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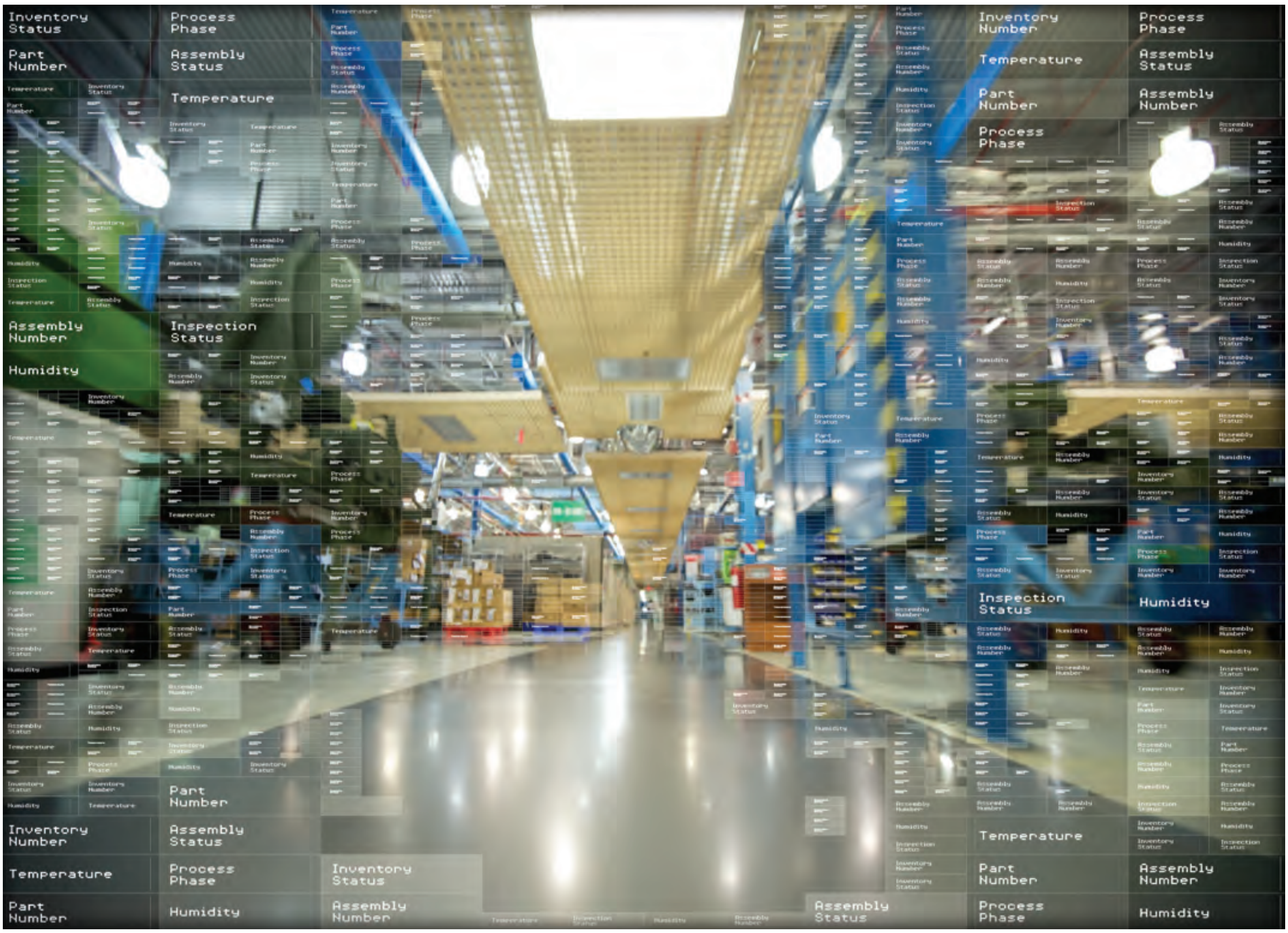
TECHNOLOGY TODAY

Highlighting Raytheon's Engineering & Technology Innovations



SPOTLIGHT

INNOVATION IN OPERATIONS

ADVANCEMENTS IN METHODS, SYSTEMS AND PROCESSES

EYE ON TECHNOLOGY

NEW MIRROR TECHNOLOGIES

Supporting Raytheon's advanced electro-optical and infrared systems

PEOPLE

GLASSBLOWING IS IN THE GENES

Second-generation glassblower Konrad Gleissner applies his craft to next-generation solutions

Raytheon

TECHNOLOGY TODAY

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ON THE COVER
Data visualization (artist's depiction)
of measurements that empower
factory optimization

A MESSAGE FROM
MARK E. RUSSELL

VICE PRESIDENT OF ENGINEERING, TECHNOLOGY AND MISSION ASSURANCE

Operations no longer begins and ends in the factory. Across the aerospace, defense and commercial industries, the fourth industrial revolution is expanding the focus of manufacturing technology and techniques from design to delivery. Raytheon Operations is embracing this transformation, introducing the strategies and innovations that will help shape the future of how we bring advanced solutions and capabilities to our customers.

Today, our product designs optimize automated build and assembly processes and take advantage of robotics, additive manufacturing and other advanced and emerging technologies. Model Based Engineering in combination with the Digital Thread and Internet of Things is helping Raytheon maintain full product lifecycle accounting of our systems; from initial design through development, manufacturing, test and fielding. This information also supplies Machine Learning algorithms that provide prognostics for proactive sustainment and for data analytics used to improve product quality and manufacturability. Driving these technologies and processes is fundamentally a lean operations approach, incorporating collaborative and agile methods that maximize efficiency and reliability and deliver cost-effective solutions.

This edition of *Technology Today* presents Innovation in Operations, the many innovative advancements in methods, systems and processes comprising Raytheon's operations. Our spotlight introduction includes a discussion of Industry 4.0 and the importance of introducing new technologies and cybersecurity to the next generation of advanced manufacturing systems. The feature articles include topics from Design for Manufacturing and Assembly to sustainability in our factories and buildings. We highlight key technologies such as additive manufacturing and augmented reality and show how collaborative robots work side by side with technicians and operators in the factory.

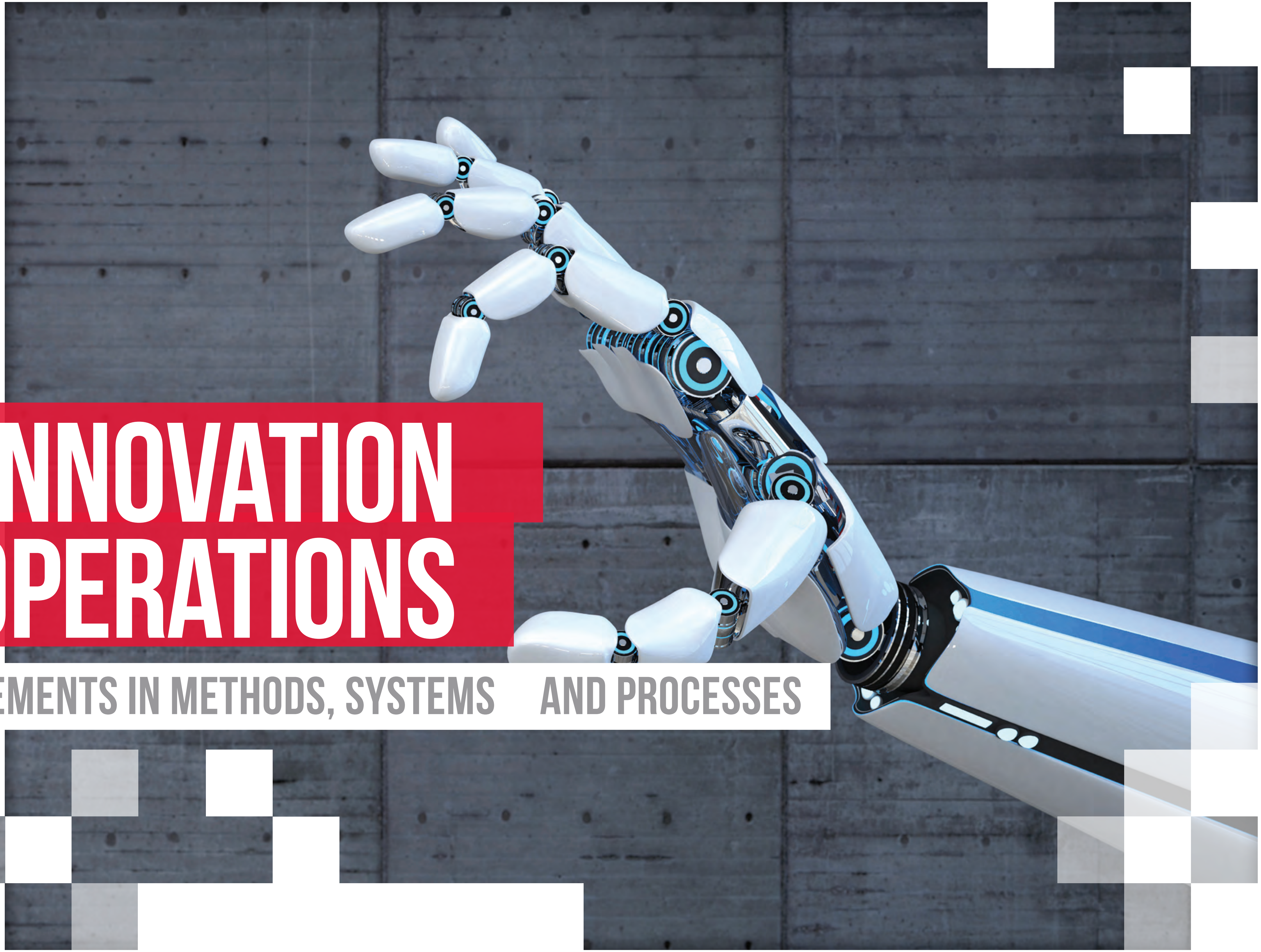
In our Leaders Corner, we talk to members of the Raytheon Operations Council about the current manufacturing revolution, collaboration across the company and how Raytheon is using advanced technologies and innovation to meet tomorrow's production demands.

