After the part completes debinding, the fin is sintered to 2,300°F (1,260°C); the sintered part contains less than 2 percent porosity and is ready for secondary operations. All the pores are closed and located inside the grain — not at the grain boundary — thus eliminating any effect on the strength of the material. The airfoil is then coined to the final shape and attachment points are machined to their final dimensions. Final heat treating is completed to attain the strength required.

Table 1 compares the properties of MIM 17-4PH material with 17-4PH precipitation hardened stainless steel, showing that they have comparable performance. The cost of manufacturing the part using MIM, however, is on the order of 25 percent of the cost using traditional machining methods. (In the table, SAE AMS means “Society of Automotive Engineers Aerospace Material Specification.”)
Use of MIM to Manufacture RF Housings

The thin walls, unique hole design and large quantities of parts for some of today’s radio frequency (RF) electronics packages rule out casting, forging and machining. MIM is often the only process that can meet this need (Figure 4).

Electronics packages normally require a thermal management system attached with an adhesive bond. The thermal management system is limited in its ability to remove heat from the electronics package by the thermal properties of the adhesive and the bond thickness. With MIM, alloy compositions are adjusted so that the package and the thermal management system are co-molded and processed together. This provides intimate contact of the electronics package to the thermal management system for higher heat transport. Fewer parts and assembly steps reduce cost and enhance reliability.

With MIM, the rules are changed in favor of the designer and thermal management engineer. The Kovar™ ratio of iron and nickel can be changed to lower the coefficient of thermal expansion (CTE) of the alloy so the CTE of the alloy is closer to the CTE of glass. This lower alloy CTE reduces the probability of cracking the glass seal around package leads, a common cause for the loss of package hermeticity and of the failure of electronic components inside the package.

The MIM process facilitates producing components with unique properties, allowing designs that are significantly easier to incorporate into present and future systems. These attributes result in higher-value systems that have better performance at lower cost.

Mitchell Gross

<table>
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<tr>
<th>Stainless Steel Material</th>
<th>Yield Strength (ksi)</th>
<th>Ultimate Tensile Strength (ksi)</th>
<th>Elongation (%)</th>
<th>Modulus Elasticity (Gsi)</th>
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<td>149</td>
<td>14</td>
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<tr>
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<td>140 minimum</td>
<td>5 minimum</td>
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<td>170 minimum</td>
<td>190 minimum</td>
<td>5 minimum</td>
<td>28.5</td>
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</table>

Table 1. Properties of MIM 17-4 PH steel in comparison to precipitation hardened 17-4 PH steel (i.e., SAE AMS 5604) for different heat treatment conditions (H1100, H1025, H900).
Dan Dechant assumed the role of vice president of Corporate Engineering within Engineering, Technology and Mission Assurance in May 2012. Dan provides leadership in engineering execution and oversees the development of engineering processes, tools and practices, enabling collaboration across the company to support Raytheon’s growth strategy. He ensures engineering curriculum alignment across all Raytheon businesses to improve workforce productivity, effectiveness and efficiency. Dan leads and actively participates in initiatives that improve productivity, program execution and innovation. We also discussed the importance of modeling and simulation in Raytheon programs.

**TT: What are your objectives in your role as VP of Corporate Engineering?**

**DD:** The primary objective is to maintain and improve our competitiveness. This ensures the future of the company and of our jobs. This is accomplished in three ways: 1) continue improvements in productivity, 2) continue technical excellence and innovation leadership, and 3) flawlessly execute on our programs to ensure good customer relations, confidence and past-performance ratings. We need to offer superior technical solutions at the most cost-effective price.

