Raytheon Sources of Technology
Enabling New Solutions, Capabilities and Processes
The Raytheon name has long been associated with innovation in technology. Today our many products and businesses span the markets of the domestic and global defense industries, as well as adjacent commercial sectors. While much of this success is the result of internal investment in our people, processes and technologies, throughout Raytheon’s history, collaboration with universities and research institutes, business partnerships, acquisitions and joint ventures have played an important role in shaping product capabilities, growth and market presence.

In this issue of Technology Today, we will see where these external collaborations benefit the broader Raytheon in contributing not only to the tremendous talent of our engineering and technical staff but also the technological advancement and breadth of our customer solutions.

In recent years, Raytheon has made significant investment in cybersecurity through partnerships and acquisition. In the featured articles we highlight technologies such as cyber hunting, persistent surveillance and critical technology protection. Also featured are Raytheon’s work with universities, machine learning applications and recent innovations to our software development processes.

Our Leaders Corner — featuring Kim Caruso, vice president of Corporate Operations, and Alan Glickman, vice president of Corporate Engineering — provides insight into how their organizations interact and help shape the Engineering and Operations functions across the company. Also in this edition we speak to Tomaz Seignemartin, director, Raytheon Six Sigma™ (R6s™) and Kurt Mittelstaedt, director of Operations for Enterprise Lean Manufacturing, about the critical role R6s plays throughout the company.

This edition’s Eye on Technology section highlights the world of physics-based modeling and how this simulation technology is allowing engineers to explore design spaces unattainable in the past.

Our special interest article focuses on the “Systems Engineering V,” detailing the path to successful product development as well as how it can be used to shape an engineer’s path for career growth. And finally, in our People section we showcase the RAYVETS (Raytheon Veterans) Employee Resource Group (ERG), Raytheon’s most recently formed ERG dedicated to increasing the visibility and contributions of Raytheon veterans through their unique experience, product knowledge and customer-centric insights, across the Raytheon businesses.

Mark E. Russell
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RAYTHEON SOURCES OF TECHNOLOGY

ENABLING NEW SOLUTIONS, CAPABILITIES AND PROCESSES

Raytheon consistently delivers advanced solutions and key capabilities to support customer missions around the world. To achieve this, Raytheon must constantly assess and apply new technologies. Within Raytheon, some of the most promising new technologies are developed, matured and applied to solve our customer’s needs, through both independent research and development (IR&D) as well as contract research and development (CRAD). While the breadth of Raytheon’s technological and engineering capabilities is among the best in the industry, it is not always possible or efficient to rely solely on company resources. In some cases, solutions are gained through university partnerships and teaming with other companies and government laboratories, in other cases, companies are acquired as a way to gain unique expertise and capabilities. In this issue of Technology Today, we will highlight some of Raytheon’s sources of technology and their importance in providing Raytheon with key strategic capabilities and speed of delivery that continually strengthen its position among the world’s best technology companies.

CYBertechnologies

Raytheon has placed a strong emphasis on cyber hardening over the past several years through key acquisitions and partnerships in the cyberindustry. The goal of cyber hardening is to examine nearly all industry products, those currently in production and all future designs, and to provide those products with the necessary level of cyber protection. In this issue of Technology Today, we have included a number of feature articles representing Raytheon capabilities in the cyber arena.

Blackbird Technologies™, a leading provider of persistent surveillance, secure tactical communications and cybersecurity solutions, was acquired by Raytheon in 2014 to expand an already well-established footprint in these areas. In addition, Blackbird Technologies offered key synergies with Raytheon’s existing cybersecurity, sensor, communications and command and control capabilities. The Raytheon Blackbird Technologies article presents Atmospherex™, an advanced, highly scalable, high-performance social media analytics platform that provides real-time, global media analysis capabilities to U.S. government customers as well as customers in the commercial and nonprofit sectors (Figure 1).

Raytheon Pikewerks™, located in Madison, Alabama, develops capabilities to defend against sophisticated cybersecurity threats facing our customers. Today, Raytheon Pikewerks has been integrated into our Intelligence, Information and Services (IIS) business, greatly enhancing Raytheon’s cybersecurity offerings in the areas of anti-exploitation and critical technology (CT) protection software, insider threat protection and forensics. This edition’s article on Electronic Armor™ (EA) technology describes how Raytheon’s flexible approach to CT results in a unique custom-tailored version of EA that meets each customer’s specific environment and needs.

A joint venture of the Raytheon Company and Vista Equity Partners, Forcepoint™ was formed in 2015, combining the user protection, data security and cloud expertise of Websense® with the defense-grade insider threat and analytics technology of Raytheon and the next-generation network protection capabilities of Stonesoft®. Forcepoint’s product line provides advanced content protection for users whether they are within the corporate firewall, roaming or in the cloud. Also in 2015, Raytheon acquired Foreground Security™, whose cyber experts and proactive cyber-hunting technology offer a unique set of managed detection and response capabilities. In this issue of Technology Today, the article “Cyber Hunting: The Raytheon Way” presents cyber-hunting examples that highlight the combined capabilities of Forcepoint and Raytheon Foreground Security.
MACHINE LEARNING AND HUMAN-MACHINE INTERFACE TECHNOLOGIES

In October 2009, Raytheon acquired BBN Technologies, a world leader in research and development (R&D) and provider of critical solutions for national defense and security missions. The broad range and depth of scientific and engineering talent inside BBN contributed to tremendous technological capabilities and a diverse portfolio including advanced networking, speech and language technologies, information technologies, sensor systems and cybersecurity. Ultimately, Raytheon BBN transitions very advanced technologies into larger programs, creating both the most advanced systems possible for customers and rich opportunities for scientists and engineers. This edition of Technology Today highlights Raytheon BBN’s significant R&D efforts, as well as applications in machine learning. In the feature article, “Machine Learning Applications,” the benefits of this R&D are demonstrated through applications in natural language processing, using the Multimedia Monitoring System (M3S) (Figure 2); in multimedia processing, using optical character recognition (OCR) to find text in images; and in networking and cybersecurity, using user and entity behavior analytics to identify and describe anomalous behavior. A second article, “Automated Medical Transcription,” discusses how speech recognition technologies and deep neural networks combine to create an advanced automated medical transcription service for Electronic Health Record (EHR) solution providers, allowing them freedom to focus on their key strength of medical information management.

ANALYSIS AND PROCESS TECHNOLOGIES

Technology is not solely applied to our products — in fact, it is just as important when applied to our processes to achieve program cost and efficiency improvements e.g., modeling, simulation and analysis (MS&A), design and test. In this issue of Technology Today we explore Raytheon’s recent application of DevOps (development operations) and cloud computing to the software development process. Augmenting the company’s Software Innovation for Tomorrow (SWIFT) initiative, they combine with lean and agile processes, automation and rapid feedback for a continuous development, integration, delivery and deployment capability. This issue’s feature article “Advances in Software Development Enabled Through Automation and Cloud Computing” explains how this combination enables improved productivity, reduced rework and higher product quality for the customer.

Nationally recognized for its capabilities in the development of advanced surveillance systems, Photon Research Associates (PRA) joined Raytheon in 2004. Having been a subcontractor for Raytheon programs, this acquisition not only provided depth to Raytheon’s advanced surveillance system development activities, but also included many years’ experience in sensor system MS&A; phenomenology basis modeling; data analysis and exploitation; and surveillance systems’ concepts of operation. The “High-Fidelity Simulation and Phenomenology” article presents a brief history of PRA and describes how these innovative capabilities were integrated into the Raytheon engineering organization to enhance our existing technical capabilities.

UNIVERSITY PARTNERSHIPS

Raytheon partners with universities and research institutions to expand development of leading-edge capabilities. Not only do these activities provide a collaborative research environment, but they also serve to foster a source of future employees in graduates who are skilled in many of the technologies important to Raytheon’s future. One of the feature articles in this edition, “Working With Universities on Technology,” describes some of the key technology areas of focus in Raytheon’s strategic partnerships along with the many benefits of collaborations with academia. Also, included as an inset to this article, “Nanotechnology: Methods and Tools Work With Northeastern University” discusses activities with Northeastern University (NEU) in the areas of cold spray, an additive manufacturing process for isolated area repair of large parts; nanoscale offset printing for applying electrical shielding and ruggedized features; as well as other research initiatives at NEU.

Tony Pandiscio

Solypsis Corporation joined Raytheon in 2003, expanding capabilities in the tactical HMI and sensor data fusion technologies. The histories of the Raytheon Solipsys integration and the Tactical Display Framework (TDF) product are discussed in the feature article “A Tactical Command and Control Operator Display Architecture.”
Today, there are an estimated 2.2 billion social media users worldwide (Figure 1). This number represents an increase of 19 percent since 2014 and is expected to rise by another 24 percent to 2.75 billion by 2019. As the number of social media users continues to grow, so too does the desire to quickly extract meaningful insights, trends and other aggregate information from the billions of messages generated on a daily basis. Raytheon Blackbird Technologies’ AtmosphereX™ is an advanced, highly scalable, high-performance social media analytics platform providing real-time, global media collection and analysis capabilities to Raytheon’s U.S. government (USG) customers as well as commercial and nonprofit sectors.

There are countless use cases for the AtmosphereX analytics platform in both the domestic and international segments. For example, marketing and customer service organizations are now using social media to measure the impact of marketing campaigns; detect market trends; listen to the sentiment of their customers; and assess the views of focus groups. Government and non-government organizations alike use social media as an early warning and situational awareness tool. A system like AtmosphereX, for instance, allows users to follow geopolitical events in real-time; learn about natural disasters and terrorist attacks well before broadcast on traditional news media; detect, monitor and analyze terrorist networks and their cyber recruiting activities; and track pandemic outbreaks. Figure 2 shows the AtmosphereX message viewer interface as it displays results from a global, Zika virus-related search across multiple social media outlets, such as Twitter and Facebook.

All social media data collected and processed by AtmosphereX is publicly available and AtmosphereX only collects messages that are marked “public” (i.e., shared freely by everyone). AtmosphereX also does not capture low-level network messages or perform decryption.

**A BRIEF HISTORY**

The development of AtmosphereX began in 2014 as an internally funded IR&D effort. The project was performed in close collaboration with Raytheon Blackbird’s social media analysts, taking advantage of their many years of experience in social media analysis for the USG and their extensive knowledge of the strength and weaknesses of competing solutions. End-user feedback was incorporated into the design cycles from the start, allowing development to focus on the most important, high-impact features early on. This approach also helped close gaps and introduce significant functionality differentiators with competing solutions.

The first customer deployment of AtmosphereX was in early 2015, where it has been in continuous operational use. It is also currently in use by several USG clients.
AN OVERVIEW OF THE TECHNOLOGY

AtmosphereX provides real-time, global social media collection and analysis capabilities for users to rapidly obtain social-media-derived insights. It is built upon open source, big data technologies for a scalable, open and extensible architecture. This open source stack currently includes high-performance Apache® products also used by many social media sites such as Twitter, Facebook, Instagram™, Linkedin™ and others. Apache® Kafka, developed by Linkedin, is used for high-speed messaging and queuing. Apache® Storm, created by Twitter, provides a real-time, parallel stream processing capability. Apache® Accumulo, developed by the National Security Agency as a secure, highly scalable, NoSQL-based key/value store, is used for high-performance data warehousing and multisource search. Finally, Apache® Hadoop® provides parallel processing and distributed, fault-tolerant storage, and Apache® Solr is used for entity search.

AtmosphereX leverages cloud-deployed nodes to continuously collect real-time data from some of the world’s most popular social media sites (Figure 3). It employs a modular architecture, where clients can instantiate as many initial collection nodes as necessary and easily add more collectors as new social media sites emerge. Similarly, the system’s back end scales in both processing and storage infrastructure to match the front end collection nodes’ message throughput. Vital system components are deployed repeatedly and are configured in high-availability fail-over mode preventing single points of failure.

As illustrated in Figure 3, the cloud-deployed collection nodes stream raw data to a high-performance, Apache® Kafka-powered message queuing system which then forwards the data to an Apache® Storm-powered, parallel data ingest engine. Here, Storm normalizes and maps the various social media data streams to a unified format and performs basic entity detection and sentiment analysis operations.

Entities in this context are people, organizations or locations. AtmosphereX’s Solr-based search engine has access to a very large, Raytheon Blackbird-developed entity index that contains a copy of all the entities found in Wikipedia (free online encyclopedia). As social media messages are ingested, Solr scans each message for references to known entities. If an entity reference is found, the data ingest system marks the exact location of the entity reference with the insertion of metadata inside the message. As part of the message enrichment process, Atmospherex visually highlights the entity (or entities) and provides additional, Wikipedia-derived background information during subsequent message display and analysis. In future releases of Atmospherex, users will be able to add their own entities and...
entity descriptions, teaching the system the entities they are most interested in. This new feature will allow social media analysts to share important information on an entity with other authorized analysts, as once a new entity is registered, it is automatically detectable and tagged in all future messages.

AtmosphereX’s integrated sentiment analysis algorithm is designed to determine whether views or opinions expressed in a social media message are positive, negative or neutral in nature. Marketing experts, for example, use social media sentiment analysis to determine whether a new product or commercial was well received by their targeted audience. AtmosphereX’s sentiment algorithm currently supports 29 different languages. In its message analysis, it not only analyzes each word in a social media post, but also incorporates the meaning of emoticons inserted or appended by the author.

After completing the above preprocessing steps, the reformatted, sentiment-enriched and entity-tagged social media data is routed to the Apache® Accumulo-based data warehouse for indexing and storage. Apache® Solr is then used for entity matching and enrichment.

**THE USER INTERFACE**

AtmosphereX provides an intuitive, web-based, access-controlled user interface featuring a real-time and forensic search capability; heat maps; integrated translation of more than 50 languages; social network analysis; trend detection; pattern-of-life analysis; and real-time alerts (Figures 4 and 5). AtmosphereX uses heat maps to show where the most social media activity occurred during a user-selected observation time frame. The system measures social media activity in terms of number of messages posted at each location. For example, the red-colored regions in the center map of Figure 4 represent the areas from which the most Twitter messages (Tweets) were sent. The green-colored areas represent the regions with the least amount of Twitter activity.

The grey-colored circles shown on the map in Figure 5 are examples of user-defined, geospatial data collector regions. Each time a social media user generates, geo-tags and sends a public message via the supported social media sites in one of these areas, AtmosphereX collects the message through a cloud-hosted collection node. AtmosphereX can also collect messages based on keywords and user accounts, regardless of sender location.
DEPLOYMENT
AtmosphereX is designed to support several deployment options — cloud-based, on-premise and hybrid mode. It is typically fully deployed and provisioned in a cloud-based environment, such as Amazon Web Services™ (AWS™), within just a few hours. In a hybrid deployment scenario, the social media collection engine(s) and associated components are deployed in the cloud (i.e., AWS) and the remaining back-end processing (Storm, Accumulo, Solr, Hadoop® and redundant web servers) is securely deployed in either a co-location facility or the customer’s data center. Most clients, however, prefer a complete cloud-based solution which allows them to be operational very quickly with only a small-scale system for evaluation purposes. They can subsequently scale up the system easily and rapidly to meet their expanding processing and storage needs.