Electro-optical and infrared (EO/IR) devices play a key role on many sensor platforms that are critical to our customers' mission success. Mirrors are an important component in many of these devices. The Eye on Technology article discusses two recent Raytheon advances in the areas of fast steering mirrors and ultralight metallic mirrors. Both promise increased capabilities for EO/IR systems and applications. Finally, in our special interest section we highlight Konrad Gleissner, a glassblower, who has a unique role and special legacy in the development of Raytheon's IR sensor components.

Mark E. Russell

SPOTLIGHT

INNOVATION IN OPERATIONS: ADVANCEMENTS IN METHODS, SYSTEMS AND PROCESSES



INNOVATION IN OPERATIONS

ADVANCEMENTS IN METHODS, SYSTEMS AND PROCESSES

Manufacturing operations at Raytheon has an "innovation" focused mindset, realized in the many activities and initiatives, including agile and lean methodologies and factory continuous improvement projects, that result in increased efficiencies, improved quality and reduced costs. These projects and initiatives often depend on the creation and/or application of advanced manufacturing techniques and technologies.

Part of being an industry leader in manufacturing is the ability to deliver quality products, on time, at competitive costs and in a safe environment. It means not just keeping up with industry trends but setting them, through innovation and staying on the forefront of manufacturing technology and its application.

TECHNOLOGY PLAYS A CRITICAL ROLE IN MANUFACTURING AND THE ABILITY TO PRODUCE QUALITY, COST-EFFECTIVE PRODUCTS ON TIME IN A SAFE AND EFFICIENT ENVIRONMENT

Innovation solves current and future problems. It can come anywhere in the value chain, from associates assembling products in the factory to manufacturing engineers implementing processes and tooling for the production floor. A key component in this vision is the Raytheon Six Sigma™ (R6s™) program, a business strategy supporting company mission and goals. While traditional Six Sigma focuses on statistical methods to identify causes of variation and eliminate defects, the R6s program extends the process to include Lean objectives (e.g. eliminating waste to increase throughput and reduce costs) and a 'total system' approach to eliminating bottlenecks that contributes to overall operational improvement. R6s provides value across the enterprise from manufacturing to business development, and extends to supplier and customer communities as well. It adapts to changing business needs and empowers every employee to deliver impactful and far reaching improvements that support business growth.

In addition to R6s, Raytheon employees are provided other avenues for innovation ranging from basic crowdsourcing tools to corporatewide programs that present innovation challenges and solicit new technological ideas and methodologies. These activities are designed to create opportunities for everything from problem solutions to operational improvements to solving critical customer mission needs. In the broader scope, resources are geared toward ideas that are either entrepreneurial in nature, define new process methods or require initial study/proving prior to Independent Research and Development (IRAD) or Contract Research and Development (CRAD) funding. The intent is to quickly provide innovators the initial support needed to refine their ideas for a follow-on funded activity.

There are multiple business areas within Raytheon continually innovating and solving problems. While the development of a new methodology or resolution of a problem in a specific organization is good, being able to utilize new ideas throughout the company is even better.

Raytheon created Technology Networks, a collaborative organizational infrastructure designed around individual technology areas, to facilitate enterprisewide communication and promote technology sharing. The networks include technology workshops and interest groups as well as internal technology focused symposia. While strengthening contributions to programs and Businesses, the Technology Networks provide employees opportunities to engage and share knowledge with colleagues having similar technology interests across the enterprise.

Technology plays a critical role in manufacturing and the ability to produce quality, cost-effective products on time in a safe and efficient environment. It is also a driving influence on the fourth industrial revolution, or digital transformation known as Industry 4.0 (See inset). In 2012, Raytheon created the Manufacturing Technology Network (MfgTN). With a focus on the development, optimization and proliferation of advanced manufacturing technologies, the MfgTN facilitates communication between all technical disciplines that support manufacturing across the enterprise. It promotes cost and risk reduction through common manufacturing methods, creates avenues for manufacturing technology transfer among business segments and fosters technical communication through Technology Interest Group (TIG) meetings and a biennial Manufacturing Technology Symposium.

Raytheon has implemented many advanced manufacturing methods and processes, incorporating state of the art technologies such as robotics, machine vision, remote sensors, data analytics and machine learning. These process improvements have resulted in cycle time reductions, cost savings and increased quality. Tremendous benefits have also been realized in designing new products for manufacturing that take full advantage of process capabilities such as common factory test platforms and fully automated assembly cells.

Many of Raytheon's innovative manufacturing solutions create intellectual property in the development of quality, cost-effective solutions. Raytheon also works closely with academia, standards bodies and consortia, such as the Manufacturing USA® Institutes, to effect improvements to industry standard processes and practices on a more general level. These technology contributions are shared for the betterment of the US defense industrial base and to accelerate advanced manufacturing in the United States.

Manufacturing USA, originally known as the National Network for Manufacturing Innovation, is a group of research institutes in the United States that focuses on creating and commercializing advanced manufacturing technologies. Manufacturing USA comprises multiple institutes covering areas such as electronics, additive manufacturing,

INDUSTRY 4.0

INDUSTRY 4.0 IS A TERM COMMONLY USED TO DESCRIBE THE 4TH INDUSTRIAL REVOLUTION IN MANUFACTURING, DEFINED LARGELY BY THE EXPONENTIAL PROLIFERATION OF DATA PROCESSING POWER, DIGITAL CONNECTIVITY (OR INTERNET OF THINGS), AND HIGHLY ACCESSIBLE AUTOMATION, CREATING AN EVENTUAL INTEGRATED "CYBER-PHYSICAL" MANUFACTURING ENTERPRISE.

Raytheon is harnessing the power of this 4th industrial revolution, in combination with lean manufacturing, to change the way aerospace and defense products are manufactured, delivered and maintained. Raytheon has utilized the power of industrial and manufacturing engineering analysis to drive selective automation in high mix, low volume environments, using digital manufacturing simulation, immersive design, design for assembly and automation, and recent advancements in robotics and collaborative automation. The Smart Factory allows Raytheon to provide products at an affordable cost and level of mission assurance unattainable in previous generations.

Comprising the fabric of Smart Manufacturing is the convergence of cyber (digital) systems and physical systems, along with the convergence of traditional Information Technology (business systems) and Operational Technology (manufacturing/processing systems), augmented by the Internet of Things (IoT). These terms, once relegated to niche academic and hallway conversations, have become mainstream in aerospace and defense manufacturing. IoT is the interconnectivity of devices and systems that comprise the backbone of operations and manufacturing methods, processes and products. As the total number of connected entities increases, the capabilities enabled through information exchange alone are monumental. "Digital Thread" is a broad concept that embraces this evolution. As an enabler of Industry 4.0, the Digital Thread provides a seamless bi-directional flow of digital product information from the engineering Technical Data Package to manufacturing process systems to diagnostic, test and maintenance subcomponents in the field.