**TT: In that context, what is Raytheon doing to improve productivity?**

**DD:** The corporation is making a number of investments to improve our productivity and our ability to perform work across the company. The largest such effort is the Product Data Management (PDM) investment that provides a unique capability to “Design, Build and Support Anywhere,” which is primarily focused on mechanical engineering and CM/DM [Configuration Management and Data Management]. This is a bold vision based on a cultural change to work across the company with common tools. Another example is the Software Innovation for Tomorrow [SWIFT] initiative that addresses four pillars of focus for software and systems engineering. For electrical engineers, there is the Lean Product Realization program that improves commonality and shares critical information and tooling for CCA [Circuit Card Assembly] designs. I am encouraged by the corporation’s demonstrated commitment to make the investments, not just in technology, but also in our business processes and tools that help us improve and stay competitive in the marketplace.

**TT: How does Corporate Engineering help with program execution?**

**DD:** First, members of Corporate Engineering participate in gate reviews and color team reviews that ensure our programs are executable and are doing the right things to ensure excellence in execution. But we also are industry leaders in compiling organizational metrics that allow us to: 1) monitor ongoing performance and long-term organizational improvements and 2) provide leading indicators of potential difficulties in program execution.

**TT: And innovation?**

**DD:** ET&MA sponsors annual innovation challenges and enterprise campaigns, and our engineers are key contributors in these activities, across the board.

**TT: Given these areas, which do you consider to be Raytheon’s strength?**

**DD:** We draw our strength in these areas from our people. I am continually amazed by the depth and breadth of technical expertise our engineers have, as well as their strong commitment to succeed at every assignment they endeavor to undertake. Our engineering leaders, with our HR business partners, work continuously to recruit the best people, and further their development throughout their careers with assignment development opportunities and through classroom and online learning opportunities. Recently, our ability to identify a person’s development needs or competency...
in review teams ranging from key proposals to program independent assessments. He is focused on achieving One Company behaviors that include promoting continual improvement and providing recognition for engineering expertise; both are critical to Raytheon’s success. Dan strives to achieve cross-business coordination to offer Raytheon customers best-value solutions and technologies. Prior to leading Corporate Engineering, Dan was chief systems engineer, providing oversight and guidance to system engineering efforts enterprise wide. Prior to that, he was director of the Systems Architecture, Design and Integration Directorate within Raytheon’s Integrated Defense Systems (IDS) business.

**TT: Name some of your development opportunities?**

**DD:** Prior to joining Corporate Engineering, I was a systems engineering director within IDS and predecessor organizations for 12 years. That provided me the opportunity to be involved in many programs from start to successful conclusion. I find that some of the best learning occurs when you have the opportunity to observe the evolution of your early decisions as a program moves forward. For my role, it was making key proposal-time decisions related to the system design solution, the process tailorings we make for a program, the aggressiveness of the productivities and their balance with the risk register, and the chemistry of the systems engineering teams and their leadership. This “life cycle” of learning is available to all of us, and I always encourage people to stay in one or more roles long enough to experience this level of learning.

**TT: This issue of Technology Today focuses on modeling and simulation. Can you provide some words on how modeling and simulation contributes to our programs?**

**DD:** My first assignment as a new college graduate was in the modeling and simulation of radar systems. Back then, FORTRAN was the tool of choice rather than some of the more advanced development environments discussed in this issue. For an individual, modeling and simulation is a great way to develop a keen understanding of how systems operate and interact within an environment. As an example, you can read a book or take a training class, but the rigor required to create a correct and executable mathematical model doesn’t allow for unresolved ambiguities in understanding. As an example, for me, creating a model of distributed ground clutter, and evaluating the improvement factor of pulse-Doppler waveforms and its processing provided an excellent way to understand how radars work. Of course I need to add the caveat of George Box’s insight that all models are wrong, [but] some are useful.