Customers preferring that AtmosphereX not operate in a cloud-based environment (e.g., due to cloud security concerns or internal policies) have the on-premise option of installing the complete system in their own data center, behind the firewall.

The following list highlights capabilities which set AtmosphereX apart from many competitors:

• A highly scalable, high-performance system architecture with a proven track record of collecting and processing billions of social media messages.
• A modular, flexible framework that readily accepts addition of new collectors for emerging social media sites or other sources.
• Multiple deployment options — cloud-based, on-premise and in hybrid mode.
• Modern access-controlled, intuitive, web-based user interface. Most analysts are operational with just a single day of training.
• A multilingual user interface for data collection and analysis, incorporates integrated translation for more than 50 languages and can leverage commercial or proprietary machine translation capabilities.
• An integrated, highly scalable, attribution-managed social media collection engine that eliminates the need for purchasing costly social media data from third-party data aggregators.
• A service-oriented architecture allows for drop-in replacement and upgrades of system services, such as map server, machine translation and sentiment analysis.
• The ability to export raw data and metadata in standard formats (e.g., XML, CSV) for internal and external exchange and collaboration.
• An available application programming interface (API) simplifies integration with other systems or third parties wishing to leverage AtmosphereX’s data collection and analytics capabilities programmatically.
• An integrated sentiment analysis engine with support for 29 languages and emoticon-based sentiment analysis.

Raytheon Blackbird continues to optimize and enhance AtmosphereX. Future near-term releases include an advanced social network analysis capability; location, keyword, and user-based statistics; entity analytics; and automated event detection. These additional features will enhance the social media analyst’s situational awareness, provide deeper insights and improve operational efficiencies. The upcoming, advanced social network analysis capability, for example, will allow AtmosphereX users to slice and dice complex social networks from multiple angles and quickly identify members who share similar interests and connections.

Torsten Staab, Ph.D.
An important aspect of CT protection is guarding critical program information (CPI), and Department of Defense (DoD) Instruction (DoDI) 5200.39 emphasizes U.S. policy in this regard stating that the “U.S. warfighter technological advantage will be maintained and operational effectiveness of DoD capabilities will be preserved through the identification and protection of CPI.” The consequences of compromised CPI can include degraded mission effectiveness, ability of an adversary to defeat or copy critical technologies or capabilities, and shortening the combat-effective life of military systems.

In December 2011, Raytheon acquired Pikewerks™, a small business located in Madison, Alabama, and originator of the Electronic Armor™ (EA) technology. Today, Raytheon Pikewerks is part of the Intelligence and Information Services (IIS) Center of Innovation, greatly enhancing Raytheon’s cybersecurity offerings in the areas of anti-exploitation and CT protection software, insider threat protection and forensics.

Implementations of CT protection differ for each customer’s technology and mission. Raytheon designed EA to be a flexible solution tailorable to meet the specific goals of each customer system. As part of a customer engagement, Raytheon provides an EA integration team that works with the technical staff on the program to understand specific system requirements and operational constraints. This process results in a unique, custom-tailored version of EA that meets each customer’s program-specific operational environment.

To protect sensitive software, EA implements a system integrity approach. Raytheon designed the four major functional areas of an EA deployment (Figure 1) to prevent configuration changes, deter attacks from all user levels, detect tamper attempts and respond by blocking malicious access and reverse engineering attempts.

EA protects sensitive technology through encryption and by binding software and firmware to the specific hardware platform of interest. In contrast to traditional software protection techniques or hardware-based tamper detection sensors, this approach ensures that protected software applications only operate in the environment in which they are originally bound.

EA also provides tight integration with both physical and environmental sensors as well as other tamper-detection mechanisms. This approach creates an in-depth defense with robust tamper detection and response mechanisms that thwart malicious access and reverse engineering attempts.

EA protections are deeply embedded within the core operating system (Figure 2) and are transparent to system operators and administrators.

Figure 3 lists the key features and strengths of EA, which include support for DoDI 5200.39 requirements.

**FIGURE 1. FUNCTIONAL AREAS OF AN ELECTRONIC ARMOR DEPLOYMENT**
EA components can detect untrusted hardware that is introduced to a system and take action to ensure critical technology is protected. Trusted software only runs on the protected system and ceases to function if the system is modified or the software is moved to another system.

Because the EA threat model assumes an attacker may already have root-level access to the system, EA protects against insider attack scenarios. It also uses proprietary system lockdown and memory protection techniques to ensure that no CT is exposed during execution. All of these protections are done with minimal performance impact to the host system.

Effective CT protection of Raytheon’s and our customers’ systems has never been more important than today. EA is a proven solution designed to protect CPI from unauthorized access, malicious modification, reverse engineering, and piracy. Raytheon has secured an effective solution for CT protection beginning with the Pikewerks acquisition and continues to mature the Electronic Armor technology to meet and defeat the ever-increasing cyber-threat to today’s military systems.

### Figure 3. Electronic Armor Key Features

<table>
<thead>
<tr>
<th>Electronic Armor</th>
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<tr>
<td>• Defends against root-level attackers</td>
<td>• Does not require application source code</td>
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<tr>
<td>• Hardens the operating system</td>
<td>• Executes with minimal performance impact</td>
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<tr>
<td>• Binds software and data to specific hardware</td>
<td>• Provides event detection and penalty/response</td>
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<tr>
<td>• Enables a secure and trusted boot process</td>
<td>• Provides decoys, false paths and active defense</td>
</tr>
<tr>
<td>• Prevents untrusted software execution</td>
<td>• Supports DoDI 5200.39 requirements</td>
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Jacob Noffke  
Damon Hardy
Raytheon has been steadily advancing its cyber capabilities since 2007 in both the commercial and U.S. government sectors, leading up to a new direction and commitment to cyber in 2016. In this article, you will be taken through a brief history of these ventures, introduced to the new Forcepoint™ brand and the collective power of Raytheon Foreground Security™, and finally, given an example of cyber hunting the Raytheon way.

A SHORT HISTORY OF RAYTHEON CYBER INNOVATION

In 2007, Raytheon made its first acquisition in the cybermarket when it acquired Oakley Networks. Oakley had created SureView® Insider Threat well before the need for such a product was fully understood, and with insight from the IT Security team, this technology grew within Raytheon as a forensics tool for discovering advanced persistent threat (APT) activity in both user software applications and operating system kernel layers.

Then, in 2008, Raytheon acquired SI Government Solutions (SI Gov), a Florida-based company specializing in vulnerability assessment and software security solutions for the U.S. Intelligence community. With subsequent acquisitions of Pikewerks™ Corporation in 2011 (insider threat protection, software protection and forensics) and Teligy, Inc. in 2012 (wireless communications), Raytheon and SI Gov were combined to form the heart of Raytheon’s Center of Innovation (COI). COI was a major contributor to the founding core technologies of Forcepoint products still in use today, including Forcepoint Advanced Malware Detection and Forcepoint Linux® Security. Through this series of acquisitions, Raytheon has made a significant investment in not only creating award-winning technology, but also in extending these innovations to the commercial market where many benefit from the advances in combatting today’s cyberthreats.

Fast forwarding through several additional acquisitions and technologies, including the government solutions business of Safenet®, Visual Analytics and Blackbird Technologies, Raytheon reached a major milestone in 2015. In May 2015, Raytheon completed a joint venture transaction with Vista Equity Partners to form a new company combining Websense®, a Vista Equity portfolio Company, and Raytheon Cyber Products (Figure 1). Under the terms of the agreement, Raytheon would hold an 80 percent ownership of the new company, Raytheon|Websense. In January 2016, the company was rebranded to Forcepoint with the concurrent acquisition of Forcepoint NGFW (formerly Stonesoft® NGFW) from Intel Security. Forcepoint represents the integration of three complementary cyberbusinesses: Websense, known for its secure web gateway and email solution technology; Stonesoft®, the developers of a world-class next-generation firewall; and Raytheon Cyber Products, servicing both the federal and commercial sectors with its suite of SureView products focusing on insider and advanced threat protection.

FIGURE 1. RAYTHEON’S CYBER HERITAGE
The other half of the cyber achievement came with the acquisition of Foreground Security in October 2015. This Virginia-based company combines people, processes, tools and proprietary technology to offer a unique set of managed detection and response capabilities including Assessments, Digital Forensics & Incident Response, and Virtual Security Operations Centers (V-SOC) services. Also part of this solution is a proactive threat hunting service to augment, replace or establish cyber hunting capabilities, which are often lacking in many organizations.

**Cyber hunting depends on three key factors:**
1. Understanding the threats,
2. Understanding the environment you are protecting, and
3. Creating points of visibility.

Raytheon Foreground Security (RFS) has built technology and services to support these key factors by curating cyber intelligence information through automating playbooks, using machine-learned knowledge to improve indicators and behaviors of compromise and using human threat hunters. This last aspect is a differentiator as hunters go above and beyond tools and products, looking for techniques, tactics and procedures of threats that might be unknown or information that only human intuition can discern as nefarious. This activity of combing through logs, creating custom automation and analyzing other attacks and movements of threats is much like a hunter tracking prey; it is a method of proactive threat hunting incorporating core capabilities of Raytheon Foreground Security.

**Cybersecurity Assessments**
A comprehensive suite of security testing and assessment services coupled with a unique perspective on the cybersecurity landscape. These assessments cover everything from traditional vulnerability testing to adversarial emulation (red teaming) and security risk assessments.

**Digital Forensics and Incident Response (DFIR)**: Full life-cycle DFIR services include initial development/testing of incident response (IR) plans and procedures with table top simulated exercises and witness testimony expertise.

**Virtual Security Operations Center (V-SOC)**: a 24/7 core managed detection and response capability utilizing advanced cyber hunting techniques as an extension of the customer’s own security team to help them identify, eliminate and learn from today’s threats.

### THE PRODUCTS

Just as RFS leverages the human factor in assessing threats, Forcepoint’s security solutions and programs stop bad cyber behaviors and help organizations run more efficiently by identifying human behavior and intentions. This strategy aligns to our four focus areas:

**Cloud Security and Cloud Access Security Broker (CASB):**
Protecting people from compromise as they use the web and email from any location, on any device.

**Network Security:** Giving visibility into people’s actions throughout the network and keeping attackers out of data centers, offices and cloud environments.

**Data and Insider Threat Security:** Identifying high-risk users and data behaviors that require further investigation and deployment of the right data protection controls.

**Cross-domain Solutions:** Enabling people to securely access and transfer sensitive information across multiple separated networks with control, ease and efficiency.

Each focus area represents an opportunity to gather context around those points of contact and potential exposures an attacker may leverage.

Human-centricity also underpins Forcepoint’s approach to both cloud and cloud access security broker (CASB) solutions. Preventing and/or detecting a compromise that threatens data is extremely valuable to the company. Going forward, the solutions become integrated with the company’s data protection solutions, eliminating the artificial boundaries of legacy products. Similarly, as mobile workers proliferate, Forcepoint will extend protection to company-owned data on any device, synthesizing policies so they’re consistent, regardless of medium.

While many firewall products focus on networks and machines, Forcepoint NGFW goes further. It provides protection at the network level and at the human level, understanding the application that is sending a particular data stream. This, coupled with Forcepoint’s ability to categorize websites by content, enables administrators to control flow on a per-application (or per-task) basis.
The Data and Insider Threat Security products combine user behavior and analytics with Forcepoint’s knowledge of file content — knowing which datasets are most valuable to each individual customer. They not only enforce data use policies (preventing unauthorized access), but also protect data used maliciously by a credentialed adversary. The value of highly contextual forensics is realized in allowing an analyst (and potentially a jury) to see an attacker’s screen during an incident, whereby violations become a narrative that let the viewer differentiate between carelessness, compromise and malice.

Rounding out the portfolio are Forcepoint’s cross-domain solutions that enable secure access and transfer of data and information within and between some of the most sensitive networks and enterprises. These solutions, such as Forcepoint Trusted Thin Client, Forcepoint High Speed Guard, Forcepoint Trusted Gateway System and Forcepoint Trusted Print Delivery are in operational use in some of the most stringent environments, enabling the cyberwarrior to secure their global mission while providing a high degree of usability without compromising security.

THE SERVICES
Raytheon Foreground Security (RFS) understands that new threats require new ways of defending networks, businesses and Intellectual property. RFS delivers the tools, training, analytics, visibility and Intelligence necessary to fortify programs and improve organizational resilience. Our highly trained threat hunting experts leverage advanced technologies and security tools, working as an extension of our customer’s team to predict and detect attacks and rapidly respond before bad actors can harm business operations.

Cybersecurity Assessments
Raytheon specializes in identifying and thoroughly testing potential points of entry from an adversary’s perspective — identifying threats and vulnerabilities that pose the greatest risk to an organization. Our team of highly-skilled analysts has the depth of knowledge required to design a security solution that addresses each unique implementation. Raytheon cybersecurity assessment services include risk assessments, penetration testing, web application assessment and red team.

Digital Forensics and Incident Response (DFIR)
Raytheon’s DFIR retainer service is a cost-effective measure for dealing with the unexpected effects of a highly-integrated information security environment. By taking a proactive approach to securing our customers’ network and actively hunting for signs of intrusion, networks will be far more secure than the historical best practices of watching log events and reacting when alarms trigger. Our high-touch, consultative service delivery meets the highest technical and legal standards in the industry and provides:

- Advanced memory and disk analysis capabilities
- Proactive Threat Hunting through network and log data
- Incident containment/remediation and initial infection vector analysis
- Incident management coordination and system recovery coordination
- Law enforcement, regulatory and corporate communications coordination
- After action review, playbook development, table top exercises and red/blue team assessment
- Services that complement the breadth of your IT infrastructure including mobile device platforms

Virtual Security Operations Center (V-SOC)
Raytheon’s V-SOC service takes a new approach to managed security by automating much of the traditional Managed Security Services (MSS) model through proprietary technology and allowing analysts to spend their time conducting advanced network hunting for threats that can circumvent traditional security controls (Figure 2). The Raytheon V-SOC service is designed for customers that need an advanced hunting capability to detect threats that traditional security controls and Managed Security Services Providers (MSSPs) cannot provide by placing the focus on advanced threats and tracking attacker tactics, techniques and procedures (TTPs) rather than simple alert response. Some of the key differentiators of the V-SOC service include:

- All data stays within the customer environment
- Threat Intelligence curation through machine learning
- Ability to reduce technical debt by using existing customer infrastructure for Security Information and Event Management (SIEM), Endpoint Detection and Response (EDR) and packet capture
- RFS service supports and integrates into the customer’s process, playbooks and requirements
- Custom content development and threat intelligence for existing detection platforms
- RFS provides active, advanced detection and threat “hunting”
Managed Detection and Response (MDR)
Raytheon offers an end-to-end, collaborative approach to managed threat detection and response that optimizes threat intelligence to a specific industry and enterprise security requirements. RFS’s automated threat detection and analytics technology enables MDR services that focus on advanced threat identification, validation and proactive analyst-driven threat hunting. A team of certified, cybersecurity experts quickly and effectively identifies, assesses, manages and responds to advanced persistent threats.