Many other technologies comprise this digital transformation and are helping to weave the fabric of the Smart Factory. Robotics, both traditional and collaborative; additive manufacturing; smart operator workstations with light guided works instructions and automated data collection; digital passive auto-ID of material, assets and products; and smart building systems providing digital telemetry of building conditions and prognostics, are all examples of manufacturing advancements providing both individual capability and contribution to the digital thread.

With the advent of Industry 4.0 and the digital age comes the emergence of new threats from both nation and non-nation state actors. Digital systems are under constant exploit attempts, and manufacturing systems are no exception. Raytheon has deep expertise in both commercial and U.S. Government cybersecurity, which is used to secure our systems and factories. These practices, which include human and digital elements, are a top priority for Raytheon, and are critical to national security and both the Aerospace and Defense Manufacturing industries.

Along with the benefits technology brings to manufacturing, transition to the Smart Factory must also account for the most important resource in manufacturing — people. Raytheon maintains a robust Lean and six sigma philosophy in its digital transformation. Employing automation and Smart Factory techniques creates a smarter, more efficient, and safer environment for our workforce. *— Kelly Dodds*

Raytheon small satellite assembly lines use robotics to increase reliability and decrease cost

textiles, robotics and biopharmaceuticals. Raytheon is a member of several of these institutes, working with both academic and industry partners in areas such as multidisciplinary design analysis, solutions for lifecycle feedback for legacy manufacturing, additive manufacturing and high dynamic range RF photonics. One recent activity, through the Advanced Robotics for Manufacturing Institute in partnership with the Massachusetts Institute of Technology, is to advance the use of collaborative robotics (cobots) in manufacturing to improve the assembly and integration of wire harnesses into electrical cabinets.

Raytheon also works directly with academic institutions, developing new and innovative processes, materials and technologies, and the methods to effectively and efficiently transition them to the factory. For example, the "Raytheon at Kostas Research Institute," in partnership with Northeastern University, is speeding the development of research into new technological capabilities in additive manufacturing, artificial intelligence, thermal management, magnetics and nanotechnology. The Raytheon UMass Lowell Research Institute (RURI) continues to advance capabilities in additive manufacturing of RF components and assemblies. And collaboration with Arizona State University Polytechnic Campus is refining the university's Manufacturing Engineering degree curriculum to ensure technical support needs are met on future factory floors.

IN THIS EDITION

Raytheon has a long history of bringing innovation to the defense manufacturing industry. In this "Innovation in Operations" edition of *Technology Today* we present a series of feature articles highlighting many of the key areas in which we continue this tradition of advancing manufacturing's state of the art.

Design for Manufacturing and Assembly (DFMA®) has enabled automation advancements (Figure 1), reduced design cycle time and improved producibility. With Sustainment (DFMA/S), it is a methodology that considers cost minimization throughout a product's lifecycle. In Maria Spalt and Mark Steudel's "Design for Manufacturing and Assembly with Sustainment throughout the Product Lifecycle," we explore the significant benefits of DFMA/S methods and practices, particularly when initiated early in a product's design cycle.

In many ways, robotics highlight Raytheon's implementation of the Smart Factory (Figure 2). From a product's Design for Automation engagements to logistics enhancements on the factory floor, robotic technology is advancing the fundamentals of our manufacturing capabilities. Kristen Stone, David Miceli, Jayson Diaz and Blair Simons have authored "Robotics in the Factory" to showcase how robots are a key player in the development, optimization and proliferation of advanced manufacturing technologies across the company.

Whether combining the real world with the virtual or a manual operation with digital content (Figure 3), augmented reality (AR) is helping Raytheon reduce total costs and improve the quality of how we develop, manufacture and maintain technologically advanced products. In the "Augmented Reality: Into the Factory and Beyond" feature article by Keith Janasak, John Cogliandro, Brent Dingle, Adam Feccia and Kristen Stone, the capabilities and benefits of AR are presented through examples of immersive design, projected work instruction and remote collaboration and maintenance.

The additive manufacturing initiative was established to accelerate the adoption of AM throughout Raytheon's product family. From prototype development to production, through investments in People, Process, Tools and Technology, this focused activity creates key discriminators for new products and efficiencies for growth. Figure 4 is a photo of the laser powder bed fusion process; one of the effort's primary focus areas. In "Additive Manufacturing: Stepping into the Future," Leah Hull, Travis Mayberry and Brian Gahan discuss the technical aspects and provide examples

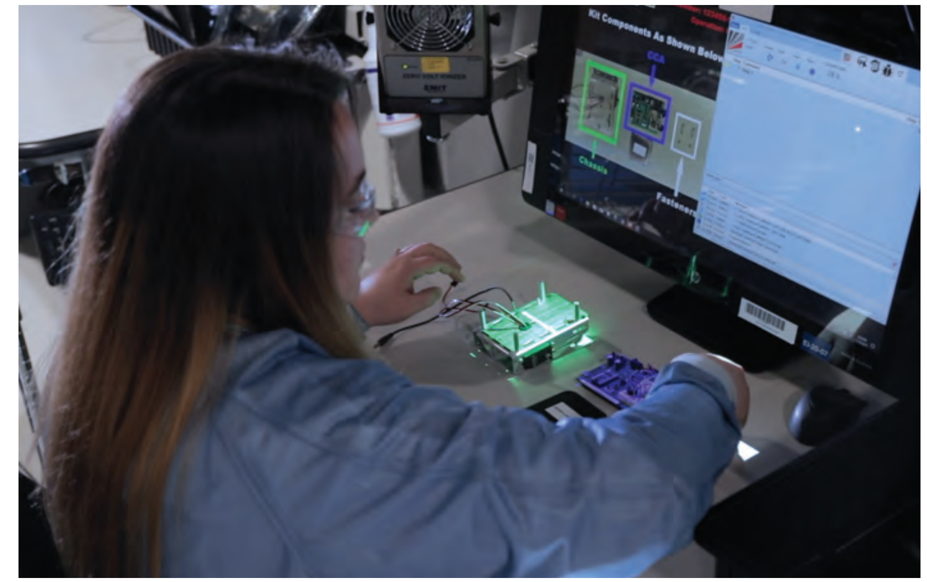


Figure 1: Automated optical inspection of a printed circuit component

Figure 2: A fist bump with a collaborative robot (cobot) on the factory floor

Chad Spalt
Raytheon Missile Systems

Chad Spalt is an Engineering Fellow for Raytheon Missile Systems. With over 16 years of experience with the company, he is currently a member of Manufacturing Operations with a focus on advanced manufacturing and innovation. Spalt was the first corporate Technology Area Director for Manufacturing. He led the creation of the Manufacturing Technology Network (MfgTN), execution of the first Raytheon Manufacturing Technology Symposium and now serves as the corporate MTN Champion.

"Getting new products out to the customer quickly and cost effectively is both important and exciting," Spalt relates. Prior to his current work, Spalt led the creation and execution of the Operations New Product Introduction (NPI) department at RMS, during which time the group developed and released a process that ensures the execution of critical manufacturing tasks during all phases of product development. "Ensuring that we are utilizing the appropriate state of the art manufacturing processes helps to achieve this," he continues. "Being certain that our new product designs take full advantage of our manufacturing capabilities is imperative."

Spalt has over 32 years of experience in manufacturing, working with both military and commercial products. His career has focused on promoting the producibility and the transition to production of newly developed products, as well as the creation of robust, technically advanced manufacturing processes.

"I have always loved to design and build things," Spalt emphasizes. "With my home being in Manufacturing, my career has focused on being the liaison between the design community and the factory. Designing a new product for manufacturing is critical when trying to control recurring cost, quality and cycle time," Spalt concludes. "A predictable product design entering production transitions quickly and with little variation and unanticipated costs."

Spalt holds two patents, he has presented numerous papers at Raytheon symposia, and he was a contributing author to the publication, Space Mission Analysis and Design, 3rd Edition. He received a Bachelor of Science degree in Mechanical Engineering Technology from Southern Illinois University and a Master of Science degree in Industrial Engineering from Arizona State University.