In this edition of Technology Today, you see many such examples where we are able to model the quantitative performance of our systems and in many cases the look and feel of our systems. We are truly dependent upon these models for development and the optimization of our solutions, and for selling off requirements by analysis. But we are on the cusp of a change in how we do engineering. Performance simulations are not the only models we create and use. We have a host of architecture models that characterize other aspects of the system such as behavior. And different models are developed by different disciplines, including systems, software, electrical, mechanical and whole life. The integration and linking of all these models will lead to a major advancement in how we develop systems. This will provide advantages for faster development times and fewer errors introduced by the manual steps that we perform today. We have begun planning for this future in activities we call model based engineering (MBE) and model based systems engineering (MBSE). Over the next few years, we will see these concepts mature, and we will be able to justify another major investment by the corporation to improve our capabilities, productivities and competitiveness. •
Danielle Curcio assumed the roles of chief software engineer for Corporate Engineering and program manager for Raytheon’s cyberrange in June 2010. As chief software engineer, she oversees and guides multiple software efforts across Raytheon’s businesses. She applies her broad range of architecture and technology experience to business software challenges and user needs, generating enterprisewide synergy for software design, development, test and

Information operations [IO] and information assurance [IA] are other areas of concentration, where I am working to further information security development, testing, implementation, deployment and accreditation.

I am also the program manager for the Cyber Operations, Development and Evaluation [CODE] Center. The CODE Center is used to test networks and systems by exposing them to realistic nation-state cyberthreats in a secure facility with the latest tools, techniques and malware. It is a critical element for building our Raytheon Cyber Strategy.

TT: What are some of the challenges facing software development in this industry today, and how are we addressing them?

DC: The software discipline faces many challenges, now more than ever. Some of the challenges are common across every discipline such as the uncertainty of the defense budget, the rising cost of maintaining existing systems, small company competition and the mounting cyberthreat to new and existing systems. The need for new capabilities continues to grow and customers demand them quicker than ever before. The unique challenge to software is that advances in computing have resulted in more software-driven features in our systems. The rate of increase in our software size and complexity is outpacing current gains in productivity. We cannot continue with the status quo and expect to remain competitive. To address these challenges, Raytheon is changing the way we develop software through the SWIFT initiative.

TT: Can you discuss the Software Innovation for Tomorrow initiative and what benefits it provides to our programs and our customers?

DC: SWIFT is the application of best practices and emerging technologies to increase software productivity and reduce cycle time while improving quality with less out-of-phase defects. The initiative originated at the 2010 Raytheon technology integration workshop as a solution for integrating and applying technologies across the company to improve productivity and program execution time. For 2011 and 2012, the focus has been on deploying Scrum, continuous integration, structured reuse and automated testing. This has been accomplished through pilot activities that have enabled us to mature our methods.
Accurately measuring productivity and quality is critical in determining the success of SWIFT. Metrics collected across the pilots are beginning to quantify the improvements that SWIFT provides. Early indications show that software teams across Raytheon that adopted Scrum as part of their pilot activities realized productivity improvements of more than 25 percent.

For 2013 and beyond, we will continue to explore emerging technologies, mature methods and expand our adoption across the enterprise.

Reducing software cycle time and increasing productivity without compromising our high standards for quality will allow us to better serve our customers. A reduction in cycle time will deliver capabilities to the warfighter at a quicker pace and fundamentally change the way systems are developed, deployed and maintained.

**TT: Can you discuss the CODE Center and what benefits it provides?**

**DC:** The CODE Center is an enterprisewide cybersecurity engineering development environment and test range for developing comprehensive solutions to serve our customers and support our products across the Raytheon portfolio. The CODE Center serves all Raytheon businesses and Corporate Information Technology as well as external customers and stakeholders. The CODE Center enables cyber resilience assessments of Raytheon products and solutions against sophisticated nation-state threats, including discovery of zero-day vulnerabilities. It provides a secure engineering environment for the integration of companywide cyber capabilities, the testing and demonstration of cybersecurity technologies, the integration of customer and partner capabilities, and cybersecurity training.

CODE Center capabilities enhance Raytheon products and strengthen our position with our customers as well as provide a key discriminator to Raytheon as a major systems integrator. Having the capability to validate the security and cyber resilience of our products will be a distinguishing factor in future competitive proposals.