Cyber Hunting
One of the more important benefits of Raytheon’s recent cyber ventures is depth of intelligence resources. The Forcepoint Security Labs team, for one, specializes in threat identification, classification and remediation. Recently, the labs team announced that CradleCore (a.k.a. “Cradle Ransomware”) is being sold as source code — an event predicted in its earlier 2017 Security Predictions report concerning today’s ransomware explosion. CradleCore is offered as C++ source code with PHP server scripts and a payment panel. It has a relatively complete feature set including an anti-sandbox mechanism, offline encryption capability and uses the symmetric-key block cypher Blowfish for file encryption. Upon infecting a system, it drops a ransom note with the filename “HOW_TO_UNLOCK_FILES_.html”. After encrypting files and appending a “.cradle” file extension to them, the ransom note is displayed.

Of late, Forcepoint Security Labs also tracked and identified Felismus, a seemingly low-profile piece of malware with interesting characteristics. Few samples of the malware appear to be available on systems within the general public; there is no previous documentation referring to the Command and Control (C2) domains and IP addresses it uses (despite the domains appearing to be at least 12 months old); and if its compilation timestamps are to be trusted, the campaign itself may have been active for at least six months before samples started to surface. The primary samples examined appear with filenames mimicking that of Adobe’s Content Management System.

The above examples demonstrate the need for highly skilled and specially trained individuals to design analytics and comb through vast amounts of data to effectively mitigate today’s advanced cyberthreats. This expertise is, at best, difficult to develop and maintain in an everyday enterprise focused on primary business objectives. This is where Raytheon and its resources provide the greatest benefit.

In a recent incident, a Raytheon analyst was alerted to an Angler Exploit Kit (EK) Indicator of Compromise (IOC) by Raytheon’s proprietary technology at a customer facility. After immediately notifying the customer, the analyst gathered all the Intelligence RFS had on the indicator, accessed the customer’s packet capture environment and pulled data from the specific session which caused the alert. The obfuscated script was extracted and analyzed, pointing to the binary code that was downloaded by the client. The binary analysis revealed the malware, providing even more information on the attack. All of the data was coalesced to establish indicators to be hunted within the customer’s environment, above and beyond the original IOC alert. Ultimately, the V-SOC team was able to provide a full report of activity with a 100 percent true positive and further recommended action; all without any internal forensic efforts by the customer.

There are times, however, when IoCs do not exist and the importance of human cyber analysts, like those of Raytheon’s V-SOC, really becomes apparent. An effective cyber hunter knows their environment, oftentimes where today’s tools struggle as enterprises grow and Information Technology infrastructures become more complex. Organizations need people that can add context to what is being examined in an enterprise. Whether employing Forcepoint’s products or Raytheon’s cybersecurity services, the highly skilled people performing the investigations and managing the processes ultimately drive the successful security operations force.

Raytheon has organically grown cyber innovation internally and through the acquisition of cybertechnologies during the last 10 years has developed extensive capabilities across the discipline. This expertise was demonstrated this past August as Raytheon’s “DeepRed” team competed in the finals of the Defense Advanced Research Projects Agency’s (DARPA™) Cyber Grand Challenge, held in Las Vegas, at Defcon. The DeepRed team comprises members of the Raytheon Center of Innovation, Raytheon BBN and Forcepoint, working together to create a system capable of autonomous cyberattacks and defense.

THE FUTURE
Forcepoint will continue to focus on protecting the human point, understanding the behaviors and intent of people as they interact with critical data and Intellectual Property. Seeing how users interact with critical data is a Forcepoint priority. This people-centric approach is most effective in stopping insider threats, whether malicious or negligent, and it is what drives our product innovation and features. While Forcepoint will continue to offer products that stop attacks, our innovation will focus on detecting insider threats.

Forging partnerships between the Raytheon cybersecurity team and Forcepoint, whether through management of insider threat programs or through the use of the V-SOC to monitor Forcepoint products for new threats, Raytheon enables small, medium and large enterprises to implement an identical, consistent cybersecurity posture. •

Joshua Douglas
Richard Ford
The documentation of patient medical history and ongoing care through detailed reports is an important but tedious daily task. Instead of typing these reports, doctors prefer to dictate their reports to scribes or a recording device for later transcription. Fully manual transcription is costly and time-consuming, however the human effort can be reduced by using automatic speech recognition to transcribe the reports and then manually correct the automatic transcript. In this manner, realized cost reductions are directly related to the accuracy of the speech recognition algorithms.

In 2015, Raytheon BBN’s Speech, Language and Multimedia department launched its Medical Transcription Service, building on decades of research and development in automatic speech recognition. This web-based service acts as a back-end processor for Electronic Health Record (EHR) solution providers, offering them a sophisticated speech recognition capability while they focus on their core strength of managing medical information.

With this service, Raytheon BBN Technologies has made significant entry into the fast-growing commercial market of health information management. In the process of bringing the statistical speech recognition technology into production, a variety of engineering challenges had to be resolved. The recognizer was re-engineered to be robust against unexpected input and the system required a design secure enough for deployment over the internet and are scalable in response to varying input volumes. These solutions as well as other design strategies employed in this effort are useful to a wide range of Raytheon’s machine learning-based technologies such as automated foreign language text translation, keyword-based audio data search and video analytics.

A typical usage scenario for the transcription service begins with the caregiver dictating a report on a recording device (Figure 1). The audio report is then sent to the EHR solution provider, where it is encrypted and sent to Raytheon BBN’s web-based speech recognition service. Here, the caregiver’s voice data is decrypted, transcribed to a text based report, re-encrypted and returned to the EHR provider. Human editors correct any recognition errors and prepare a final transcript that is forwarded back to the end user. A great benefit is realized in offering the transcription capability as a hosted service, rather than deploying it at the EHR provider or on the end-users desktop. The hosted service can be seamlessly maintained and upgraded to new features and speech modes as they become available.

In a recent integration of the Medical Transcription Service, greater than 50,000 hours of speech have been processed from more than 1,200 different caregivers across 200 clinics.

Because the transcription service processes and stores private medical information, it has to comply with the rules and regulations of the Health Insurance Portability and Accountability Act (HIPAA), the law that governs the privacy rules of Protected Health Information (PHI). The architecture and data access procedures of Raytheon BBN’s transcription service were reviewed prior to initial launch by external auditors to ensure compliance with both PHI privacy rules and 24/7 medical information availability as required by the HIPAA.

The Medical Transcription Service uses statistical speech recognition based on models learned from previously transcribed audio data. To do this, a statistical learning algorithm (Trainer) is fed a
A large corpus of several hundred hours of speech audio with the corresponding human-transcribed text (Figure 2). Through this one-to-one (speech to text) “training,” a speech model is created (Recognizer) which is then deployed to transcribe new audio input. The strength of a statistical speech recognition approach, and statistical machine learning in general, is that the models can be applied to new input, to which they had not been exposed in the training data. Statistical learning is also flexible. Systems for new applications or new data domains can be rapidly built by retraining the models with the relevant data.

Achieving high-recognition accuracy is a technically challenging task, especially with an application domain like medical dictation, which has a very large vocabulary of technical terminology from a broad spectrum of medical specialties. The variation in speech characteristics and pronunciations among the thousands of different speakers along with variation in the recording channels and background noise around the speaker further increase the technical challenge. Raytheon BBN used an iterative training procedure, developed empirically over many years, to build increasingly complex models with speech and text from a wide variety of speakers and recording conditions. High-quality portions of transcribed speech were carefully selected from the thousands of hours of available data to measure the accuracy of transcription without introducing unintended biases. These efforts, along with years of experience in the engineering and optimization of large speech recognition systems, were critical factors to achieving good recognition accuracy and the system’s overall success.

Deep Neural Networks (DNNs) have recently become a remarkably successful modeling technique for automatic speech recognition as well as many other machine learning tasks. They are comprised of multiple successive layers, each of which maps its input to a form that is closer to the output, and feeds it to the next layer in succession. These mappings, which are learned from the data, are a much more powerful framework to model the speech signal than the Gaussian Probability Distributions currently used by the recognizer. Although most of the models and algorithms for neural networks are decades old, significant improvements in the state-of-the-art have been achieved by using large DNNs with many hidden layers. This recent success is attributable to today’s substantial increases in computation power and data storage, which makes feasible the training of such large networks with previously unattainable amounts of data.

Raytheon BBN Technologies has built a new, completely re-engineered, DNN-based recognizer codenamed Sage, which achieves a significant (greater than 20 percent) improvement in recognition accuracy compared to the current system. The Medical Transcription Service is currently being upgraded to the new Sage models to take advantage of these improvements.

For every medical report, after an EHR provider’s post-editor corrects the automated system’s transcribed record, the service receives a copy of the final transcript. This continuous availability of audio reports and corresponding corrected transcripts is used to periodically update and improve the service’s speech recognition models. This advantage will be further realized in future versions of the service by automating the process of feeding corrections back into the system with continuous update for new speakers and medical specialties.

The medical transcription service was built by leveraging Raytheon BBN’s advanced speech recognition technology developed through government-funded research. Although the current service’s models are speaker-independent, and are trained using speech from many different voice patterns, an even higher recognition accuracy is planned with the use of speaker-dependent and medical-specialty specific recognizer models. Also, in addition to the current batch processing mode, a streaming audio transcription service will soon be available, enabling EHR providers to implement an interactive real-time capability.

Rabih Zbib
John Makhoul
In October 2004, Raytheon acquired Photon Research Associates (PRA) — a high-tech company based in San Diego, California — nationally recognized for its capabilities in the development of advanced surveillance systems. This is the story of PRA’s contributions and integration into the wider Raytheon technology base and programs.

**HISTORY**

PRA was founded in 1976 by Dr. James Myer and a small group of principals whose focus was on the R&D of IR signatures of targets and backgrounds. The company’s initial products were highly accurate physics-based models and codes used for predicting infrared signatures and atmospheric transmission. One of these was the development, delivery and maintenance of the electro-optic simulation codes for the Air Force B-2 bomber program.

After early successes with optical signature code development, PRA began to broaden its R&D competencies to include sensor system modeling and simulation, exploitation algorithm development, mission planning, systems engineering and sensor prototype and field experimentation. Now providing a wider spectrum of technology offerings in the surveillance system area, additional offices were opened in New Mexico, Alabama, Virginia, New York and Massachusetts — each office brings its own center-of-excellence operations to a specific discipline. PRA’s customers were the U.S. government and aerospace primes, and notably as a subcontractor to Raytheon which ultimately set the stage for Raytheon’s acquisition.

At that time, PRA had 175 employees and more than 28 years of experience performing trade studies and general analyses of advanced electro-optical/infrared (EO/IR) sensors for space, airborne and ground surveillance systems for the Department of Defense (DoD) and the intelligence community (IC). This experience was an end-to-end participation from initial concept development through production and finally operation of the EO/IR systems. Many of the trade studies involved assessment and evaluation of the complete system (Figure 1), and included sensor/system modeling and simulation; phenomenology basis modeling; data analysis and exploitation; operational exploitation system’s concept of operations (CONOPS); and field experiment support. These analyses and studies were supported by PRA developed software, algorithms and databases implemented over a commercial-off-the-shelf (COTS) foundation providing an open extensible architecture.

While this capability provided a wide selection of processing methodologies and technologies to a potentially wide set of EO/IR systems and scenarios, PRA’s experiences and contract base were and remain focused on missile surveillance, missile defense and missile threat technical assessment.

**INTEGRATION OF TECHNOLOGIES**

PRA became a wholly owned subsidiary of Raytheon in 2004. With the challenge of integrating its capabilities and contribution to the larger Raytheon mission ahead, Raytheon PRA began looking inward for opportunities to inject technologies and participate in advanced surveillance system development activities. Essentially functioning as a small business operating within the larger Raytheon, the team not only continued winning R&D contracts from traditional customers but it also supported and executed Raytheon Contract Research and Development (CRAD) and Independent Research and Development (IR&D) activities.

**FIGURE 1. PRA TRADE AND GENERAL ANALYSIS CYCLE**
THE MULTISPECTRAL TARGETING SYSTEM FAMILY OF SENSORS PROVIDE REAL-TIME TARGET IDENTIFICATION AND TRACKING AND ARE COMMONLY DEPLOYED ON MQ-9 UNMANNED AERIAL VEHICLES.

While continuing to develop core technologies (signatures modeling, intelligence, surveillance and reconnaissance [ISR] algorithms, field experiments), Raytheon PRA also participates in broader large-scale systems level development activities which include efforts to expand the Raytheon product mission space. An example of this has been Raytheon PRA’s work with the Multispectral Targeting System™ (MTS™), applying this sensor product line to the missile defense mission area, which has spanned several years of IR&D and CRAD activity from the Missile Defense Agency (MDA) in the Airborne Infrared (ABIR) area. The MTS family of sensors provide real-time target identification and tracking and are commonly deployed on MQ-9 Unmanned Aerial Vehicles (UAVs). The systems themselves have high stability and provide accurate pointing in the visible to Long Wavelength Infrared (LWIR) range. The ABIR activities consisted of tracking and trajectory estimation algorithm development for missile targets; conducting field experiments and demonstrations; collecting data against real targets; and modeling ABIR system performance.

During a field test at White Sands Missile Range, a capability demonstration and sensor data collection was performed, in which an MTS-B sensor, installed on North Oscura Ridge, detected, tracked and provided range to a very long-range target. The MTS-B sensor in its ground stand, and the portable control system set up in a van, are shown in Figure 2. Within the MTS line, Raytheon PRA works primarily with the MTS-B and-C sensors. The MTS-B sensor integrates electro-optical, infrared, laser designation and laser illumination capabilities in a configuration adapted for high-altitude applications. The MTS-C sensor provides additional IR spectral bands.

In addition to missile defense applications, Raytheon PRA has developed algorithms that enable new MTS capabilities such as Video Assisted Target Location (VATL) and Synthetic Digital Sextant (SDS). VATL utilizes measurements of features’ angular positions and angular rates in the MTS field of view, in conjunction with knowledge of platform position (from GPS) to estimate a target’s position, measured in latitude, longitude and altitude (LLA). SDS, as depicted in Figure 3, utilizes the MTS sensor to enable accurate navigation of a platform in a global positioning system-denied environment.

SDS is a modern incarnation of the classic sextant used for absolute navigation in LLA. The classic sextant was a very effective navigation device because it was based on measuring a
single differential value, for example the elevation of a star over the earth’s horizon at the same point in time, eliminating line-of-sight (LOS) jitter and biases. SDS also uses a single differential measurement, but its value is synthesized from the absolute measurements of stars and/or the horizon within the MTS sensor focal plane taken at different points in time by slewing the sensor LOS (see left side of Figure 3). The use of measurements from the sensor’s Inertial Measurement Unit (IMU) and the airborne platform’s Inertial Navigation System (INS) link these highly-accurate but separated-in-time values together to form a set of differential measurements over multiple stars and frames. The horizon can be “synthesized” by observing a low earth orbit satellite as described in Figure 3. These measurements, taken over time, are linked to form a synthesized differential measurement from which platform latitude-longitude are accurately estimated.