Figure 3: Augmented Reality wearables are beginning to replace computers and monitors in the warehouse and on the factory floor (top). Artist's Rendition – Through AR, a torque gauge is projected in the technician's visible work area (bottom)

Figure 4: Additive manufacturing of metals using a laser powder bed fusion process

of how AM is helping to bring more cost-effective solutions and advanced capabilities to our customer.

Raytheon's unique approach to the digital transformation embodies the company's implementation of the Digital Thread. Creating assimilated knowledge assets, empowering program acceleration, and enabling model based technologies are just a few of the objectives in this activity. Dave Slader, Greg Piper and Ron Williamson explain in "Digital Thread Initiative: Unlocking Business Value for Raytheon" how emerging technologies are helping to link key pieces of information across the full product lifecycle to create a "connective tissue" within the context of the deliverable product.

Sustainability in Raytheon's products extends to efforts to engineer a sustainable future through environmental stewardship and the preservation of natural resources at our facilities (Figure 5). The sustainability principles are enterprisewide and influence every aspect of our company. In "Sustainability in Raytheon Factories and Buildings," Nicole Sweeney discusses how integrating sustainability throughout our operations drives an innovative approach to problem-solving that yields solutions with co-benefits to both the environment and the business (Figure 6).

Figure 5: Unique Xeriscape™ using native, drought-tolerant and low water-use vegetation at the Raytheon Tucson site

Figure 6: Solar panels at Raytheon's Tucson facility supplement energy for both lighting and hot water

In both communication and practice, from improvement to existing operations (yield, reliability, cost, automation, etc.) to transitioning new/enabling design technologies to large scale operations, Raytheon fosters innovation throughout the company. Whether internal or through partnerships with academia and industry, Raytheon will continue to focus on advancements in technology and processes that bring added value to both customers and the defense manufacturing industry. ■

— Chad Spalt & Charles Barbour

Charles W. Barbour II
Corporate Technology and Research

Charles W. Barbour II is the Manufacturing Technology Area Director for Corporate Technology and Research with 11 years of experience at Raytheon Company. In this position, Barbour supports companywide collaboration and innovation activities in the manufacturing technical area.

"Our customers' missions require well-built, reliable hardware," Barbour states. "Specifications can change, but that demand remains, and the speed by which we can get products to the customer helps drive those missions to success. In my current role, I am able to enhance our capabilities by supporting the implementation and deployment of advanced manufacturing technologies and techniques across the company."

Prior to his current role, Barbour was a manufacturing lead responsible for managing cost and schedule as well as build/production tasking for multiple internal and customer funded programs in areas such as repair and overhaul, surveillance, communication, transportation and aircraft armament. These programs often included manufacturing readiness level assessments, Design for Manufacturing and Assembly engagements, and in several cases, support for incorporating additive manufacturing to enhance productivity in the production cycle.

"I'm really interested in how products are made," Barbour states, "as well as being a part of making them better, faster and more cost effective. I got involved in my current discipline as a way to better understand how designs are converted into reality, to be an active part of the process, and to ensure that, as designers, we are aware of the physical realities of making a product."

Barbour began his career at Raytheon as a member of the Engineering Leadership Development Program where he rotated through multiple assignments and locations, including Operations, Systems Engineering and Software Engineering. His areas of interest include additive manufacturing, manufacturing and process automation, and applications of artificial intelligence and machine learning.

"I also enjoy traveling," Barbour continues. "Having been to various parts of the United States and the world has enhanced my technical and business skill sets. It has led me to consider problems from many angles and other points of view, which then leads to more diverse solutions."

Barbour received a bachelor's degree in Aerospace Engineering from the University of Cincinnati and a master's degree in Aerospace Engineering from the University of Michigan.

FEATURE

ADDITIVE MANUFACTURING: STEPPING INTO THE FUTURE

Additive manufacturing (AM), also known as 3D printing, is a cutting edge technology that creates a physical product by adding material layer by layer according to its digital representation read from data stored in a CAD (Computer Aided Design) file. There are several advantages to utilizing this manufacturing method over conventional subtractive methods, which remove material using a cutting tool or laser. One advantage is speed to market. AM can deliver in days, products that would normally take weeks or months if manufactured conventionally. Another is the ability to create more complex configurations with lighter weights, resulting in superior performance characteristics. Also, the shorter cycle times and lower part counts achievable with AM can lead to lower product cost.

ADDITIVE MANUFACTURING:
STEPPING INTO THE FUTURE

FEATURE

ADDITIVE MANUFACTURING

The integration of additive manufacturing at Raytheon is an enterprisewide transformation focused on advancing AM across the company, from a research application to a customer product solution. Creating the processes and infrastructure to advance a new technology from prototype development to qualified production is foundational to the COE mission—examining the entire product lifecycle as it relates to AM. Utilizing AM involves implementing new design philosophies, investing in manufacturing capabilities, creating and understanding the materials database, and developing robust product qualification plans.

Historically, the hardware design community utilized AM for prototype development, shortening the cycles of learning. For example, by printing a piece of a design in days, an engineer is able to test within a short timeframe and receive instant feedback on the overall design. AM in rapid prototyping allows for more design spins during development and the opportunity for engineers to create better designs. However, making the leap from prototype to production hardware requires a new approach.

AM as a production technology is not just an investment in capital or technology, it is also an investment in the culture and processes of an organization. Organizing for innovation can be as important as the innovation itself. Raytheon has maintained a strategic focus on people, processes, tools and capital while taking a holistic approach from product selection to design, manufacturing, qualification and inspection.

Designing for AM includes a different philosophy and approach. Mechanical hardware designers are generally taught to design for conventional manufacturing techniques, such as computer numerical control (CNC) machining, brazing, welding, forging and casting. In AM, however, conventional rules no longer apply and designers must have both different skills and tools. Also, the enhanced complexity available with AM creates new frontiers in the design space. For example, the breadth and types of producible features are greater than those provided in conventional manufacturing designs, and the dimensioning and tolerance methods used are different from those to which conventional design engineers are accustomed. These differences lead to an emerging need for an infrastructure that deploys new design guidance and training, along with associated modeling and analysis tools. Raytheon is meeting that need with both enterprisewide training on AM and program centric groups that hold deep dive workshops, conduct design reviews and assess the fit of hardware and systems for AM solutions.

Figure 1a: The Radial Heat Sink, prior to removal from the Laser Powder Bed Fusion (L-PBF) machine

Figure 1b: The Printed Aluminum Radial Heat Sink

Equally important to engineering design expertise, manufacturing infrastructure plays an integral role in a company's AM capability. Careful consideration must be given to the size, process type, and functionality of additive equipment. Many different processes exist in this space, utilizing metal, polymers, ceramics and electronics components.

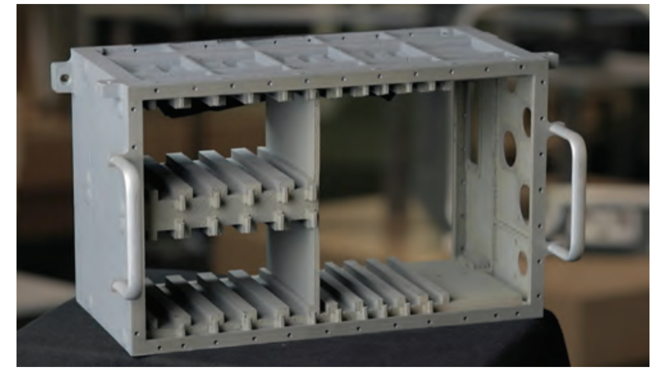


Figure 2: The Printed Liquid Flow Thru Electronics Chassis

AM processes require significant amounts of development, not only in the process parameters (layer thickness, power, etc.), but also in the materials themselves. AM provides the opportunity for designers to build complex, lightweight products, but the materials do not have the empirical data that traditionally manufactured materials (e.g. cast and wrought metals) have obtained through the years. An entirely new materials qualification framework, therefore, is required to certify and qualify these materials. In addition to material datasets, product qualification plans need re-examination to make sure they are aligned with new manufacturing methods. A key individual in this framework is an appointed Materials Lead, whose responsibility it is to establish an architecture to assess both the need for materials and the qualification standards required. Characterizing and qualifying additively manufactured materials decreases risk and increases utilization of the technology within programs.