**TT: How is modeling and simulation (M&S) used in the development of software for today’s complex systems?**

**DC:** Modeling and simulation plays a critical and evolving role throughout the life cycle of today’s systems. From concept evaluation through system development and validation, M&S can help us understand our customers, communicate the value of our products and deliver systems with reduced cost and schedule. A great example of this is the work Raytheon has done with the SDB II [Small Diameter Bomb II] program since 2012. SDB II has a challenging flight test schedule that includes multiple captive-carry, controlled and guided test flights, all in less than a year. The SDB II team uses flight software and simulation architectures that are reusable products [genSoft and genSim] shared by multiple programs. The SDB II simulation environment integrates flight software with high-fidelity hardware models that accurately represent all bit-level logic in the software-to-hardware interface. This allows the team to rapidly test flight software with high confidence that missile performance will be accurately predicted. This extensive and detailed M&S environment has contributed to the delivery of quality software and has earned a high degree of customer satisfaction.
Sixty-seven Raytheon engineers and technologists were honored for outstanding contributions to Raytheon’s innovation legacy at the 2012 Excellence in Engineering and Technology (EiET) Awards event which was held at the Smithsonian National Air and Space Museum in Washington, D.C., on January 30, 2013.

“The EiET awards represent Raytheon’s highest technical honor,” remarked Mark E. Russell, vice president, Engineering, Technology and Mission Assurance. Comparing the award-winners’ achievements to those demonstrated by the countless exhibits at the museum, Russell said, “You have pushed beyond the limits of technology to solve our customers’ most challenging problems.” Validating Raytheon’s recognized leadership in technology and innovation, Russell also noted Raytheon BBN’s recent National Medal of Technology and Innovation Award for making lasting contributions to America’s competitiveness.

After dinner, Raytheon Chairman and CEO William H. Swanson thanked and congratulated the award recipients, “For your tremendous efforts on behalf of our customers and our company. It’s an honor to recognize and celebrate your exceptional achievements in engineering and technology.”

Retired Marine Corps General John R. Dailey, director of the Smithsonian National Air and Space Museum, hosted the event. Dailey has been instrumental in expanding the size and scope of the museum to increase public outreach.

Seventeen awards were presented: 12 team awards, including one “One Company” award and one Information Technology team award; and five individual awards. These are listed on the next page.
ONE COMPANY AWARDS
Launch During Boost Ballistic Missile Defense Engagement Concept Team
Arle Beckwith, Elanor Grey, John Krasnakevich, Edward Lesnansky, Daniel Savage, Anthony Sommese and Stephen Thelin

INTEGRATED DEFENSE SYSTEMS
Individual Award
Edward Seghezzi

Surveillance Radar Program Integration and Test Team
Thomas Duginski, Jorge Hiraldo, Charles Howe, Stephen Sparagna and Zubair Zerif

Outstanding Engineering and Technical Execution on JLENS/Patriot IFC
Theresa Avino-Manning, Richard Erausquin, Steven Faulise, Michael Juliano and Benjamin Travisano

Al Diriyah Program Team
David Anderson, Kenneth Gillette, Jennifer Lewis, Sander Markel and Mason Nakamura

INTELLIGENCE, INFORMATION AND SERVICES
Individual Award
Alan Dieringer

AWIPS II Development and Fielding Team
Frank Griffith, Kevin Johnson, Scott Risch, Brad Scalio and Lee Venable

Air Soldier Team
Joe Deno, Dustin Houck, Mike Huff, Chris McMahon and Jim Negro

MISSILE SYSTEMS
Individual Award
Kim Christianson

Spherical Near-Field Antenna Measurement Facility Design and Development Team
Justin Dobbins, Michael Gallman, Jonathan Lawrence, Dale Oldham and Charles Weesner

Persistent Close Air Support Integrated Demonstration Team
Carl George, AJ Kochevar, Mike Murry, Jeffery Saunders and Joe Uidenich