Earlier efforts in ABIR with the MTS sensor line have led to more recent ongoing projects, the End-to-End Airborne Demonstration (E2EAD) for instance, and the Advanced Tracking and Targeting Sensor (ATTS) programs. These activities, for which Raytheon PRA is using the MTS-C sensor, are important to missile defense and other tactical applications.

In addition to developing missile defense applications of the MTS sensors, Raytheon PRA has long-term support to the Aegis Ballistic Missile Defense (BMD) program through the Ballistic
Missile Defense Engineering Services (BMDES) contract and has provided lead systems engineering support for the System M concept definition contract.

Raytheon’s acquisition of PRA brings innovative capabilities to the area of advanced surveillance, expanding Raytheon’s market for existing products such as MTS, as well as enabling new pursuits across other mission areas. Furthermore, the high-fidelity, physics-based modeling techniques founded by PRA augment Raytheon products, allowing them to be shown in specific mission contexts. Although now fully integrated into Raytheon’s Engineering organization and respective Space and Airborne Systems (SAS) mission areas, Raytheon PRA staff continue to work closely together, providing competitive advantage and mission success across the broader Raytheon.

Shang Hsiung
Engineering Fellow,
Intelligence, Information and Services (IIS)

Shang Hsiung’s mission at Raytheon is “to develop solutions to the customer’s hardest problems,” and find “alternate uses of technology to achieve unexpected effects.” With more than 30 years’ experience in Intelligence, Surveillance and Reconnaissance (ISR) programs, Hsiung is an Engineering Fellow with IIS. In his current role, he is responsible for providing technology guidance in IIS strategic areas as well as supporting growth initiatives across the organization, including commercial integration and signals intelligence activities.

Previously, Hsiung led the airborne component of a company-wide high energy laser initiative and was the capture manager for laser weapon system programs at the Raytheon Space and Airborne Systems business. Additionally, he was Raytheon Photon Research Associates’ (PRAs) Innovation Cell director, where he was chartered with creating new concepts and mission solutions. Prior to joining SAS, Hsiung was the chief engineer of IIS Advanced Programs, Ground Enterprise Solutions, Strategic Intelligence Systems, and Tactical Intelligence System product lines. He also led a company-wide horizontal integration activity, which developed integration and information sharing technologies to improve the capabilities of the Intelligence community.

Hsiung began his career at Raytheon in 1988, primarily working as a hardware engineer. He developed hardware for airborne surveillance systems and associated ground support equipment. He led several projects that developed advanced processors and multichip modules that radically reduced the Size Weight and Power (SWaP) required by an airborne sensor. He led the development, integration, test and field deployment of the sensor system and became the chief systems engineer and hardware lead for the program.

Hsiung worked at several ISR companies prior to joining Raytheon, and he holds a bachelor’s degree in electrical engineering from the University of Maryland. When asked what he thinks is most important for today’s newest engineers, Hsiung offers, “Challenge the status quo, don’t be encumbered by legacy.”
In March 2003, Raytheon acquired the Maryland-based Solipsys Corporation, a small company founded in 1996 by senior engineers from the Johns Hopkins University’s Applied Physics Laboratory. Having subject matter expertise in tracking, sensor fusion and human-machine-interface (HMI) development, Raytheon had previously funded Solipsys to provide tactical display software to the Cooperative Engagement Capability (CEC) program. This configuration was based on the Common Display Kernel (CDK), a C++ visualization framework for command and control (C2) systems. In the years following, this software architecture was re-engineered and expanded into a new Java®-based, commercial-off-the-shelf (COTS), customer tailor able C2 HMI called the Tactical Display Framework (TDF).

Since 2003, the Raytheon Solipsys TDF has been deployed across a variety of international and domestic programs and at numerous test ranges. Internationally, TDF-based HMIs have been installed on systems sold to Australia, the Gulf Cooperation Council states, the U.K., South Korea, Turkey and Malaysia.

Raytheon Solipsys has always recognized the value of turning their specialized products, developed under internal investment, into a COTS product line, allowing the marketing of their commercial software products on the General Services Administration (GSA) schedule. The advantage of a COTS business model for C2 software is in the predictability of cost; if a customer has a “typical” application, they can look up the price of the applications on the GSA schedule. This model enables highly competitive pricing, and agility in response to an evolving market. Two of these initial products, TDF and Multi/Source Correlator Tracker (MSCT), have evolved into a common C2 software core that is widely deployed in both domestic and foreign C2 systems (Figure 1).

The Solipsys software business model provides incentive for reuse across differing programs. Under this model, customers are charged a license fee for the base software product; additional costs are applied only for work necessary to satisfy any unique requirements. The key to the software product line model is the ability to maximize reuse. One condition of each contract, therefore, is for Raytheon Solipsys to retain rights to modifications made for all customers. This allows for the distribution of these modifications to all future customers at no additional cost. In other words, each subsequent customer receives a proven and tested base product offering, plus enhancements paid for by previous customers. The resulting benefit to the customer is a continuously improving, feature-rich product. The license fees are used for reinvestment into the software product line. Placement on the GSA schedule has been key to the broad adoption of all products as acquisition is vastly simplified.

**TACTICAL DISPLAY FRAMEWORK**

TDF is a scalable, high-performance, geospatial visualization software product designed for use as a real-time display and advanced information system. Its target applications include C2 air traffic management, missile defense, wide-area surveillance, emergency response and disaster management and distributed mission operations. TDF also has a customized toolkit which allows customers to easily extend the capability beyond the base offering to meet their own unique or individual needs. This framework was born out of a 1997 Internal Research and Development (IR&D) effort to investigate the emerging Java software technology as the basis for a scalable, high-performance, geospatial visualization software product.
for a new visualization framework. Having had prior experience with the CDK, Raytheon Solipsys drew upon the expertise gained in its application to tactical displays for programs, along with the lessons learned from its development, to create a new Java-based display framework. While TDF initially started as the operator interface for other Raytheon Solipsys products, a companion third-party developer’s kit expanded the use of TDF across the defense industry.

SOFTWARE ORGANIZATION
TDF is organized into class libraries divided into five major categories: 1) Java/Javax; 2) TDF Core; 3) Geographic; 4) Tactical; and 5) Project-specific classes. Oracle®’s Java/Javax classes provide the foundation on which Raytheon Solipsys builds its own core libraries. The TDF Core defines the framework of the application and lays out the basic design approach into generic objects such as views, models, listeners and factories. The geographic classes comprise coordinate systems, transforms, projections and database manipulation methods commonly used to present two-and three-dimensional (2-D and 3-D) geographic data. The tactical libraries provide C2-specific components such as track databases, sensors, track and event histories, communications links and symbol sets. The project-specific classes provide a layer of additional functionality on top of the TDF, customizable for specific mission applications.

DESIGN PARADIGMS
There are three major paradigms used in the design of the TDF: model/view, object/listener and factory.

The **model/view paradigm** separates underlying data, known as the model, from the presentation of the data, known as the view. Although simple in concept, this powerful design technique leads to modular, maintainable code that permits the rapid yet isolated addition of new features. The model provides the data representation of the object and is the basic building block of the design. The view provides a visual representation of the model in a given format such as an editor, text readout or a 2-D/3-D display. Because the model is completely independent of the view, new views can be introduced at any time without affecting the model, other views or system performance. Figure 2 graphically depicts the separation of the model and highlights examples of several distinct views.

The **object/listener paradigm** decouples the objects interested in certain events (button clicks, mouse motion, state changed, etc.) from the object generating the events. A common analogy used to describe this relationship is a public speaker and an audience of listeners. The speaker is completely decoupled from the listeners and delivers information, analogous to the events of an object-oriented software application, to audiences of varying sizes. Each audience member can choose to listen to none, some or all of the information being presented. The speaker’s performance is unaffected by the number of listeners and each listener is completely independent of all the other listeners. Listeners can individually decide to react to a given piece of information or they can choose to ignore it altogether. When used as a software design approach, the object/listener paradigm maximizes object decoupling, leading to a clean design that is both extensible and readily modifiable.

The model/view and object/listener paradigms are complementary, and often interact with one another within the TDF. For instance, the tactical situation main display simultaneously acts as a view and a listener, visually representing an underlying series of data models while updating itself based on events generated by the objects it displays.
The *factory paradigm* is used to efficiently produce commonly used objects such as tracks and sensor plots. Objects are runtime representations of data, and the functions or methods used to manipulate that data. Since objects are created and destroyed constantly during the course of an application’s lifetime, it is important to have an efficient and well-tested mechanism to produce objects on a just-in-time basis. An object factory is a software construct that permits specialized objects to be created quickly and correctly, and makes them available to threads of execution upon request.

**CONCEPT OF EXECUTION**

The TDF receives messages and track data from external sources and acquires geographic and imagery data from binary files. These varying forms of information are displayed to the operator in geographical and tabular formats. The most common method of communication to external sources and applications is by standard network protocols such as Transmission Control Protocol/Internet Protocol (TCP/IP) or User Datagram Protocol (UDP) although other forms of communication can be supported (DDS, JMessage, etc.). The TDF utilizes multiple threads of execution to perform processing, in parallel whenever possible. This multithreaded architecture keeps the user display interactive while a significant amount of processing takes place in the background.

Most objects within the TDF are plug-ins that load at run-time using a built-in Dynamic Loader. The Dynamic Loader operates both at system startup and during program execution to load and unload various types of plug-in objects. A plug-in object can be an entire application or a single graphical entity such as a slaved overlay. At startup, the Dynamic Loader inputs from the configuration a user specified file path or collection of paths indicating the location of plug-ins. The plug-in capability permits dynamic reconfiguration of the TDF at program execution time. A runtime discovery mechanism is also available to execute and verify Java classes on the fly. The Dynamic Loader facilitates creation of powerful user applications and display customizations with a minimum amount of development time.

**THIRD-PARTY DEVELOPMENT**

Key to the success of large-scale third-party development is the well documented, object-oriented API which is provided as part of the TDF Developer’s Kit. The API provides direct access to all features commonly present within modern C2 and surveillance systems such as tracks, sensors, maps, tactical data links, and geographic coordinate systems. The TDF development environment extends the inherent Java APIs through a dynamic plug-in architecture that enables programmers who are unfamiliar with the product to excel in a relatively short period of time. Experienced Java programmers become productive within days and deploy moderately complex applications within a week or two from initial exposure to the toolkit.

The API incorporates elements of Java™ Beans for component-based software and facilitates the development of dynamically loaded, customized plug-in objects which are then seamlessly distributed across the network.

**COMMUNITY ADOPTION**

On Sept. 12, 2001 Solipsys was contacted by the USAF with a request to immediately install its Common Command and Control software into the continental U.S. air defense sectors, as there was no capacity for surveillance over the region. By December 2001, the installation of the North American Aerospace Defense Command (NORAD) Contingency suite was complete (Figure 3). The ability to adapt the products to the largest C2 application in the world was a testament to the scalability and flexibility of the product line.

In 2002, the USAF and the Boeing Company officially selected TDF, known within program circles as the Primary Airborne Warning and Command System (AWACS) Display (PAD), as the HMI for AWACS 40/45. This decision was the culmination of more than two years of detailed engineering and operational analysis, and it included extensive input from the user community.

![Figure 3: North American Aerospace Defense Command (NORAD) Contingency Suite Software Display](image)
At its initial adoption by the USAF, TDF was considered revolutionary in its flexibility and ease of use, and in allowing its operators to tailor displays to focus on critical information. TDF display screenshots serve as reference examples in the USAF C2 HMI style guide.

NONTRADITIONAL APPLICATIONS
The TDF Framework is also used in nontraditional C2 applications. For example, Figure 4 is a prototype HMI used for visualization of intelligence-related data. In this implementation, a combination of geospatial and entity relational presentations provide complementary perspectives of synthetic Counter-Insurgency (COIN) data to the operator. The relational display is implemented using an open-source library and the model/view capability. Figure 5 illustrates the use of TDF for real-time status monitoring of telemetry from launch vehicles. In addition to the 3-D geospatial presentation, a color-coded timeline provides a quick-look status of all vehicles with “knots” to reflect significant events in the vehicle flight plan. Data is presented through tabbed displays for discreet details on selected vehicles, as well as inset panels in the 3-D display. Finally, Figure 6 is a screen capture of the Surface Search Radar operator display. Developed by Raytheon IDS engineers, this display incorporates third-party software and hardware within the TDF architecture to provide a synthetic video underlayment allowing legacy analog displays to be replaced with digital monitors.

FUTURE
Currently on its fifth major release, TDF-based displays continue to be the benchmark for HMI in the command and control community. It is available on the GSA schedule and to date, over 14,000 TDF-based HMIs have been deployed across all branches of the Department of Defense as well as to international customers. Future plans for TDF focus on performance, open-system standards and improvements in user interface, leveraging commercial technology whenever possible.

Robert C. MacKenzie
Richard J. Harman
Raytheon BBN Technologies has performed significant Research and Development (R&D) in machine-learning work over the last decade. Spanning theoretical to field-deployed applications, this activity has bridged multiple problems, from natural language processing to network flows and cybersecurity.

**NATURAL LANGUAGE PROCESSING**

Raytheon BBN’s MultiMedia Monitoring System (M3S) is a deployed application utilizing numerous machine learning solutions to provide analysts a unified interface for direct access to diversified media including television, web and social media. It allows analysts to more readily understand and work productively with vast quantities of media by leveraging the power of machine-learning enabled technologies such as speech transcription, machine translation, entity and event extraction (Figure 1), sentiment analysis, topic spotting, thematic geolocation and speaker clustering. Without a unified interface, an analyst might require multiple tools to search different channels separately (text, speech and video) for a given term, person or place name.

With the combined speech transcription, machine translation and keyword search capabilities of M3S, they can search efficiently for terms and topics across many individual or collective media streams. Instead of running the same search multiple times, M3S presents corresponding results across all media with a single search, automatically including results from sources originally in a different language. The graphical interface enables analysts to interact with the results via word clouds, statistical graphs, hub-and-spoke relationship graphs (see Figure 2) and other visualizations to find new relationships, trends and insights in the data.

At the heart of M3S is Raytheon BBN Technologies speech transcription engine, SAGE, providing automatic speech recognition and transcription with keyword spotting. SAGE also includes a multilingual acoustic modeling capability comprising a combination of deep neural networks (DNNs), convolutional neural networks (CNNs) and chain models. Automatic translation from foreign languages to English is provided through the Machine Translation Engine. The engine uses a statistical model trained to automatically associate millions of translation rules with their probabilities as estimated from human-translated sample sentences. Raytheon BBN’s statistical translation model uses deep neural networks to estimate word probability translations. This approach, significantly improving the accuracy of translation over the current state-of-the-art, was awarded Best Paper at the meeting of the Association for Computational Linguistics (ACL) in 2014.