A prime example of AM is its use in the manufacturing of heat sinks. Shown in figures 1a and 1b is an aluminum radial heat sink for a CO_2 (Carbon Dioxide) canister used in an evaporative cooling system. The design team chose AM on this project for a better performing part compared to a similar heat sink manufactured with traditional methods. AM also provided a shorter lead time helping to meet key project deadlines.

The Liquid Flow Thru Electronics Chassis[1] shown in figure 2 is another example of an AM application developed by Raytheon to leverage the benefits that AM provides. Typical liquid cooled chassis are manufactured through a brazing and machining process where each wall is made separately. Designing the chassis for AM reduced the lead time and allowed the entire chassis to be built as one piece, significantly reducing part count and eliminating leakage between parts. Additionally, the flexibility that AM offers allows the thermal paths to be optimized within the chassis to improve heat transfer.

Beyond the heat sink and chassis, Raytheon envisions other opportunities for leveraging AM technology, whether through thermal solutions, lightweighting of airborne product, printed electronics or large scale additive. The corporatewide AM initiative is helping to advance the maturity of additive in Raytheon—taking design, production and quality systems into tomorrow, and providing more cost-effective solutions and advanced capabilities for our customers. ■

— Leah Hull, Travis Mayberry & Brian Gahan

[1] Monolithic multimodule electronics chassis with multi-planar embedded fluid cooling channels (US Patent Number 9468131)

Leah Battle Hull
Raytheon Missile Systems

Leah Battle Hull leads the enterprisewide Additive Manufacturing initiative, a focus group responsible for developing the technology infrastructure to support AM development throughout the company. In addition to overseeing the day-to-day activities of the team, Hull serves as the general subject matter expert and advocate for AM technology, supporting proposals, training of personnel and creation of AM strategy.

Hull was introduced to additive manufacturing by chance. "I was asked to look into the viability of metals additive manufacturing for Raytheon," she states. "I had a unique skill set of metallurgy, operations experience and strategy experience that made this assignment a natural fit."

When asked how AM supports Raytheon customer missions, Hull explains: "Additive manufacturing is an exciting technology, and there have been groundbreaking demonstrations of its capability. The AM initiative is adding the infrastructure to this technology to make it production-ready and available for all programs considering AM. This leads to a new understanding of not just how to manufacture product, but how Raytheon designs and develops hardware solutions."

Hull has more than 17 years of experience with Raytheon. In addition to her AM responsibilities, she has worked as a Metallurgist in Process Engineering and as a Value Stream Manager for Raytheon Precision Manufacturing. She has further diversified her experience through cross-functional rotations in areas such as Hardware Engineering, Business Strategy and Human Resources. "Cross functional rotations forced me out of my comfort zone and gave me the confidence to excel," Hull admits. "Through technical symposia, leadership development programs, mentors and day-to-day interactions, I was able to build a large and diverse network over the years. I love being on the forefront of new technology and applying that technology to help our company make things more efficiently, and to be more competitive for tomorrow's challenges."

In considering what advice she might have for engineers beginning their careers, Hull offers: "Do the small things well and they will lead to bigger things. Take the 'stretch' assignments. And build your network by forging authentic connections with others."

Hull holds a bachelor's degree in Metallurgical Engineering from the University of Missouri-Rolla and an MBA from the University of Texas at Dallas. She is a graduate of the Engineering Leadership Development Program and a recipient of Raytheon's prestigious Excellence in Engineering and Technology (EiET) award.

FEATURE

AUGMENTED REALITY: INTO THE FACTORY AND BEYOND

Advanced Visualization Technology (AVT) has come a long way in the past 20 years, fueled by improvements in computer processing, Graphics Processing Units (GPU), micro optics, and the increasing availability of applications to support a growing set of use cases. Raytheon has made significant investment in the research and development of AVT capabilities to improve productivity and quality both in the factory and in the field. In this article we discuss various applications of AVT with a focus on Augmented Reality and present several examples of how Raytheon has taken advantage of these.

AUGMENTED REALITY:
INTO THE FACTORY
AND BEYOND

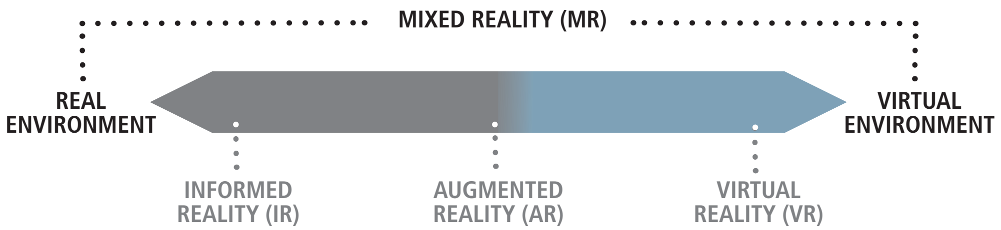


Figure 1: Virtuality Spectrum

AVT addresses multiple "realities," with Virtual Reality (VR) and Augmented Reality (AR) being the most widely referenced. Each reality is tied closely to its visualization technology, and each has its own strengths and weaknesses depending on the given application. Figure 1 represents how these realities can be considered as being on a continuous spectrum ranging between the real world and the virtual world. Specifically, Mixed Reality (MR) provides different amounts of spatially registered digital content overlaid onto views of the real world, and it handles real world occlusion of the content. Informed Reality (IR) provides non-spatially registered digital content overlaid onto views of the real world; AR provides spatially registered digital content overlaid onto views of the real world and VR places the user in an entirely virtual environment and occludes the real world. Note that IR and AR are very similar, differing mainly in whether information is locked down to a specific point of reference.

If you are a gamer or have seen visually stunning advertisements and media on TV or at the movies, odds are, you are familiar with today's nearly photo-realistic VR environments. The Entertainment Industry continues to mature the underlying AVT for creating and consuming MR based content, and companies like Raytheon stand to benefit from these advances. While VR leverages a synthetic totally immersive computer generated 3D environment, AR based applications leverage computer generated information overlaid onto the user's real world environment. Through closed visors or goggles, VR blocks out the user's current surroundings and transports him or her to another place. AR, however, takes current reality and adds information to it. It "augments" a user's current state of presence, often displayed on a smart phone, clear glasses or visor. While VR may be more in the gaming mainstream, AR is gaining momentum in supporting a growing set of business use cases. AR's ability to effectively provide hands-free information while maintaining the user's situational awareness is a critical attribute. AR helps facilitate the completion of a real world task and enables Raytheon to do business in an innovative and more cost effective manner.

AR Wearables (ARW) support a wide variety of use cases across a breadth of industries, from commercial to Aerospace and Defense. They are beginning to replace computers and monitors in warehouses and on the factory floor. Common examples of this include factory assembly guidance, inspection, test support, warehouse logistics, troubleshooting, training and field support. Mobile hands-free information and remote collaboration capabilities are enabling more efficient diagnosis and resolution of problems both in the factory and out in the field. Across industry, companies are realizing the benefits of implementing AR technology in everything from product assembly, diagnostics, test and inspection to remote technical support and customer product preview. ARW promote hands-free operation contributing to faster manufacturing cycle time, improved quality, and significant reductions in post deployment problem resolution and repair times.

BENEFIT	ASSOCIATED FUNCTION
Decreased Travel: Rapid, on demand support from technical experts	System Integration and Test, Training, Field Support
Increased Focus: Increased time on task and quality of work with less stress and fewer errors	Assembly, Test, Inspection
More Complete Information: On-demand access to latest technical documentation provides more accurate representation of task with decreased errors	Manual Assembly, Troubleshooting, Repair
Novel Understanding: Previously unattainable system/component views (i.e. As-Is / To-Be, magnified, cut away)	Training, Troubleshooting, Repair
Enhanced Collaboration: On-demand remote guidance, shared point of view across team, demonstration of complex posturing	Assembly, Test, Inspection
Situational Awareness: AR Wearables sensors/IoT, alert to emerging threats or safety hazards	Warehouse, Material Movement, Integration
Information Mobility: Eliminate need for computer and monitor, hands-free access to information, voice driven manufacturing execution system inputs	Assembly, Test, Inspection

Figure 2: Augmented Reality (AR) benefits and associated functions

At the recent Enterprise Wearable Technology Summit (EWTS 2018), the Gartner® Technology Hype Cycle was referenced multiple times in regard to the fast moving ARW industry. The Hype Cycle is a representation of a new technology's maturation based on the evaluation of its position in five key phases of a technology's lifecycle: Innovation Trigger; Peak of Inflated Expectations; Trough of Disillusionment; Slope of Enlightenment; and Plateau of Productivity. Based on demonstrated successes, Information Technology (IT) organizations at multiple companies are taking a leadership role in championing the push of ARW up the Slope of Enlightenment onto the Plateau of Productivity.[1] As with many innovative and disruptive technologies, however, the key to success in a company is to ensure delivery of business value.