SPACE AND AIRBORNE SYSTEMS
Individual Award
John Bedinger

Individual Award
David Hendry

Family of Advanced Beyond Line of Sight Terminal Alternate Proposal Demonstration Team
John Denorscia, Matthew Gates, Michael Kuchera, Paul Marinilli and Jeff Turgeon

Kestrel Receiver Design Team
Carl Enarson, Tatsuya Kawase, Christopher Moye, Rick Nicklaus and Harold Pratt

Bladerunner™ Team
Tom Armstrong, Scott Hansen, Randy Koch, Nicole Roberts and Jeffrey Slack

INFORMATION TECHNOLOGY
IISNEXT — Affordable Integrated Development Environments Architecture Team
Kara Conn, Michael Hays, Bob Peterson, Steve Porter and Andrew Steele
At the MathMovesU booth, students participated in a hands-on project that allowed them to build a hover-board out of common household items — a blank compact disc (CD), a push-pull cap from a water bottle, glue, and a rubber balloon — and test it. Raytheon volunteers helped the students pump the balloon with air and glue the water bottle cap to the CD. Balloons were then attached to the water bottle cap. The students pulled the cap open, releasing the air in the balloon, and watched the CD appear to float over the table. The students learned that the floating effect was a result of air from the balloon flowing through the

Colorful Experiments Engage the Next Generation: Raytheon MathMovesU® Attends the AAAS Family Science Days

On February 16 and 17, 2013, Raytheon MathMovesU (MMU) participated in the annual meeting of the American Association for the Advancement of Science (AAAS), held at the Hynes Convention Center in Boston, Mass. Thousands of participants from a very diverse audience visited the Raytheon MathMovesU® booth, and more than 700 elementary through high school age students learned physics principles by building and testing a hover-board. As part of the event, hundreds of participants watched a stage show where Raytheon volunteers created a dramatic chemistry experiment in keeping with the meeting’s theme: The Beauty and Benefits of Science.

The annual meeting of the AAAS, the world’s largest general scientific society, draws thousands of participants from dozens of nations and provides a rich opportunity to reach curious students who may enter science, technology, engineering or math (STEM) fields. Raytheon engaged this next generation of scientists and engineers during the free, hands-on events of the meeting’s Family Science Days. An enthusiastic team of Raytheon volunteers guided students through a fun booth experiment about flight physics and performed a stage show featuring colorful chemical reactions.

Raytheon employees led a “Science is Fun” stage show.

Students, led by Raytheon volunteers, were guided through fun physics and chemistry experiments.

Raytheon Math-MovesU® Attends the AAAS Family Science Days

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open bottle cap through the center of the CD, forming a volume of air under the CD. As the air flowed from the balloon, students enjoyed tapping on the balloon and watching their hover-craft float over the table.

The highlight was a Raytheon-led stage show titled “Science is Fun: A Beautiful Burst of Color Through Chemistry.” The stage show demonstrated how exciting chemistry and science could be via a dramatic, colorful experiment. Students learned how combining two solutions can produce a heat-producing, lively eruption of oxygen-filled foam that looks like a giant stream of “elephant toothpaste.” The Raytheon team presented two experiments of this principle. The first used a low-grade hydrogen peroxide with yeast as a catalyst and demonstrated a repeatable, straightforward classroom experiment. The second, more dramatic, experiment used much stronger hydrogen peroxide and potassium iodide solution as a catalyst. Food coloring was added to make the foam colorful. The first experiment produced a small amount of foam that simply bubbled over the top of the cylinder, but the second experiment produced large amounts of red, blue and yellow foam. The audience cheered as they watched the foam spill onto the stage. Steam could be seen exiting the cylinder due to the heat produced by the reaction.