Machine translation drives the Machine Foreign Language Translation Systems (MFLTS) developed by Raytheon BBN Technologies. These systems, currently deployed to soldiers, allow for effective communication with civilians in Pashto, Iraqi Arabic, Dari and Modern Standard Arabic using two-way speech-to-speech and text-to-text translation. Available in portable, mobile and web-enabled configurations, MFLTS uses the machine learning-enabled technologies of speech transcription, machine translation, and speech synthesis to provide seamless communication across language barriers and cultures, especially in the force protection domain. For example, soldiers can use MFLTS at traffic stops, during medical scenarios, and for intelligence gathering or other multilingual interactions.

For foreign language speech transcription and keyword search capabilities, Raytheon BBN employs the latest neural network models including DNNs, CNNs and Bidirectional Long Short-Term Memory (BLSTM) chain models. These techniques are
used for feature derivation, a method of transforming an acoustic signal into low-dimensional feature vectors. The use of DNNs and BLSTMs for multilingual acoustic modeling has also been explored by Raytheon BBN for associating feature vectors with the correct phonemes, modeling multiple languages at once. Our system has been used for keyword search on languages as diverse as Amharic, Guarani, Javanese, and Pashto.

Similar machine learning approaches to those above are used in the related tasks of speech activity detection (SAD), language identification (LID) and speaker identification (SID). The ability to accurately perform these tasks automatically is crucial for sorting through large amounts of audio data to find valuable information in speech. The task is complicated by highly variable noise conditions and very short speech snippets. Using deep neural networks in the speech activity detection task, Raytheon BBN researchers concluded that DNNs out-perform Gaussian mixture models for modeling non-linear decision boundaries between speech and non-speech. The DNNs are trained on features from both the spectral and temporal domains, and the decisions are improved with smoothing techniques that deal with outlier frames.

For language identification, it is crucial to encode information about sequences of sounds. This is achieved by training multi-layer perceptrons (MLPs) to learn the contextual dependencies between individual phonemes. The inner layers of the MLPs are concatenated to produce stacked bottleneck features, which normalize channel and speaker information, emphasizing the phonetic contextual dependencies that are most discriminative for language ID. The signal is then transformed into a representation known as an i-vector: a fixed length, low-dimensional representation of the full speech segment. For speaker identification, similar approaches to feature derivation and i-vector formation are in play, except additional features that preserve inter-speaker variability are also used.

The machine learning approaches used in SAD, LID and SID are also being recast in the naval domain of sonar and vessel detection. Raytheon BBN is transforming data from passive sonar into features that will be used to train models for vessel detection, classification and identification. Such technologies will help naval analysts efficiently search and understand the data received from hydrophone arrays, whose use and number is increasing at a high rate.

Machine learning plays a large role in text processing, where unstructured linguistic data is transformed into searchable, structured actionable information. For instance, if a natural
disaster were to occur in Kazakhstan, how could the U.S. and coalition responders use news or social media broadcast in the local language, Uyghur, to make decisions about where and how to allocate resources? Without reams of labeled training data on which to train models, the approach to tasks such as named entity recognition and machine translation must rely more heavily on knowledge-focused resources. Raytheon BBN’s system for processing low-resource languages makes use of annotated grammars, unsupervised semantic clusters and conditional random fields to accomplish named entity recognition.

Interest has grown recently in the use of massive amounts of available linguistic data to predict the occurrence of rare or surprising events as well as the outcome of known events such as foreign elections. Using Markov logic networks and Bayesian modeling, Raytheon BBN has developed successful predictors of civil unrest, election outcomes and disease outbreak through modeling of word usage and relevant events occurring in open source data sets.

Raytheon BBN developed a suite of machine learning tools for prediction of distress indicators related to Post-Traumatic Stress Disorder (PTSD), depression and suicidality as well as prediction of emotional status from text and speech. Associated models have also been developed for prediction of PTSD indicators from multiple signals collected using a protocol that elicits participants’ neuro-psychological responses to emotional stimuli, and open-ended self-reporting questions. The machine learning tools include a wide range of classification models for structured output prediction, such as conditional random fields, Bayesian networks and support vector machine (SVM) models. Domain knowledge learned from subject matter experts is incorporated into the prediction models with Markov logic networks. Multi-view learning algorithms exploit certain high-cost data sources that are available only in the training phase, not at deployment. In transition to our partners in Veterans Affairs Boston, Raytheon BBN developed a data exploration and model building tool that allows researchers to examine current and future instantiations of longitudinal databases for prediction of PTSD risks.

MULTIMEDIA PROCESSING
Linguistic content is not always available in computer-readable form. Important text may appear within images or as handwritten data, requiring optical character recognition (OCR). For example, to find Arabic text in images and convert it to machine-readable text, Raytheon BBN’s OCR engine uses the same neural network techniques used for speech transcription and machine translation. These include the extraction of hand-engineered features including both industry-standard features and novel features patented by BBN. With these, a DNN is trained and the softmax function applied over the DNN output layer to provide output probabilities to a hidden Markov model. Hidden Markov models are well suited for recognizing text in which characters are connected, such as Arabic script or handwriting in any language. Conventional OCR approaches segment text into individual characters or parts of characters, which is straightforward for machine print in most languages, but difficult for Arabic text or for handwriting as the segmentation obtained may not be optimal for recognition. By contrast, when training a hidden Markov model, the optimal segmentation is obtained jointly with the other model parameters.

Raytheon BBN incorporated many years of expertise in developing cutting-edge video analytics solutions into its Video Indexing and Search with Event Recounting (VISER) software system (Figure 3). VISER is equipped with a powerful user interface operating on top of a video processing engine that detects semantic concepts (objects, actions, scene types, etc.) and events. Internally, VISER uses state of the art models for video processing and prediction including novel convolutional network architectures developed at Raytheon BBN. Information is fused from video, audio, automatic speech recognition, and OCR. The VISER system detects videos containing known event types (those where event models are pre-trained on labeled data), and identifies videos related to natural language searches when metadata is not available (purely content-based zero-shot learning retrieval). Users can refine search results, annotate positive and negative examples and train models for new events on the fly by selecting relevant examples. VISER can operate in a cloud environment.
environment or as a standalone workstation application. Its architecture allows for cost-sensitive processing, where performance can be traded for processing speed.

**NETWORKING AND CYBERSECURITY**

Raytheon BBN is expanding its machine learning expertise from linguistic data processing to issues in user and entity behavior analytics. One such project is Event Modeling with Evidence Tagging (EMET), in which multipurpose techniques are being developed for finding and tracking normal behavior in order to use that knowledge to identify and describe anomalous behavior. For example, a network is an environment where activity logs provide a data stream in which normal and anomalous behavior can be found. One approach is to apply Vectors of Locally Aggregated Descriptors (VLAD) to encode fixed-time-length windows of activity as “supervectors” describing that window’s distance to each of multiple baseline-trained k-means clusters. Including the distance to all trained clusters rather than choosing a single cluster to represent the activity provides a rich representation of a given window. This technique results in much higher recall and precision in source IP prediction, a component of anomaly detection. Other approaches include applying time-series analysis to one or multiple fields of the data stream, and using the encoding layer of a stacked autoencoder (a type of deep neural network) to represent windows of activity.

Also within the networking and communications realm, Raytheon BBN’s Strategy Optimizer uses machine learning to adaptively reconfigure radio and network stacks to maintain consistent communications on mobile ad hoc networks (MANETs). The Strategy Optimizer dynamically chooses new configuration parameters, or strategies, to accommodate changing environments by consulting a support vector machine (SVM)-trained model that associates environmental variables with network performance. When the SVM prediction error exceeds a threshold, a new round of SVM retraining is kicked off to incorporate new observations and to develop a new set of effective configuration strategies.

Machine learning is used to protect networked server applications within the Advanced Adaptive Applications (A3) Environment, designed to stop cyberattacks (including zero-day cyberattacks) and to automatically repair vulnerabilities to protect against future attacks. One aspect of this fully-developed middleware environment is the use of decision trees to learn the distinguishing characteristics of malicious inputs and their association with undesired system conditions. Adapting input channels with filters to avoid malicious inputs protects the system from future attack. In addition to adapting input channels, A3 can adapt output filters, generate localized code modifications, and deploy execution shepherds using Virtual Machine Introspection (VMI) to mitigate undesired system conditions.

**AUTOMATED MACHINE LEARNING**

Data modeling is an iterative process that includes ingestion and filtering of heterogeneous and noisy data sources; selecting model structure and model components; learning component parameters and hyper-parameters; incorporating domain knowledge; and refining models based on evaluation results. In each of these steps, data scientists rely on prior experience regarding data transformations and model structure for similar data sources. In order to cope with a growing number of data modeling tasks, Raytheon BBN is automating the model building process; a capability that will allow shifting the end-to-end data modeling from data scientists to domain experts who need and use the completed models. In collaboration with academic researchers, Raytheon BBN is developing and implementing automatic model-building techniques to optimize model structure, primitive selection and parameter selection. Model primitives are developed via unsupervised pattern discovery in time series and the models are optimized by exploiting both the specific prediction problem and a database of best models built for related tasks and data sources.

**SUMMARY**

Machine learning is the mechanism by which Raytheon BBN Technologies approaches some of our customer’s most difficult problems in intelligence, information collection, networking and cybersecurity. Leading the development of seminal machine learning techniques in speech, text and video processing, Raytheon BBN integrates state-of-the-art technologies into its offerings to USG partners. The resulting advances in technology continue to enhance the efficiency of intelligence analysts, networking experts, cybersecurity agents and others protecting and serving our country.

Ilana Heintz

**MACHINE LEARNING IS USED TO PROTECT NETWORKED SERVER APPLICATIONS WITHIN THE ADVANCED ADAPTIVE APPLICATIONS (A3) ENVIRONMENT, DESIGNED TO STOP CYBER ATTACKS, INCLUDING ZERO-DAY CYBERATTACKS (INCLUDING ZERO-DAY CYBERATTACKS) AND TO AUTOMATICALLY REPAIR VULNERABILITIES TO PROTECT AGAINST FUTURE ATTACKS.**
Technology has always been a key discriminator used by Raytheon in delivering value to our customers. In today’s global economy, corporate research is less commonly pursued at major central research laboratories where activity typically centers on the development of very specific technology areas. Raytheon’s research into development of new technologies is done in a highly collaborative environment, with ideas originating internally and from partners in academia, small businesses, large contractors and national laboratories. This breadth of research enables not only upgrades to existing products but the development of entirely new capabilities as well.

Raytheon seeks to partner with universities for access to early-stage or basic research in order to gain an understanding of scientific advances before the technology roadmaps are fully defined. With an emphasis on innovation, engineering and scientific research, results from our partners are combined by applying existing knowledge in new ways to deliver novel products, methods and services that add value for our customers. Innovation is part of Raytheon’s culture of bringing forward new solutions, and it is this innovation in research, focused primarily on technology development, that brings value to all areas of our business.

Raytheon actively partners with leading technologists to bring the best minds to bear on developing unique and strategic product solutions for the customer. These partnerships include active university research, both through individual directed research projects and through membership in university consortia. Some examples of emerging technology areas in which Raytheon currently sponsors these collaborations are shown in Figure 1.

Universities are an important source of highly educated people, ideas and intellectual property serving as fuel for Raytheon’s innovation engine to convert research results into...
business opportunities. One example is Raytheon’s work with Northeastern University in nanotechnology (see inset, next page). They are also a key source of potential employees, with undergraduate engineering majors and graduate-level research in technology areas that are of specific interest to Raytheon. Colleges and universities are equally valuable teammates in pursuing science and technology Contract Research and Development (CRAD) opportunities.

A key area of collaboration with universities is the development of leading-edge capabilities for cybersecurity. Cybersystems cover nearly every aspect of our lives, and cyber-based attacks have become frequent and can be devastating. Weaknesses in hardware and software threaten not only data integrity and confidentiality of private information, but also availability of systems that support critical operations, secure logistics and manage assets and personnel. Raytheon, in partnership with a number of university cyber research institutes, continues to develop next-generation cybersecurity technologies.

Another area of focus that is important to Raytheon’s product development is advanced materials. This collaborative work includes development of lightweight metals for structures, low-thermal resistance materials for cooling semiconductors and coatings to withstand the effects of corrosive environments. It also involves modeling and analysis of material characteristics and properties to determine suitability for specific product applications.

The American Society for Engineering Education (ASEE) identifies 368 U.S. engineering colleges and universities. Raytheon works with approximately 100 of these schools, the selection criteria being based on research relevant to Raytheon technology, willingness to collaborate and proximity to Raytheon engineering centers. Recent college graduates, co-ops and interns from these institutions are an important source of engineers for Raytheon. Maintaining long-term partnerships with schools provides the opportunity to align faculty and curriculum with industry needs. It exposes students to a mix of invention and process know-how required to mature concepts from ideas, to prototype, to product. It also helps foster an environment of graduates both familiar with industry and who can make immediate contributions to business.

As technology progresses, a shift has taken place from the hardware base to one that is more computer and software...
oriented — a change that is reflected in recent university enrollment. ASEE data shows students graduating with a bachelor’s degree from an engineering program increased by 7.5 percent from 2014 to 2015, continuing a trend of annual growth since 2007. Some of the largest year-to-year percentage increases were seen in computer engineering-related programs: computer engineering, 16.2 percent; computer science, 17.6 percent; and electrical/computer engineering, 21.3 percent. Similar increases were observed in masters and doctoral program graduates.

Raytheon hires within the scientific, engineering and technology disciplines from institutions across the United States, as shown in Figure 2. This map represents undergraduate, doctoral-level and doctoral-level recruiting, and depicts a large set of institutions offering a diverse mix of candidates in background, capability, education and field of study.

Dedicated collaboration and partnership with colleges and universities is essential in maintaining the pipeline that brings

**NANOTECHNOLOGY: METHODS AND TOOLS WORK WITH NORTHEASTERN UNIVERSITY**

Nanotechnology is the study and manipulation of matter at the atomic or molecular scale, dimensions of less than 100 nanometers. Its application spans the scientific, engineering, medical and manufacturing fields and is a significant area of focus for the Northeastern University (NEU) School of Engineering. NEU pursues a number of nanotechnology initiatives that promise benefit to Raytheon. Having a long-standing relationship with the Center for high-Rate Nanomanufacturing (CHN), led by NEU Professor Ahmed Busnaina, Raytheon also maintains collaborations with NEU in advanced materials, thermal management, magnetics and other technology domains. NEU established the George J. Kostas Research Institute (KRI) for Homeland Security at the Burlington, Massachusetts campus (Figure 1) to provide facilities and other resources that help enable the development of new opportunities for academia-industry collaborative research and development.