MIXED REALITY APPLICATIONS AT RAYTHEON

Raytheon began evaluating AVT several years ago as a means to reduce total costs to develop, manufacture and support technologically advanced products. Since that time, many benefits of AVT have been appreciated through multiple integration, pilot and deployment efforts across the enterprise. Figure 2 describes some of the observed benefits and associated functions where these benefits are realized.

[1] https://www.gartner.com/en/research/methodologies/gartner-hype-cycle

With the maturation of cost-effective ARW technology, users now have hands-free access to information, checklists and instructions, along with on-demand technical support. Wearables provide real-time information while allowing the user to maintain focus on the physical environment. With the advent of smartglasses (ARW with onboard processing and communication), the next generation ARW spawns a more comfortable form factor with much greater capability. While ergonomic comfort and battery life remain high on the list of ARW challenges, AR based technologies have matured to where they are now being effectively used across Raytheon.

Raytheon personnel in the factory experience significant advantages from mobile, real-time, hands-free information. Opportunities in this area include material movement logistics, assembly, inspection and test. Projected Work Instructions (PWI) augment an assembler's reality by leveraging a vision system to detect hardware and project context sensitive step by step guidance onto a work surface. While PWI solutions come in many configurations for both small and large scale assembly, the implementation concept is the same. These systems can highlight specific locations to draw the assembler's attention to the proper assembly points and sequence. PWI based assembly has proven to be faster, with improved quality and significant savings over traditional assembly methods.

Furthering the information visualization advantage is the ability to go mobile and hands-free. Today's ARW smartglasses provide the comfort and capabilities to give factory floor personnel the information they need, when they need it, while maintaining attention to their assembly or inspection tasks. Figure 3 shows conceptually how ARW technology is being used today.

Many next generation smartglasses hold the promise of eliminating tethers to computing devices, increasing both mobility and safety. Similar AR Wearables are being used today at Raytheon in conjunction with Universal Serial Bus (USB) camera microscopes to enable remote supplier inspection. With just one person at the supplier utilizing this remote collaboration technology, the remainder of the inspection team can provide support as needed from the home location. For example, a Subject Matter Expert (SME) can capture video evidence of the inspection remotely, eliminating the cost of traveling to the supplier's location. Moving forward, Raytheon continues to work with customers who are interested in, and can take advantage of, remote inspection technologies.

Given the complexity of today's products and systems, even trained maintenance personnel may need help with troubleshooting and repair. AR based remote collaboration is a key enabler in this regard, connecting the remote worker with the appropriate SME, on-demand,

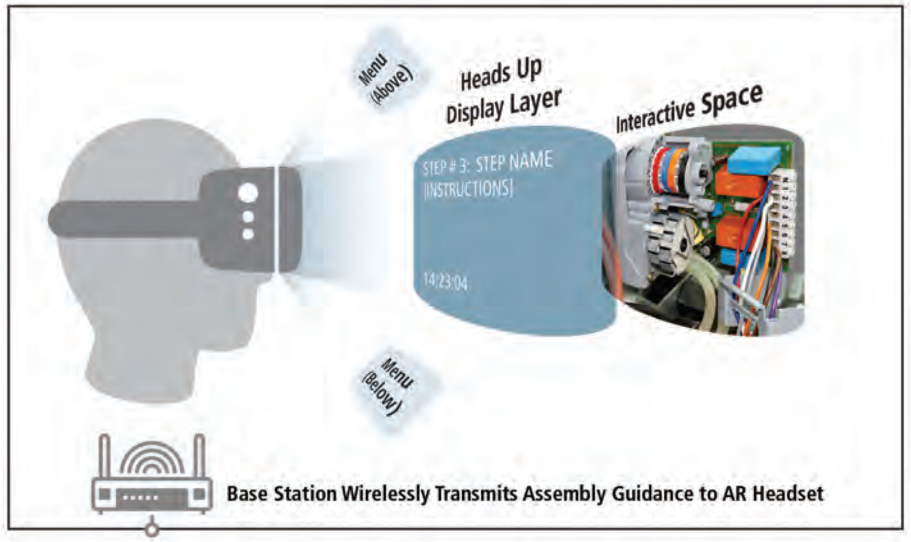


Figure 3: AR-based Wearables enable hands-free information display

utilizing the expertise required for rapid problem resolution. In this way, the SMEs are able to more effectively share a broad knowledge base when and where it is needed.

In the advancement of a remote maintenance capability, Raytheon has partnered with strategic AR hardware and software suppliers and leveraged Commercial Off The Shelf (COTS) technologies to create a secure AR based remote collaboration environment. The Remote Maintenance for Reduced Manning (RM2) capability is a platform agnostic, mobile, secure augmented reality based system that enables multi-user communication for remote collaboration. Figure 4 highlights examples of the RM2 system used internally between Raytheon factories and program engineering personnel, as well as externally with suppliers and customers. In application, a SME sees the remote system via a secure encrypted audio and video connection from the remote user's tablet or AR glasses. Their hands, posture, tools and parts are captured by a downward looking camera on the pointing pad, and the resulting image is projected back in a real-time AR overlay in the remote user's field of view. In this way, a SME can point or use telestration (superimposing a markup over the picture) to direct the remote user with 'ghost hands.' And the remote user is then able to place their hands in alignment with the SME to ensure correct hand posture and position.

The technology and CONOPS (concept of operations) of the RM2 augmented reality hardware and software environment are well established and provide a secure responsive collaborative infrastructure worldwide. It enables a broad spectrum of collaboration across the enterprise for many use cases, from repair and upgrade to training and inspection. The primary objective is to provide effective technical support communication between a remote user (depot or field) and subject matter expert. RM2 is helping programs significantly lower manning costs and improve responsiveness through reduced reliance on travel. It leverages SME time and resources to improve utilization of key intellectual assets, while helping new programs with remote maintenance needs. RM2 is also being deployed internally to Raytheon factories, providing internal and external customers with more timely, lower cost collaborative technical support across sites. RM2 helps to significantly cut travel costs while promising a positive impact on product availability.

[2] 9DOF IMU refers to a combined 3-axis accelerometer, 3-axis gyroscope and 3-axis magnetometer.

[3] https://www.gartner.com/en/research/methodologies/gartner-hype-cycle

CHALLENGES TO AR ADOPTION

While AR Wearable suppliers are still improving field of view, battery life and ergonomic fit, current ARW technology is viable for office and factory use. And while most devices are not rated for harsh physical environments, deployments into some austere and remote field locations are possible. Most companies, however, still face barriers to broad implementation. Today's AR smartglasses are wearable computers. They include a myriad of onboard sensors and networking technologies such as Wi-Fi, Bluetooth and GPS. Several versions are equipped with a variety of microphones, cameras for digital photos and video, thermal sensors and 9DOF (nine degrees of freedom) Inertial Measurement Units (IMU).[2] Users of these devices must understand and comply with Information Assurance policies that address operating systems; applications; security; software updates; wireless connectivity to corporate network infrastructure; and procedural approvals for safe use of video recording equipment. If AR Wearables are to be used outside of the continental United States, Export/Import regulations must be observed and local country telecom regulations must be addressed. Questions also frequently arise regarding data ownership and licensing rights. For organizations that seek the benefits of adopting emerging technologies like AR, a key consideration is oftentimes striking the right balance between governance and innovation.