Raytheon’s MathMovesU program is an initiative for increasing middle and elementary school students’ interest in math and science education by engaging them in hands-on, interactive activities. MathMovesU seeks to excite and motivate students to pursue careers in science, technology, engineering and math. The program features interactive learning programs — including the traveling interactive experience MathAlive!™ and Raytheon’s Sum of all Thrills™ experience at Innoventions® at Epcot® — as well as scholarships, sponsorships and events.

Nora Tgavalekos, Ph.D., and Diane Mahoney

The Raytheon volunteer team supports the AAAS annual meeting.

Students use modeling, simulation and analysis tools to learn about physics and mathematics.
Systems Engineering Technical Development Program Capstone Project: Deploying Predictive Analytics in Healthcare Systems

Dr. Beth Wilson, IDS Principal Engineering Fellow, delivers the keynote address at the SEtdp Wave 32 graduation banquet.

Systems Engineering Technical Development (SEtdp) Program
Raytheon’s Systems Engineering Technical Development Program (SEtdp) is an enterprise talent development program designed to accelerate the development of Raytheon’s future technical leaders (i.e., chief engineers, lead systems engineers, technical directors). Program participants, nominated from top engineering talent enterprise-wide, undergo an intensive screening process. SEtdp includes both formal presentation-style learning as well as informal learning through team projects, and interactions. Each year a new “wave” of SEtdp participants study for a week at each of Raytheon’s business headquarters. Subject matter experts and leadership team members present technical and business overviews of important programs and technologies within each business. A graduation event acknowledges students’ accomplishments and highlights their new responsibilities as systems engineering leaders.

A key component of SEtdp is the capstone project. Project topics are selected from business and corporate proposals and are designed to allow the SEtdp participants to develop their systems engineering skills in cross-business teams of five to six engineers. Recent projects have been selected to support business growth, develop participants’ business and financial acumen, and challenge their analytical skills in addressing critical problems.

Wave 32 was assigned a set of five projects related to healthcare, and they were asked to look at opportunities to leverage Raytheon’s core competencies and technologies in this arena. A panel of leading systems engineers from across the company selected one project, “Deploying Predictive Modeling in Healthcare Systems,” as “Best in Wave.”

John Shea, a SEtdp project sponsor, described the healthcare project ideas as a way of challenging the SEtdp participants to “imagine ways to translate our know-how and engineering methodologies into a totally foreign problem domain. The experience taught us that as engineers we can apply our skills and energy to practically anything and see results in terms of ideas, specifications and architectures.”

Deploying Predictive Modeling in Healthcare Systems Capstone Project
The SEtdp Predictive Analytics team, as part of their winning project, designed the Raytheon Medical Analytics System (RMAS) that accesses electronic medical/health records (EMR/EHR) and, using predictive analytics, predicts patient outcomes after discharge from a hospital (see Figure 1). A discharge planning use case was used to define the design and development of RMAS. This use case was defined by how likely a patient was to be readmitted to a hospital 30 days after discharge. This topic choice was motivated by research which showed that reduction of readmission rates...
could reduce Medicare costs and improve the quality of patient care. The SEtdp team demonstrated that by providing an RMAS-calculated risk metric, healthcare organizations could improve discharge planning and reduce the number of readmissions.

The RMAS system functions via a web-based interface from which the discharge planner can search for and select the specific patient/visit record within the hospital’s EMR/EHR database and then extract the selected patient’s clinical data from the healthcare organization’s EMR/EHR database. Using a predictive analytics algorithm, RMAS assesses the patient’s readmission risk and displays it to the planner. The planner can then leverage the risk assessment as an input to discharge plan development, allowing recommendations for increased hospital stay duration or follow-on home visits post-discharge.

RMAS is expected to increase the accuracy and fidelity of a patient’s health state assessment, support the assessment of the readmission risk and enable preference-based planning that considers different post-discharge plans based on these inputs.