Raytheon and NEU have partnered with U. S. Army Research Labs (ARL) to advance cold spray capabilities and apply this technology to fielded structures. Cold spray is an additive manufacturing process where powders are deposited on a substrate at supersonic speeds, resulting in adherence to the substrate upon impact. Due to the relatively low processing temperature (approximately 100 to 500 degrees Celsius), there is minimal or no degradation of material properties for cold spray-deposited metals. Raytheon is working with ARL and NEU to develop methods of applying cold spray for repair of fielded equipment. Raytheon deploys large, ground-based radar systems around the world, in environments that represent extremes in humidity, temperature, UV radiation and sand ablation. Repair of corroded metallic parts can be an expensive and time-consuming process, resulting in undesirable equipment “downtime.” Cold spray offers the ability to repair a specific damaged area rather than replacing an entire part, potentially realizing significant reduction in sustainment costs and increase in product utilization. NEU is in process of installing a cold spray system at KRI, which can be used to develop repair processes and other applications of cold spray technology.
Raytheon and Northeastern have also begun efforts to use cold spray to generate novel alloys for extreme thermal, electrical or corrosion-resistant performance.

Another nanotechnology initiative at the university is CHN’s Nanoscale Offset Printing System (NanoOPS), housed at KRI (Figure 2). With the NanoOPS tool, a template is coated with nanoparticles via electric charge. The template then transfers those nanoparticles to a substrate, much like stamping, but with layers as thin as 20 nanometers (nm). This allows for very rapid generation of high-resolution features. At speeds 100 to 1000 times faster than 3-D printing, this technology promises reduced costs for nanoscale components compared to traditional lithography and wafer processing. NEU is exploring the use of NanoOPS for drug delivery, electronics, flexible sensors and other applications. The university partnered with Milara Incorporated of Medway Massachusetts, a maker of industrial printers, to produce the nano printer. The project was funded in part by a grant from the National Science Foundation with additional funding from the Massachusetts Technology Collaborative. Raytheon is currently working with NEU to explore the use of NanoOPS for applying electrical shielding and ruggedized features on optical components.

In April 2016, the governor of Massachusetts announced a $3 million grant to NEU to establish the Advanced Nanomanufacturing Cluster for Smart Sensors and Materials (AN5SeM), to be used by the CHN at the Kostas Research Institute. A university-industry consortium, AN5SeM will leverage NEU’s capabilities to develop smart sensors and nanomaterials for a range of medical, defense and energy applications.

NEU’s Electronic Materials Research Initiative (eMRI) mission is to synergize and catalyze research and education in nanomaterials for nano-, bio- and info-technologies. More than 30 faculty members work with external companies and government research institutions on interdisciplinary projects such as electronic and photonic nanostructures, nanomedicine, fuel cells and computation modeling at the nanoscale.

The Center for Microwave Magnetic Materials and Integrated Circuits (CM3IC) is a research organization located at Northeastern University focused on novel microwave magnetic materials and device solutions for use in microwave electronics and multifunctional integrated circuits, particularly for radar and other high-frequency electromagnetic applications. The CM3IC works closely with the Department of Defense to facilitate the transfer of novel and advanced technologies from the university to the DoD and its contractors, including Raytheon. Research areas include circulators, metamaterials, ferrites, magnetic semiconductors and magnetic nanoparticles.

Raytheon is excited about the opportunities that NEU offers for the development of advanced materials. This productive collaboration not only presents new capabilities for Raytheon applications, but develops a potential pipeline of students with skills critical to meeting Raytheon’s future employment needs.

Mary Herndon
Software is a key component in Raytheon’s product capabilities and great emphasis throughout the company is placed on the continual evolution of software development to ensure the most advanced techniques, technologies and practices are in place to optimize delivery and quality of effective solutions for our customers. This strategy has seen the introduction of the software innovation for tomorrow (SWIFT) initiative, designed to establish a framework for software development methods which incorporates people and environment, automation and efficiencies, structured reuse, and advanced test built on a foundation of customer alignment (communication and collaboration).

The SWIFT framework provides an approach to incrementally develop and field customer solutions quickly and reliably. Its methods are designed to reduce development and life-cycle costs by providing predictable, stable processes based on the latest technologies. They can be selected and tailored for use on software development programs as a means of delivering specific mission solutions faster and more efficiently while meeting or exceeding the software quality levels customers expect.

More recently, Raytheon’s software development activities have placed an emphasis on the adoption of cloud computing and DevOps, and their integration into the SWIFT framework. Figure 1 shows the specific areas of SWIFT embodying the cloud computing and DevOps concepts, where increased attention is given to interconnecting these methods and processes to support the entire DevOps pipeline.

DevOps is a contraction of the words development and operations, and at Raytheon, represents a culture of collaborative relationships connecting engineering, test and operations to optimize the delivery of incremental capability. A complete capability is a collection of features and functionality, which after completing acceptance test in its entirety, is considered production ready and is delivered to the production environment. During product development, DevOps methods provide the ability to augment existing software and systems processes with agile/lean techniques, tools and cultural changes. These, in turn, enable continuous, incremental functional releases with the benefits of reduced development time, accelerated product delivery and improved product quality. Some of the key tenets of a successful DevOps deployment are:

- Cross-functional members working together to develop features
- Accelerating capabilities delivery through increased automation and improved quality, minimizing manual labor and rework
- Shifting the manual staged delivery approach to an automated continuous delivery model
- Focusing team members and contributors on delivery of capabilities
- Maintain concentration on small batches of work to improve flow through the software development system, and the entire program
- Continuous attention to delivering the capabilities that add value

DevOps spans the software and systems engineering product development process (Figure 2), relying on automation tools and agile, lean processes to develop software in smaller functional pieces. Figure 3 describes where the specific DevOps concepts are incorporated within the various stages of software development. This is an iterative process beginning with the planning stage, where requirements are gathered from the customer and other stakeholders to develop the product backlog (prioritized features list) based on delivering incremental capabilities. During the code phase, the stories (requirements) that make up the features and capabilities are created according to the backlog and then built to prepare for the testing phases. The software and system are tested using automation to ensure the desired functionality on as close to a target platform as possible. During the release stage, automation is used to produce a package containing the product and then deployed to the target environment. During the operate stage, the product is in the target production environment and results are fed back to the entire DevOps pipeline. In practice, DevOps can include some or all of the underlying concepts shown below in an iterative approach with automation tools to achieve the desired benefits.

- Agile/Lean Development: Using short, iterative development cycles, including frequent collaboration with the customer, and other agile/lean techniques resulting in the delivery of “working” software throughout the program’s life cycle
- Continuous Integration: Integrating early and often, incorporating small incremental changes, in order to uncover defects faster and isolate fixes to small change sets
- Automated Software/Systems Test: Using automated software and verification systems and methods to test product functionality on as close to an operational platform as possible

Dr. Nora Tgavalekos, is chief software engineer for Corporate Engineering within the Engineering, Technology and Mission Assurance (ET&MA) organization of Raytheon Company. In this role, she directs the Software Engineering Council and provides oversight and guidance to software efforts across the Raytheon businesses. Dr. Tgavalekos applies her broad range of engineering and technology experience to business software challenges, generating enterprise-wide synergy for software design, development, test and support. “My role is to create synergies across the company in the tools, processes and development of people within the Software discipline,” she explains. “The expectation is that we have improved execution on programs which provides Raytheon the ability to produce cost effective solutions while still delivering a high-quality product to our customers.”

Dr. Tgavalekos also serves as the technical competency definition and development lead for the ET&MA organization. Since assuming this role in 2011, she has been responsible for coordinating the execution and sustainment of existing ET&MA learning curriculums including the Johns Hopkins University master’s program and the Systems Engineering Technical Development Program. She also leads the development and deployment of technical content for ET&MA learning programs including Mission Assurance, Engineering Export/Import Technical Advisors, Cyber and the Lead Systems Engineer (LSE) Development Program. When asked about her thoughts on keys to a successful career, Dr. Tgavalekos offers “Throughout your career, take every opportunity you can to learn, whether experiential, applied learning or through mentorship. Work in roles that make you feel uncomfortable to broaden your skillsets and gain confidence.”

Prior to joining Corporate Engineering, Dr. Tgavalekos held several key positions on ground based radar programs at Raytheon including flight test director; design and analysis lead; deputy integrated product team lead; and lead of the radar discrimination team. She also served as a section manager within the Systems Architecture Design and Integration Directorate at Raytheon Integrated Defense Systems (IDS).

Prior to joining Raytheon, Dr. Tgavalekos held positions of increasing responsibility in the fields of electrical and systems engineering at General Electric™ Healthcare. These included leading teams for investigating methods of detecting metal distortion in electromagnetic surgical tracking platforms, and leading the development and deployment of algorithms to model electromagnetic navigation accuracy.

Dr. Tgavalekos holds a bachelor’s degree, a master’s degree and a doctorate in biomedical engineering from Boston University. She has been awarded patents in the fields of medical devices and radar discrimination, and has written more than 30 publications and abstracts on the topics of medical devices and missile defense.
• Continuous Delivery: Automation components in place to build, test and provide instantaneous application delivery to any target environment.

• Continuous Deployment: Layered on top of continuous delivery, automates deployments through to operations.

DevOps concepts are defined within the SWIFT architecture and developed according to enterprise guidelines with checklists, handbooks and training materials to provide technical support to programs for method training, implementation and adoption.

A DevOps approach is important in defect detection and resolution as it is oftentimes the case that they are not isolated to a specific component’s functionality, but rather surface in the interaction of several components when part of the integrated system. Therefore, putting components together as early as possible and testing frequently can not only reduce development and delivery time, but also improve product quality.

Maintaining this integration and test capability requires an environment that can emulate all remaining components of the test system. This may not be feasible due to the extended efforts required in supporting all the necessary emulations and the costs of computing systems required for multiple test beds to quickly test many components simultaneously. Reducing capacity on the other hand can introduce bottlenecks, possibly defeating some of the benefits of DevOps. Cloud computing is one means of providing an effective solution to creating and maintaining an environment for frequent test and integration.

Figure 2: DevOps iterative stages
Cloud computing enhances the DevOps pipeline by providing on-demand virtual environments as resources to enable rapid cycles of software development, systems engineering development, integration and testing. It offers network-based, location agnostic and dynamically configurable computing, networking and storage resources designed to maximize resource utilization. Cloud computing provisions both speed and flexibility through virtualization and significantly improves time for program startup through rapid creation of development and integration environments. It also enables mission assurance through automated configuration of operationally relevant test environments and enhances value delivery in sustainment through operational monitoring and centralized service provisioning.

The benefits of DevOps in software and systems development are realized through the application of agile and lean techniques coupled with automation tools and rapid feedback to achieve a continuous development, integration, delivery and deployment capability. A well-executed DevOps strategy can result in improved productivity, reduced rework and higher product quality for the customer. Leveraging the scalability of cloud computing can accelerate both initial capability and product maturity.

Cindy Molin
Terry Godwin
Nora Tgavalekos

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FIGURE 3: HOW DEVOPS CONCEPTS MAP TO DEVOPS STAGES

CLOUD COMPUTING ENHANCES THE DEVOPS PIPELINE BY PROVIDING ON-DEMAND VIRTUAL ENVIRONMENTS AS RESOURCES TO ENABLE RAPID CYCLES OF SOFTWARE DEVELOPMENT, SYSTEMS ENGINEERING DEVELOPMENT, INTEGRATION AND TESTING.
Kim Caruso is vice president of Corporate Operations within Engineering, Technology and Mission Assurance at Raytheon. Since joining Raytheon in 1988, Caruso has held positions of increasing responsibility within engineering in the areas of hardware development and system integration and test, including field and flight tests. Most recently, she was senior director of domestic programs, where she was responsible for providing program and organizational leadership in the development, production and sustainment of the Patriot Air and Missile Defense System in support of the U.S. government and international partner customers. Caruso is responsible for the execution and strategic initiatives of operations across the company, including driving advanced manufacturing technologies, innovations and capabilities; depot, manufacturing facilities and real-estate strategies; and effective business continuity operations. She helps ensure a safe, secure and sustainable workplace.

Technology Today spoke with Vice Presidents Kim Caruso and Alan Glickman about their roles, objectives and key aspects of the Corporate Operations and Engineering organizations.

T.T.: What are your main objectives as vice president of Corporate Operations?

Kim Caruso: I am focusing on three main objectives: right-size our facilities footprint to meet utilization goals; drive lean and continuous improvements; and advance manufacturing technologies through innovation. An important goal in this respect, is achieving these objectives through cross-collaboration with each of the four business operations vice presidents and their teams.

In right-sizing our facilities footprint, the real estate team reviews metrics for office space, laboratory, manufacturing and warehouse utilization. We also include analysis of manufacturing capabilities and utilization metrics for factories from each of the four business units. This data is analyzed to develop strategies for more efficient use of facility and manufacturing space and to determine best use of space to accommodate business growth needs.

In the area of lean and continuous improvements the team is focusing on driving margin expansion through numerous initiatives including employee idea generation; employee participation in tiered accountability meetings; improved focus on process flow across factories to drive waste elimination; expanded automation in areas such as robotics, automated torqueing, advanced (model-based) work instructions and machine learning; and implementing additive manufacturing, and advanced test automation.

The Manufacturing Technology Network technical area director (TAD) is the key advocate to promote the development, optimization and proliferation of advanced manufacturing technologies across the Raytheon enterprise. Working in collaboration with both universities and industries, the TAD’s main focus areas include rapid prototyping; model-based manufacturing; additive manufacturing; advanced testing; visualization for manufacturing; and manufacturing systems and execution.

T.T.: How would you describe the influence Corporate Operations has on creating competitive advantage across the Raytheon businesses?

K.C.: Operations’ objective in Competitive Advantage is to deliver maximum customer value through innovative solutions and advanced capabilities and services — each an enabler of mission assurance, flawless execution, business growth and best-in-class return on invested capital. A key way in which we accomplish this is through the Operations Council whose members consist of the four businesses’ Operations vice presidents and the functional vice presidents from Engineering, Mission Assurance, Supply Chain and Global Business Services. The council meets monthly to discuss business unique initiatives, best practices, lesson learned and process improvements that help reduce overall operations costs and improve efficiencies across the businesses; both key influences in improving Raytheon's competitive advantage.

T.T.: How does Operations keep up with advances in technology?

K.C.: There are many ways Operations keeps up with advances in technology. For example, through partnerships with industry, universities, the National Network for Manufacturing Innovation (NNMI) and manufacturing innovation institutes, we collaborate and develop next-generation technologies and advanced manufacturing processes. The manufacturing TAD is the key conduit to these initiatives, keeping pace with advances in technology and the manufacturing Technology Interest Groups (TIG). The TIGs are a collection of subjects matter experts (SMEs) from across the company who foster and promote manufacturing technology transfer across all the Raytheon businesses. Their primary focus areas include automation, additive manufacturing, model-based work instructions, auto-ID technologies, digital manufacturing, cleanroom management, adhesives and advanced materials. Through direct funded research projects, memberships in consortia and sponsorship of student projects, we continually strive for early stage involvement in technology advancements and to broaden our technical network, keeping manufacturing technology innovation moving forward.

T.T.: Raytheon continues to build its global presence and international business. How is Operations evolving to support this growth?