THE FUTURE OF MIXED REALITY AT RAYTHEON

While Raytheon and its customers are now benefiting from the use of AR technology in the factory and in the field, we have yet to reach the Plateau of Productivity.[3] Technologists in Raytheon's companywide network of Immersive Design Centers continue to evaluate the latest generation of AR Wearables in an effort to provide lower cost AR solutions with improved comfort and performance. Feature recognition capabilities and pertinent tactile haptics are also being researched today for incorporation into next generation AR solutions. Additionally, RM2 capabilities continue to expand as the latest COTS technologies and Raytheon patented and patent pending features become available. ■

— Keith Janasak, John Cogliandro, Brent Dingle, Adam Feccia & Kristen Stone

Figure 4: A Remote RM2 user with tablet (top), a Remote RM2 user with smartglasses (middle) and an SME's 'ghost hands' providing instruction in the remote user's field of view (bottom)

Keith Janasak
Space and Airborne Systems

Keith Janasak is a Senior Principal Operations Engineer for the Space and Airborne Systems (SAS) business of Raytheon Company. With more than 40 years of experience, Janasak is currently the Advanced Visualization Technology Lead for SAS, responsible for the development, integration and deployment of Augmented Reality (AR) and Virtual Reality (VR) technologies across the product lifecycle. Janasak has extensive experience in advanced engineering automation tools, including leveraging three dimensional (3D) models of Raytheon products and mannequins to assess, visualize and improve how products are assembled, tested, operated and supported.

"The need to provide 3D virtual reality based training to our customers' operators and maintainers opened the door for me getting into Advanced Visualization," Janasak relates. "An early exposure to multi-player online gaming got the creative juices flowing as a viable way to conduct immersive customer team training. I also had the opportunity to lead the Raytheon requirements team for the first Immersive Design Center in SAS. This facility features a virtual reality CAVE™ Automatic Virtual Environment and was fundamental to enabling programs to leverage their native engineering applications to support immersive design reviews, including Design for Manufacturing and Assembly engagements."

Janasak was the principal investigator for the Remote Maintenance for Reduced Manning (RM2) project, an activity that leveraged AR to develop a remote collaboration capability for use both internally within Raytheon and in the field. His current focus is in the deployment of this technology to facilitate remote collaboration between the factory floor and program subject matter experts. "The goal is to utilize the next generation AR Wearables to put contextually relevant information in the field of view of the user while maintaining hands-free user mobility," Janasak explains.

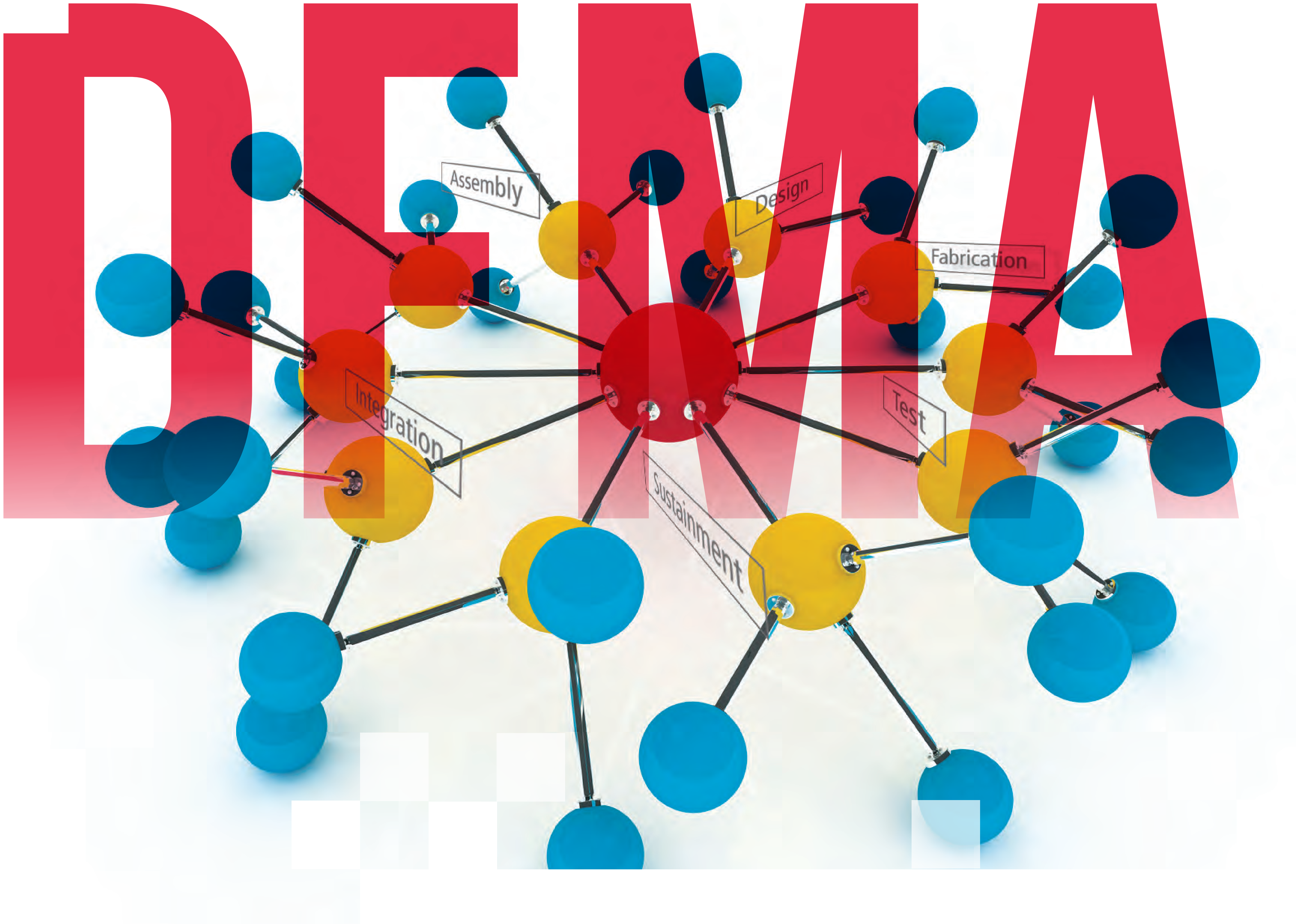
Janasak is co-chair of Raytheon's Immersive and Interactive Visualization (I2V) Technology Interest Group, where he is responsible for fostering communication and collaboration within I2V across the company. Janasak encourages new employees to: "Network with people through Raytheon's Technology Interest Groups to grow personal knowledge in technology domains that align with your passion. Always look for opportunities where your technology passions can be applied, and get involved in driving innovative solutions."

Janasak received his Bachelor of Science in Electrical Engineering from Auburn University, and he holds a Master of Science degree in Engineering Management from Southern Methodist University.

FEATURE

DFMA: DESIGN FOR MANUFACTURING AND ASSEMBLY WITH SUSTAINMENT THROUGHOUT THE PRODUCT LIFECYCLE

Raytheon Design for Manufacturing and Assembly (DFMA®) is an integral part of the design process that ensures the manufacturability and affordability of products and processes. While achieving customer requirements, DFMA puts an emphasis on design, fabrication, assembly, integration, test and sustainment. It is the methodology for designing products and systems to more effectively utilize overall manufacturing and assembly processes. Collaboration is critical to the success of DFMA, as the design of a product is optimized when there is cross-functional participation from Engineering design teams and from operations and other disciplines' subject matter experts (SMEs).



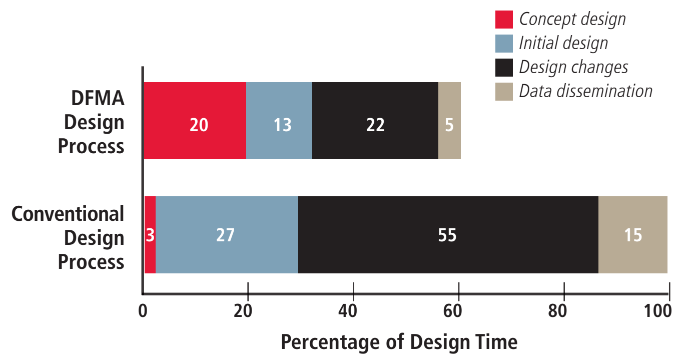
WHY DFMA?

Understanding every aspect of customer requirements as early as possible in the design process is an important part of staying competitive in the defense industry. Raytheon programs face the challenge of defining product requirements and developing robust designs under increasingly greater need for quality, lower cost and reduced schedule. Utilizing DFMA provides an advantage by addressing three key program metrics: Total Ownership Cost (TOC), Design Cycle Time and Cost of Poor Quality (CoPQ).

Design decisions can drive the TOC of a program, which includes elements of the program Life Cycle Cost as well as other infrastructure or business process costs not normally attributed to the program. New programs, therefore, as well as major upgrades to existing programs, have the greatest potential for TOC reduction. When applied at the earliest design stages of a program, DFMA practices have the greatest impact on the TOC, and reduce the overall design cycle time.