Raytheon Enterprise Engineering Talent Development Program Information
SEtdp is one learning program in a suite of programs offered by Raytheon’s Engineering, Technology and Mission Assurance and Global Talent Development organizations to support engineering development. For more information on eligibility for these programs, contact your business talent development representative or Paul Benton at Global Talent Development.

Nora Tgavalekos, Ph.D., is senior manager for technical competency definition and development in the Engineering, Technology and Mission Assurance (ET&MA) organization of Raytheon Company.

Since assuming this role in November 2011, Tgavalekos has been responsible for assessing and improving the technical competencies of the engineering, technology, operations, Mission Assurance and Raytheon Six Sigma™ workforce. "By assessing and improving the technical competencies of the engineering, technology, operations, Mission Assurance and Raytheon Six Sigma™ workforce," she remarks, “we can identify, design, develop and test solutions that more effectively meet our customers’ product needs.” Tgavalekos partners with Raytheon’s Global Talent Development organization and universities to develop technical competency improvement solutions based on identified competency gaps.

Prior to joining Corporate Engineering, Tgavalekos was the flight test director for the Sea-Based X-Band Radar (XBR) at Raytheon Integrated Defense Systems (IDS), responsible for the execution of all targets of opportunity and flight tests. She was also the design and analysis lead for XBR and oversaw all design changes and pre- and post-mission performance analysis. Tgavalekos led the radar discrimination team and was the deputy integrated product team lead for XBR. She served as a section manager under the Systems Architecture Design and Integration Directorate at IDS. Tgavalekos is a graduate of Wave 32 Systems Engineering Technical Development Program.

Prior to joining Raytheon, Tgavalekos held positions of increasing responsibility in the fields of electrical and systems engineering at General Electric Healthcare. Her roles included leading teams that investigated methods of detecting metal distortion in electromagnetic surgical tracking platforms as well as developed and deployed of electromagnetic tracking systems.

Contributors: Alba Ortiz-Diaz, Brian McFarland, Josh Danker and Jorge Rodriguez
United States Patents
Issued to Raytheon

At Raytheon, we encourage people to work on technological challenges that keep America strong and develop innovative commercial products. Part of that process is identifying and protecting our intellectual property. Once again, the U.S. Patent Office has recognized our engineers and technologists for their contributions in their fields of interest. We compliment our inventors who were awarded patents from July through December 2012.

CATOUI, MIRON
8217730 high power waveguide cluster circulator

BROWN, KENNETH W
SOTOLO, MICHAEL J
8217847 low loss, variable phase reflect array

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8218220 variable aperture optical device having a microshutter

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8221635 process for multiple platings and fine etch accuracy on the same printed wiring board

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8222398 ld based polarization, phase and amplitude spatial light modulator

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8224761 system and method for interactive correlation rule design in a network security system

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8227939 reconfigurable multi-cell power converter

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8228129 photonic crystal resonant defect cavities with nano-scale oscillators for generation of terahertz or infrared radiation

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8228490 system and method for precise measurement of deflection

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8232915 three quarter spatially variant apodization

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8232928 dual-polarized antenna array

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8240251 reactive shaped charge, reactive liner, and method for target penetration using a reactive shaped charge

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8240611 retro-geo spinning satellite utilizing time delay integration for geosynchronous

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8242862 tunable bandpass filter

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8244870 distributing traffic to multiple GNS devices

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8246748 method and apparatus for coating surfaces

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8245728 quick speed transfer system

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8248320 lens array module

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8248321 broad-band/multi-band horn antenna with compact integrated feed

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8248693 reflective triplet optical form with external rear aperture

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8249101 mobile ad hoc network configured as a virtual internet protocol network

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8294103 system and method for viewing an area using an optical system positioned inside of a dewar
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8294232 high quantum efficiency optical detectors
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8294888 dual field of view refractive optical system with external pupil and internal stabilization
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8302410 inerter tube and surge volume for pulse tube refrigeration
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8312814 simulated hand grenade having a multiple integrated laser engagement system
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