K.C.: One primary activity with which Operations supports Global Growth is through companywide standardization of material and production tools and processes, driving the concept of “build anywhere.” The Enterprise Resource Planning (ERP) team was established and chartered for just this purpose. The ERP is a cross-business collaboration whose steering team determines the priorities for work in areas which bring the most value to the “build anywhere” approach. The ERP builds on the foundation of our common resource planning systems to accelerate Enterprise Collaboration and drive competitive advantage in the global environment. Seven value streams are used to focus on key steps in the product life cycle: capture, design, plan, source, make, deliver and sustain. Standardizing the tools and processes used throughout the product life cycle allows Raytheon to leverage common people and resources while building its international business and global presence.
Alan Glickman is vice president of Corporate Engineering within the Raytheon Engineering, Technology and Mission Assurance organization. Throughout his career, he has held positions of increasing responsibility and has positively impacted numerous programs and projects in Air Defense, Missile Defense, Naval Surface Warfare, Undersea Warfare and Air Traffic Control. At Raytheon, Glickman has been actively involved in the Multifunction Radio Frequency Systems Technology Network, Electrical Systems Council and the Analog/RF Engineering sub-council. He is a qualified Raytheon Six Sigma™ Specialist, and was named IDS Game Changer of the Year for 2009.

T.T.: What are your main objectives as Vice President of Corporate Engineering?

Alan Glickman: The primary objectives of Corporate Engineering are to focus on our people, process, performance and technology. Each of these are enablers to the corporate focus areas of Global Growth, Enterprise Collaboration and competitive advantage.

Our people are the backbone to our company success and as such, we concentrate on hiring the best talent and developing the future technologists, scientists, leaders and managers that will keep Raytheon strong and competitive for the future. We invest in our employees through higher education programs; enterprise-level training for technical skills such as the Principles of System Engineering (PoSE) course and the Systems Engineering Technical Development program (SEtdp); Leadership Development programs; and experiential learning opportunities. These programs provide employees the ability to develop their own career paths.

The Integrated Product Development System (IPDS) process and developmental “V” (see “Career Growth Through the Engineering V” in the Special Interest section of this issue) are the foundation of how we conduct business on all our programs from the early capture phase to the operation and sustainment of fielded systems. Continually enhancing our processes to improve productivity and effectiveness of engineering design and development is critical. For example, incorporating commercial best practice approaches in design, as with Software Innovation for Tomorrow (SWIFT), yielded substantial improvements in software development productivity. Looking forward to Raytheon’s future competitive advantage, we are starting a new initiative across electrical, mechanical, systems and life-cycle engineering which embraces the work accomplished by SWIFT and builds upon it for development of our systems to deliver products with improved productivity and efficiencies.

Regarding performance, we focus on the fundamentals of good engineering. Driving due diligence in system design and development, maximizing reuse, ensuring design failures are not repeated, and sharing best practices and lessons learned are all imperative actions. Applying the Design Guidance System (DGS) process to ensure design rules and guidelines in process and independent reviews, and utilizing the Raytheon Lessons Learned System (RLLS) and system complexity reduction measures such as Cost as a Requirement (CaR) and Cost as an Independent Variable (CAIV) will continue to improve our overall program execution.

As relates to technology, we continue to understand current and emerging customer needs and identify the technologies of the future that will maintain Raytheon competitiveness and relevance in the defense and aerospace business. Through investment in IRAD and winning CRAD, we focus our technologies to fill gaps and respond to future customer mission needs. Collaborating with universities and strategic suppliers also provides opportunity for innovative ideas that enable future military applications.

T.T.: Can you tell us about the Raytheon Engineering Common program and how it has shaped Engineering across the company?

A.G.: The Raytheon Engineering Common Program (RECP) creates companywide collaboration and common process and tool development. Each engineering council annually develops initiatives that focus on improvements in common process, metrics and tools that enable improved productivity and design efficiency. Annual internal symposiums and workshops provide a means to share critical technology developments and ideas within each business and across the company. Also, international growth is supported through critical investments in areas like the Global Substances Program (GSP) which keeps ahead of the increasing substance regulations.

T.T.: This issue of Technology Today is about “Raytheon Sources of Technology”, including acquisitions. What do you see as the key challenges and benefits for Engineering associated with expanding Raytheon’s technology through acquisition?

A.G.: One of the many ways we build on Raytheon’s vast portfolio of technologies is acquiring tangential businesses and assimilate them into future products and programs. A key challenge with any acquisition is aligning the new organization with the Raytheon business process while promoting the creativity and innovation which originally inspired the acquisition. If done properly, however, the benefits to engineering are multiplicative, evolving with new and innovative products and technologies across many business areas and customer needs.

T.T.: What are some key engineering work products necessary for a seamless design transition into manufacturing?

A.G.: Our investment in Common Product Data Management System (cPDM) and integration with Process Reinvention Integrating Systems for Manufacturing™ (PRISM) has been instrumental in addressing both seamless transition to production and collaboration with Operations and Supply Chain. Early engagement with Operations and suppliers in the design process ensures engineering work products transition smoothly into manufacturing work products and enables efficient manufacturing and product integration.
Tomaz Seignemartin is the company’s director of Raytheon Six Sigma. With more than 16 years of experience in engineering, quality, operations, services and sales, Tomaz is responsible for driving the company’s R6s vision and strategy, including continuous improvement in processes and systems. Previously, Tomaz worked at General Electric Company where he was responsible for leading a number of international product areas. He also led a number of six sigma design projects where he was able to deliver results that led to a significant increase in customer satisfaction and margin enhancement. He received the GE President’s Award for Quality in 2009 and was certified as a Lean Six Sigma Black Belt by GE in December 2006. Tomaz earned a bachelor’s degree in mechanical/aerospace engineering from Rutgers University and an MBA from Northwestern University’s Kellogg School of Management.

There was a time, before my career at Raytheon, when every improvement action had to be a Six Sigma project — not an entirely healthy approach. Traditional Six Sigma by itself is a great way to achieve two process goals: reduce variation and shift the mean. And although these are some of the toughest business problems we encounter, not all problems are of that nature. Teams need to pick the right tools to solve the right problems.

My second thought is that, over time, customer expectations evolve. Achieving true Six Sigma process capability (3.4 Defects per Million Opportunities) is most often a journey, not a destination. Our upper and lower specification boundaries are ever shrinking as our customer expectations evolve. As such, the importance of continuous improvement — striving for perfection — must really be something each of us takes on personally every day.

T.T.: How do you see the role of R6s at Raytheon evolving in the future?

T.S.: Raytheon is moving towards optimizing our processes end-to-end, from our customer’s perspective, independent of traditional internal channels. Enterprise Collaboration occurs naturally when you approach the problem from that perspective. When we apply R6s with a focus on customers and suppliers, and ask “What are their pain points?” we work to minimize the “white space” that many times occurs between us. I also see a future where R6s is deeply involved at the forefront of innovation. For example, our current enterprise project is helping the business accelerate change and adoption of new software development processes.
Kurt Mittelstaedt is Director of Operations for Enterprise Lean Manufacturing within Raytheon’s Engineering, Technology and Mission Assurance function. He is responsible for driving operational excellence and productivity through multifunctional company improvement initiatives focused on collaboration between Operations, Engineering, Mission Assurance and Supply Chain. Most recently, Mittelstaedt led a Design for Six Sigma™ (DFSS) initiative, driving affordability and performance by increasing DFSS deployment on programs, integrating DFSS into product development and creating DFSS subject matter experts. Mittelstaedt joined Raytheon in 1988 and has held technical and leadership positions in Operations, Mission Assurance, Integrated Supply Chain and Engineering. He is a graduate of the Raytheon Leadership Excellence Program and is a certified Raytheon Six Sigma Master Expert. Mittelstaedt earned his bachelor’s degree in mechanical engineering from the University of Rochester in 1988 and his master’s degree in manufacturing systems engineering from Stanford University in 1994.

T.T.: What is your role in corporate operations as director of Operations for Enterprise Lean Manufacturing?

Kurt Mittelstaedt: My role is to develop a strategic, enterprise approach to deploying existing lean and evolving industry best practices to drive competitive advantage. Raytheon has strong teams of lean practitioners in each business who successfully engage employees in manufacturing sites, improving our production processes. We see an opportunity to highlight best practices from each business and share them across the company, empowering facilities new to lean to leverage the gold standards of the entire company; and giving sites with mature lean practices a path for continued improvement.

It’s an exciting time to work in Operations. Technology continues to open new opportunities for improving manufacturing. Raytheon is always exploring and implementing new practices such as Industry 4.0 initiatives which will revolutionize manufacturing.

T.T.: How is today’s R6s different from the original approach developed by Motorola?

K.M.: Raytheon has a rich history in Six Sigma and continuous improvement, going back to the companies that make up our organization today. Texas Instruments Defense Systems worked closely with Motorola in the development of Six Sigma, and their Black Belts brought along their experience and lessons learned to Raytheon. Additionally, Both TI Defense Systems and Hughes were early aerospace pioneers in the application of agile/lean methods in their factories and DFSS in product development. Leveraging these methodologies and pulling in the business improvement focus of GE and Allied Signal™ in the late 1990s enabled Raytheon to become the first aerospace company to unleash the integrated power of a lean Six Sigma program under the banner of Raytheon Six Sigma.

T.T.: From an enterprise perspective, what are some of the key benefits of R6s to Raytheon Operations?

K.M.: Lean and other R6s methodologies have provided significant improvements to Raytheon operations. Its benefits are seen across the company — cost reductions drive margin expansion and return dollars to our programs; cycle time reductions help programs achieve customer milestones; and defect reduction impacts scrap and rework costs. In addition, employees submit thousands of ideas every year through the Total Employee Engagement program.

The Operations Council also supports initiatives with engineering to improve the quality of new designs. For example, the number of Design for Manufacturing and Assembly workshops has dramatically increased enterprise wide, leading to affordable, producible designs.

T.T.: How do you see the role of R6s at Raytheon evolving in the future?

K.M.: R6s will always stay focused on our customers and our people. At the same time, we can leverage new methods and technology to further optimize our continuous improvement efforts. The pace of change over the next few years will have a dramatic effect on our people, products and factories. It is important that we drive change rather than react to it.

THE PACE OF CHANGE OVER THE NEXT FEW YEARS WILL HAVE A DRAMATIC EFFECT ON OUR PEOPLE, PRODUCTS AND FACTORIES.
At Walt Disney World’s Epcot Center, the Raytheon-developed Sum of all Thrills™ attraction allows riders to design their own roller coaster and experience a simulated ride on the new design. The robotically controlled movement of the ride is the result of a computer program that interprets the track design and simulates how an actual coaster car would run if the track were real. This is physics-based simulation, and is quite different from many video games where vehicles are not rigidly bound by the physics of the real world and can perform maneuvers that are not physically possible. The simulation model for the ride uses equations for force, motion, friction and other physical concepts to ensure the cars motion stays true to the laws of physics.

Raytheon manufactures some of the most sophisticated weapons systems in the world. The combination of rapidly changing threats to national security and the increasing complexity of the systems needed to defend against these threats makes the traditional decades-long development process untenable. Shortening this development cycle within the defense industry requires an ever increasing use of physics-based simulation tools. These tools provide engineers the ability to design and test their ideas within a virtual environment — avoiding the slow, costly development of physical prototypes.

Models have always been a part of engineering design. When the Wright brothers were creating their first airplane designs they used models to understand the physics of flight. Kites were a way for them to study flight controls and a wind tunnel helped them to understand the aerodynamic properties of various wing shapes. Whether a drawing, mathematical equation or a physical scale representation of an object, models are essential to the engineering process. Using supercomputers, engineers can now construct virtual models, and through simulation they can assess how their designs will work in the real world. For example, as you drive your car around a curve on the freeway, you experience the physical forces acting on the vehicle. However, understanding how physical forces act on a missile moving at supersonic speeds requires very complex and sophisticated computer analyses.

Figure 1 illustrates the steps used to develop a model for wind flow across a wing surface. The engineer first determines the wing shape (left) and then uses a computer program to create a collection of small triangles that form a mesh representation of the wing (center). With this mesh version, the engineer can use simulation to understand the forces the wind might exert on the wing surface (right). As an object moves through the atmosphere, especially at high speeds, the object experiences forces in the same way you do in your car. If the forces acting on a wing surface are incorrect, the wing may not provide enough lift, or it may cause instabilities, or it may just simply fail.

Figure 2 visualizes a computer generated simulation of a missile flying at supersonic speed. The red color on the nose indicates the high pressure due to compression of the atmosphere in front of the missile. Similar to the pressure experienced when you put your hand out the window of a moving car, that same force is magnified many times as the speed increases. The large green areas around the canards depict the level of fidelity (described below) used by the model relative to distance from the missile body.

Raytheon is a leader in adopting simulation as a critical part of the engineering design and manufacturing processes. Whether designing a new guidance system or an assembly station on the factory floor, models and simulations are essential to product success and customer satisfaction. That said however, all models are not necessarily equal, and this is most evident in a property known as “fidelity.”
A model is, by definition, a representation or abstraction of an object or system. The level of fidelity, typically referred to as low, medium, high or perfect, determines how closely it can represent what is being modeled, with perfect fidelity representing an exact copy of the reality. There is also a direct correlation between the level of fidelity and the amount of computing resources required to simulate the physical and environmental factors. Low-fidelity models generally run very quickly and on ordinary computing hardware, whereas high-fidelity simulations such as weather prediction can require a significant increase in computing resources, oftentimes to a level described as high performance computing or HPC. Referring back to Figure 2, the "blocks" around the missile are an indication of the level of fidelity exhibited by the model. Here, the missile is rendered in very fine detail but the atmosphere is represented in much lower detail the greater the distance from the missile. This is a desirable attribute of the model as the lesser influences of the atmosphere on the missile’s flight at these greater distances can be accurately simulated more quickly with lower fidelity and, consequently, with much less computing resource.

Raytheon uses a number of modeling and simulation tools and has been working with the Office of the Secretary of Defense (OSD) Engineered Resilient Systems (ERS) office to increase utilization of simulation. A DoD-funded project known as Computational Research and Engineering Acquisition Tools and Environments (CREATE) has developed a set of next-generation tools for simulating many aspects of defense-related systems. These new tools are capable of simulating complex systems at very high fidelity, such as an entire aircraft. Executing one of these fighter aircraft simulations on a typical engineering desktop workstation, if even possible, could take many, many years. Raytheon utilizes very large-scale super computers to make this type of simulation practical. These high-performance computing (HPC) machines have the processing equivalent of as many as one hundred thousand computers or more in a single machine and run very specialized programs such as CREATE’s Kestrel model.

Kestrel is capable of simulating an entire aircraft and its weapon systems (Figure 3) using a physics-based simulation known as computational fluid dynamics (CFD). CFD uses complex algorithms to model the flow of liquids and gases along an object’s surfaces. Kestrel is one of the few computer applications that can perform the millions of mathematical calculations required for this type of simulation. With this capability Raytheon assesses how weapons will react when released from an airframe at combat speed.

Understanding the impact of turbulence in the airflow around the aircraft is critical to a safe release and operation of the weapon. In Figure 3, the pressures on the aircraft (similar to the missile in Figure 2) are reflected by the color gradient, which indicates that the plane is turning to the pilot’s right since the higher pressure areas (yellow to red) are offset to one side. It is important to understand what will happen to both the aircraft and the weapon when it is released at any time other than horizontal flight.

Physics-based simulation is used throughout Raytheon, not only for the more popular CFD models, but in other equally important applications such as blast damage assessment; analysis of thermodynamic properties in electro-mechanical systems; and the effects of radiation on satellite components. Physics-based simulation is also used to predict the effects of weather and other environmental conditions; for instance dust, heat, cold and rain (Figure 4). The weather forecast shown on your local television station is a prime example of this type of high-performance simulation that touches everyday lives.

Raytheon continues to embrace the best technologies available in the development of next-generation weapons systems. The integration of physics-based simulation environments such as CREATE and other simulation tools into normal workflow processes allows Raytheon engineers to explore design spaces that would not have been attainable 20 years ago.*

George Ball
Designing complex systems at Raytheon takes knowledge, discipline and experience. The “Systems Engineering V”1 (Figure 1), the road map to the discipline required for successful product development, can also be used as a map for career growth. At Raytheon, the process of developing a product — from initial user need, through design, development, delivery and finally, operations — is a multidisciplinary approach that requires human, organizational and technical variables working together to create complex systems. Over the course of an engineer’s career, gaining experience across all phases of system development greatly expands an engineer’s skill set and systems understanding. These experiences will build the engineer’s experiential grid. This provides a big-picture view of multifaceted problems and potential solutions encompassing customer needs, system constraints and operating environment.

The experiential grid is defined by the phases of the product life cycle. The product life cycle is the natural progression through phases of product development comprising the flow of activities from customer need to customer satisfaction including requirements development, design, build and integration and test. More specifically, starting at the left hand side of the “V” in Figure 1, the scope of product development begins with the identification of a user (customer) need. This is translated into a system architecture; a high-level design that provides a logical and/or physical representation of the product. Then, through a thorough analysis of the customer’s needs and objectives, a properly aligned set of system and subsystem requirements is developed. These are the statements of fact and assumptions defining the expectations of the system in terms of mission objectives, environments, constraints and

1 Building on a Legacy: Renewed Focus on Systems Engineering in Defense Acquisition, Mary C. Redshaw, A publication of the Defense Acquisition University, January 2010
measures of effectiveness. The next phase of development is system design; incorporating both the hardware and software functions to convert the architectural concept and requirements into a realizable design. It is important to note that as we move down the left hand side of the V from architecture synthesis to hardware/software design, an iterative re-balancing of requirements (depicted by the circled arrows) occurs, as needed, to control cost and complexity. For example, are all the requirements being levied on the system verifiable? Will the system, as currently specified, meet the cost target? Will the suppliers be able to deliver the product in a timely fashion? A negative response to any of these questions may require a return to an earlier requirements development phase.

At the base of the V is product build, integration and test where additional experiences in supply chain, operations and quality are gained. Integration is the merger of low-level components, parts and/or configuration items into the complete system; satisfying the logical and physical interfaces as well as the original intended use of the system. Tests are used during integration to examine interfaces and confirm performance of the higher level assembly.

Moving up the right-hand side of the V is subsystem and system verification — the formal proof of compliance with requirements. The four methods of verification are test, demonstration, inspection and analysis. These methods assess whether or not the system is well-engineered, error-free, complete and in compliance with requirements. Verification ensures that the implemented solution meets its specified technical requirements and properly integrates with interfacing products. Next is the validation phase, which is the formal proof that the resulting system complies with and meets the customer’s needs in the operating environment. Finally, in the operations and maintenance phase, the system is fully operational, undergoing regularly scheduled maintenance, and performance measures are monitored.

Through the various experiences acquired during each phase of the V, engineers learn how to write valid requirements; design and build hardware and software to meet those requirements; integrate and test subsystems and systems; and deliver product to the field. Along the way, they also learn about engineering standards, practices, policies, and procedures; how to collect and analyze metrics; and how to use and develop tools to help them execute their tasks. At Raytheon, the Integrated Product Development System (IPDS), shown in Figure 2, is the set of common processes that are used to execute the work in each phase of the V to increase speed and cost-effectiveness as well as guarantee the solution will meet the customer’s needs. IPDS integrates engineering disciplines with organizational functions and represents the compilation of Raytheon’s best practices, guidelines, methods, tools and other enablers of successful process execution.

An IPDS gate is an evaluation point where it is determined whether or not the program is on track toward meeting program requirements, and if not, the necessary corrective actions to bring it back on course. In Figure 1, the red circles identify these IPDS gates in relation to the product development life cycle. In the beginning are Gates 1 to 4, the pre-proposal gates, where Systems Engineering is determining user needs, performing trades and working within the Business Development and Strategy capture process for winning new business.

Demonstrating successful execution within a program and within specific phases of the V can lead an engineering professional to positions of significant technical responsibility. Gaps in proficiency for specific roles are addressed through rotations to different programs and/or discipline directorates; international assignments; accelerants (i.e., mentoring); or applied learning; all of which ultimately promote career development. An example of this is the Principles of Systems Engineering (PoSE) curricula, a learning program developed by Raytheon, designed for the entry-level systems, software engineering professional.
and hardware engineering target audience to provide an introduction to the V and how it is used at Raytheon. Higher level courses such as the Systems Engineering Technical Development Program (SEtdp) and the Certified Architect Program (CAP), intended for mid-level to senior level engineers, offer additional depth on how to execute the product life cycle.

Raytheon tools, such as the Talent and Career Explorer (TACE) tool, help identify and isolate skill gaps and strengths for specific technical roles of increasing responsibility. The four frameworks of the TACE cube (Figure 3) describing competencies for engineers are:

- **Mission Area**: The customer-defined market segment
- **Domain**: That which is built, supported and deployed in support of the mission area
- **Discipline**: An area of expertise; for example, an engineer’s major in college
- **Technical Leadership**: The skills needed to lead a technical program

The TACE tool allows employees to rate their proficiencies according to their level of knowledge in the skills that make up the competencies in each framework. Employees can compare their skill levels to specific technical role requirements, identify gaps and develop appropriate strategies to close those gaps such as rotational assignments, enrolling in specific learning programs or receiving focused mentoring.

**REPRESENTATIVE CAREER PROGRESSION**

The different phases of the V (figure 1) can also be used to demonstrate a representative technical career progression for an engineer. For example, a new college hire with an electrical engineering degree might begin with a position in hardware design for a program and eventually transition to new roles in hardware integration and test and then, continuing up the right-hand side of the V, on to support verification.

![Figure 3. TACE Cube of Competencies](image-url)
and validation activities. This transition may occur in a few months’ time or it may take several years. The timeframe is typically determined by the program phase, the engineer’s career goals and the opportunities available to them for new assignments. Eventually they may move on to work within the development phases on the left-hand side of the V, on a new program, or even to a new business unit to lead a requirements development effort or contribute to an architectural design. As the engineer takes on new assignments, the experience aids in the development and broadening of their domain knowledge in areas such as cyber, radar or lasers. One of the keys to a person’s technical breadth is to have experiences in all phases of the V and if possible, to follow a single program from start to finish, i.e., through all phases of the V.

Career growth, no matter the path, is not a static endeavor and no one size fits all. An engineer desiring experience at different points along the V can attain this experience by working on different programs at different times and at different levels of support. Although it takes time to attain a level of experience in all areas, each assignment offers new challenges, opportunities for growth, and its own rewards.

*Nora Tgavalekos, Ph.D.*

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**AS THE ENGINEER TAKES ON NEW ASSIGNMENTS, THE EXPERIENCE AIDS IN THE DEVELOPMENT AND BROADENING OF THEIR DOMAIN KNOWLEDGE IN AREAS SUCH AS CYBER, RADAR OR LASERS.**
On Veterans Day 2014, Raytheon Veterans (RAYVETS) became the ninth Employee Resource Group (ERG) within Raytheon. The RAYVETS vision is to be a best-in-class global employee network, operating as a strategic business partner and fostering employee success in an inclusive, engaged culture. RAYVETS mission includes energizing employees to support business objectives, growth and innovation across the company; attracting, retaining, and developing employees; and sustaining community connections.

COLLABORATION
Raytheon ERGs create many opportunities for collaboration with other ERGs and the community. RAYVETS has nurtured an alliance with Raytheon Persons with DisAbilities (RPDA) (renamed in 2016 to the Raytheon Alliance for Diverse Abilities [RADA]) in seeking jointly sponsored projects and events which will benefit group members across the company. For instance, recently, RDPA South reached out to RAYVETS to assist with the Disability Awareness Seminar held at the University of Texas in Dallas. In addition to donation towards the cost of the event, several RAYVETS members attended and supported the event. The purpose of the seminar was to educate students and local businesses on the advantages and challenges of employing individuals with disabilities. Speakers included Emanuel Brady and Gary Lamont from Raytheon as well as members of the Student Veterans Association, with which RAYVETS maintains close collaboration.

Another example of partnerships was when RAYVETS East partnered with Raytheon Black Employees Network (RAYBEN) and Strayer University Alumni in the Susan G. Komen Race for the Cure event. RAYVETS Northeast supported the Hispanic Organization for Leadership Advancement (HOLA) Northeast golf tournament, assisting with setup and execution of the annual event that raised more than $10,000 for local charitable veteran’s organizations. RAYVETS Northeast chapter also provided the key note speaker for the Raytheon Global Business Services (GBS) IT team-building building cookout to discuss RAYVETS and the importance of company collaboration. Between the GBS-IT raffle and donations, this event raised $4,000 for the Wounded Warrior Project®.

EMPLOYEE INVOLVEMENT
RAYVETS membership includes both veterans and civilian employees who are passionate about serving Raytheon’s customer, the warfighter. At the time RAYVETS was becoming an ERG, a corporatewide transformation was underway for all Raytheon ERGs to expand Global Growth and innovation; enabling and aligning the ERGs to better support business objectives. This new focus also stimulated and promoted partnering and collaboration among the different ERGs, strengthening their capabilities and providing a broader resource to enterprise and business leaders. Through the transformation, RAYVETS’ reach has increased significantly from what was once predominately a grassroots effort, largely concentrated on the East Coast. At its creation as an ERG in 2014, RAYVETS had just slightly more than 700 members — and today that number exceeds 3,000 members across the company.

Our warfighters are the next generation of veterans. RAYVETS acts as the consistent and coherent source of support within Raytheon for veterans and currently active employees, and their families. It
promotes the veteran’s identity within the company and fosters a community to share information — increasing the awareness of both issues and opportunities influencing veteran’s lives. RAYVETS proactively collaborates with, and supports the missions of all Raytheon ERGs in creating and leveraging a common approach and process for efficiency in activities.

GLOBAL GROWTH
While RAYVETS supports all four pillars of ERG activity (recruitment, retention, employee development and community outreach), the group’s key discriminator is in the ability to influence domestic and international business growth through the voice of the veteran. RAYVETS inclusive approach utilizes the institutional and product knowledge brought to Raytheon by its veteran population — an advantage to both products and services which also promotes Raytheon’s continuing leadership in diversity.

Members across the company are actively engaged in developing the Veteran Workforce Management database to keep veteran’s unique capabilities available to support global business growth. Used by the Business Development community, the database allows strategic positioning of subject matter experts, knowledgeable from an operator vantage point, to participate across all phases of a program — business development, capture, execution and sustainment.

RAYVETS supports both community outreach efforts and Raytheon’s commitment to the science, technology, engineering and math (STEM) programs. An example is the Boys and Girls Clubs of America (BGCA) where RAYVETS provides members

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Raytheon employees participate in the RED SHIRT FRIDAYS campaign, showing their support for Remember Everyone Deployed (RED).
to assist with the set up and operation of five pilot STEM centers at BGCA locations serving families stationed at American military bases.

The group also plays a key role in Memorial Day and Veterans Day activities, coordinating companywide memorials, arranging for speakers and setting up meals to honor veterans working at Raytheon — providing consistency across the country in message and celebration. RAYVETS is specifically tasked to work with company leaders in providing manpower and support to the Wounded Warrior Project, the Student Veterans of America and the American Corporate Partners. Raytheon’s Operation Phoenix has formed an alliance with RAYVETS to assist in transitioning veterans from military life into civilian life as part of recruitment within Raytheon.

Raytheon’s annual “Week of Service” event encourages employee participation, across all Raytheon businesses, in local events that support Raytheon’s commitment to the armed services. In 2015 RAYVETS South kicked off a RED (Remember Everyone Deployed) Fridays campaign that was so successful, within six months it was chosen for the grand finale of the Week of Service global activities.

**INNOVATION**

The annual Raytheon Innovation challenge is an interactive opportunity for employees to develop innovative technology ideas. It is a forum to nurture novel solutions to emerging technological needs across a broad range of topics. RAYVETS Northeast members with current military operational experience from each of the branches attend these conferences and engage directly with the innovators to help bridge the gap between idea and operational fit. It is critical for innovators to work directly with those having expert operational perspective in order to ensure customer vetting of innovative ideas and concepts early on and to provide the most relevant technologies to those that support and defend our country.

RAYVETS Northeast recently partnered with Raytheon’s Advanced Technology and Innovation Supply Chain in sponsoring a table at the NDIA (National Defense Industrial Association) New England
Chapter’s Natick Soldier Research, Development and Engineering Center (NSRDEC) Industry Day. The event provided direct interaction with NSRDEC and U.S. Army Research and Development and Engineering Command (RDECOM) customers, stimulating research and development as well as new business opportunities. It also provided an environment to interact with New England universities and small businesses for potential new partnerships. Ultimately, this activity led directly to multiple new veteran owned small business collaborative relationships and partnerships with IDS Innovation Supply Chain and the Advanced Technology business area.

Finally, RAYVETS has had a number of opportunities to innovate internal Raytheon processes and projects. A recent example is when the group was called upon to assist with a substance abuse reporting program for international Raytheon employees. The cross-business team responsible for the activity was aware of a similar U.S. Army program called the “Army Substance Abuse Program” (ASAP), but was unable to find additional details on its implementation. RAYVETS was able to quickly identify a group of Raytheon personnel across the company who had participated in the program including individuals who were in charge of administering tests; others who had participated in the testing process; and some who commanded units responsible for testing schedules and selection criteria. The feedback from this group provided valuable insight which could be used in creating Raytheon’s international program.

More than half of RAYVETS members are prior active duty military, providing a pool of expertise that understands the needs of the warfighter and how Raytheon products and services can best support them. RAYVETS commitment to increasing the visibility and contributions of Raytheon veterans reinforces the company’s goal of being the veteran’s employer of choice; boosts both employee recruitment and retention; and optimizes Competitive Advantage as the warfighter’s preferred solution.

Anne Wavra
Wally Massenburg
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 (IP). Once again, the U.S. Patent Office has recognized our engineers and technologists for their contributions in their fields of interest. We congratulate our inventors who were awarded patents from January through December 2015.

**MAURICE J. HALMOS**
Using multiple waveforms from a coherent LADAR for target acquisition
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