Studies by Boothroyd Dewhurst on products, with and without DFMA, across hundreds of businesses concluded that performing DFMA early in the concept phase of a product results in fewer disruptions in subsequent phases, requiring less change notices and rework. The result is an average of 40 percent reduction in design cycle time (Figure 1).[1] With early DFMA, what normally involves a stepwise peer review through Quality, Operations and other functions becomes a proactive real-time closed loop feedback that influences the design starting at conception.

Cost of Poor Quality (CoPQ) is the costs associated with poor quality products or services which, in some cases, can result from poor designs. Quality issues throughout the program lifecycle can be reduced when production and sustainment information on process capability, cost drivers, cycle time, yield and defect



Source: Boothroyd Dewhurst, Inc.

Figure 1: An early DFMA strategy provides reduced design cycle time

opportunities is available early on to support data driven design decisions. With DFMA, engineers can predict and minimize manufacturing, assembly and sustainment risks early in the development process.

Examples of DFMA principles combined with cross team collaboration help to highlight these ideas. In a recent Raytheon printed wiring board (PWB) design activity, engineers engaged independent subject matter experts (SMEs) and the PWB supplier to create a more affordable design. Collectively, the team was able to create a list of more than 50 improvement ideas, prioritize the list through use of an ease and impact assessment and, finally, produce a recommended set of cost reduction activities. The recommendations included elimination of four layers of the PWB, an increase in panel utilization (# of boards per panel), optimization of the plating process, and improved PWB yields. In the end, the effort resulted in a greater than 25 percent cost reduction.

In another example, DFMA and Agile/Lean principles were used to meet the performance and cost targets of a product chassis. Engineers and SMEs from multiple program disciplines leveraged both manufacturing and test process capabilities to reduce weight and cost of the chassis.

In this instance, more than 30 improvement ideas were again prioritized through an ease and impact assessment to produce a set of cost reduction initiatives that resulted in 31 percent fewer parts and a greater than 40 percent cost reduction for the chassis.

DFMA WITH SUSTAINMENT (DFMA/S)

Raytheon has built upon the generally accepted principles of DFMA to better meet sustainment goals and the requirements of the industry in which the products are deployed. There are 15 Raytheon DFMA/S principles (Figure 2) that provide the foundation for reducing the complexity of the design and assembly sequence along with identification of alternative manufacturing processes, all of which helps to reduce the overall cost and complexity of production, integration and sustainment. The first 11 principles address simplicity of design, minimizing both parts and operations steps while meeting product requirements. These also stress using standard, easy to assemble, self-locating parts that do not require special tooling. Raytheon has modified these industry standard principles (highlighted in white) to better support sustainment, product use and maintenance by end-users.

DFMA/S at Raytheon incorporates three methodologies: DFMA/S workshops, Integrated DFMA/S (iDFMA/S) workshops and Concurrent Engineering.

DFMA/S workshops are collaborative events, led by a facilitator, that utilize DFMA/S principles and tools to identify design simplification ideas. These are typically larger cross-functional meetings of 12 or more people that focus on system level assemblies and are often held in one of Raytheon's Immersive Design Centers (IDCs), Figure 3. IDCs provide an ideal collaborative space with 3D capability in a CAVE™ Automatic Virtual Environment where a team is immersed in virtual technical content with real-time model interrogation and idea capture. Here, using 3D models or prototypes, they are able to

RAYTHEON'S 15 PRINCIPLES OF DFMA/S

1. **Minimize the number of parts and obsolescence**
2. **Minimize the use of fasteners**
3. **Standardize/commonality**
4. **Avoid difficult components**
5. **Use modular assemblies and subassemblies**
6. **Use multifunctional parts**
7. **Minimize reorientations**
8. **Use self-locating features**
9. **Avoid special tools, test and support equipment**
10. **Design and provide accessibility**
11. **Minimize process steps**
12. **Design for service life and reliability**
13. **Minimize footprint in the field**
14. **Design for Exportability**
15. **Ergonomics & Safety**

Raytheon updates for sustainment

Figure 2: Raytheon's 15 principles of Design for Manufacturing and Assembly with Sustainment (DFMA/S)

[1] Boothroyd G., Dewhurst P., Knight W. A., "Product Design for Manufacture and Assembly" Second Edition, (Boca Raton, FL, CRC Press, 2001)

Figure 3: The Immersive Design Center provides an ideal setting for cross-functional team collaboration

investigate early on, producibility issues such as operator physical interference, ergonomics issues during component manipulation and/or assembly tool accessibility limitations. Workshop activities are documented using a DFMA/S template from the Raytheon Six Sigma™ toolkit and an implementation plan with prioritized recommendations is produced.

CONCURRENT ENGINEERING INVOLVES USING A CROSS-FUNCTIONAL TEAM TO SIMULTANEOUSLY DESIGN PRODUCTS ALONG WITH ASSOCIATED MANUFACTURING PROCESSES AND SUSTAINMENT METHODS

While also a collaborative event, an iDFMA/S workshop is smaller in both size (usually only three to five people) and scope. Its narrowed focus is defined by product cost or size of the design; circuit card assemblies, interconnects and sub-components for example. The iDFMA/S workshop also uses the DFMA/S template to create a prioritized recommendations list and implementation plan.

Concurrent engineering involves using a cross-functional team to simultaneously design products along with associated manufacturing processes and sustainment methods. By integrating quality, operations and product support functions into the design and development process, trade studies on all critical processes and product areas can be performed concurrently. For example, studies may include production process capabilities, manufacturing costs, special tooling and test equipment along with manufacturing and sustainment issues such as material constraints and availability, field accessibility, special training requirements, and ergonomics.

When combined, the three methodologies form a foundation to help integrate DFMA/S across the enterprise, providing consistency in both application and focus for cost-effective manufacturability, quality and sustainment of Raytheon's product lines.

BEYOND DFMA/S, DESIGN FOR "X"

Going beyond the DFMA/S umbrella, Design for "X" (DfX), where X is a variable with many possible values, adapts the standard DFMA/S infrastructure processes, tools and people to influence and simplify other product development opportunities. For instance, DfX may include Design for: Automation, Test, Safety, Human Factors, Corrosion Mitigation, Additive Manufacturing or Facility Optimization. In all cases, understanding a program's requirements and involving a program's process experts as well as cross-functional influences is paramount to a successful DfX activity.

SUMMARY

DFMA/S is being used throughout Raytheon to reduce design cycle time, improve producibility and sustainability, and to promote cost competitiveness during product development. Resources are available across the enterprise through a DFMA/S website and the Raytheon Six Sigma toolkit for organizations to utilize the wealth of experience, tools, processes and methods key to developing the most efficient design solutions for customer mission success. DFMA/S is a product development best practice and is essential to how products are designed and improved at Raytheon. Although leveraged in the early development phase of a product, DFMA/S provides significant savings through the product lifecycle, and it helps ensure that systems are manufacturable, affordable and sustainable. ■

— Maria Spalt & Mark Steudel

Maria Spalt
Raytheon Missile Systems

With more than 16 years of experience with Raytheon Company, Maria Spalt has been instrumental in the successful transition of several key product lines into production. As a Manufacturing Engineering Manager at Raytheon Missile Systems, she has led or held a major role in the development of tools and processes used in Operations proposals, product producibility and affordability, and transition to production. In her lead manufacturing engineering role, Spalt's efforts touch many different functions on a daily basis, providing a broad perspective and foundation for productive decisions.

"A career in Manufacturing Engineering has given me diverse project management experiences," Spalt states. "Manufacturing Engineering touches the entire lifecycle of the product and has allowed me to create positive and collaborative relationships across Raytheon and with our customers."

Spalt's 29 years of operations leadership and manufacturing engineering experience includes both military systems and commercial and government electronics. She has been influential in designing product features that enable economical fabrication, assembly and test while leveraging existing manufacturing technology and capabilities. This upfront involvement with the program team is a major discriminator between competing system solutions.

"It is imperative that we are able to get new capabilities into the hands of the warfighters quickly," Spalt impresses. "This means that Manufacturing must be involved in the design and development process to ensure producible, affordable, quality products are delivered on time."

Prior to joining Raytheon, Spalt held management positions in several manufacturing factories, including a rapid prototype facility that provided quick turn hardware to development teams and enabled advanced manufacturing process development.

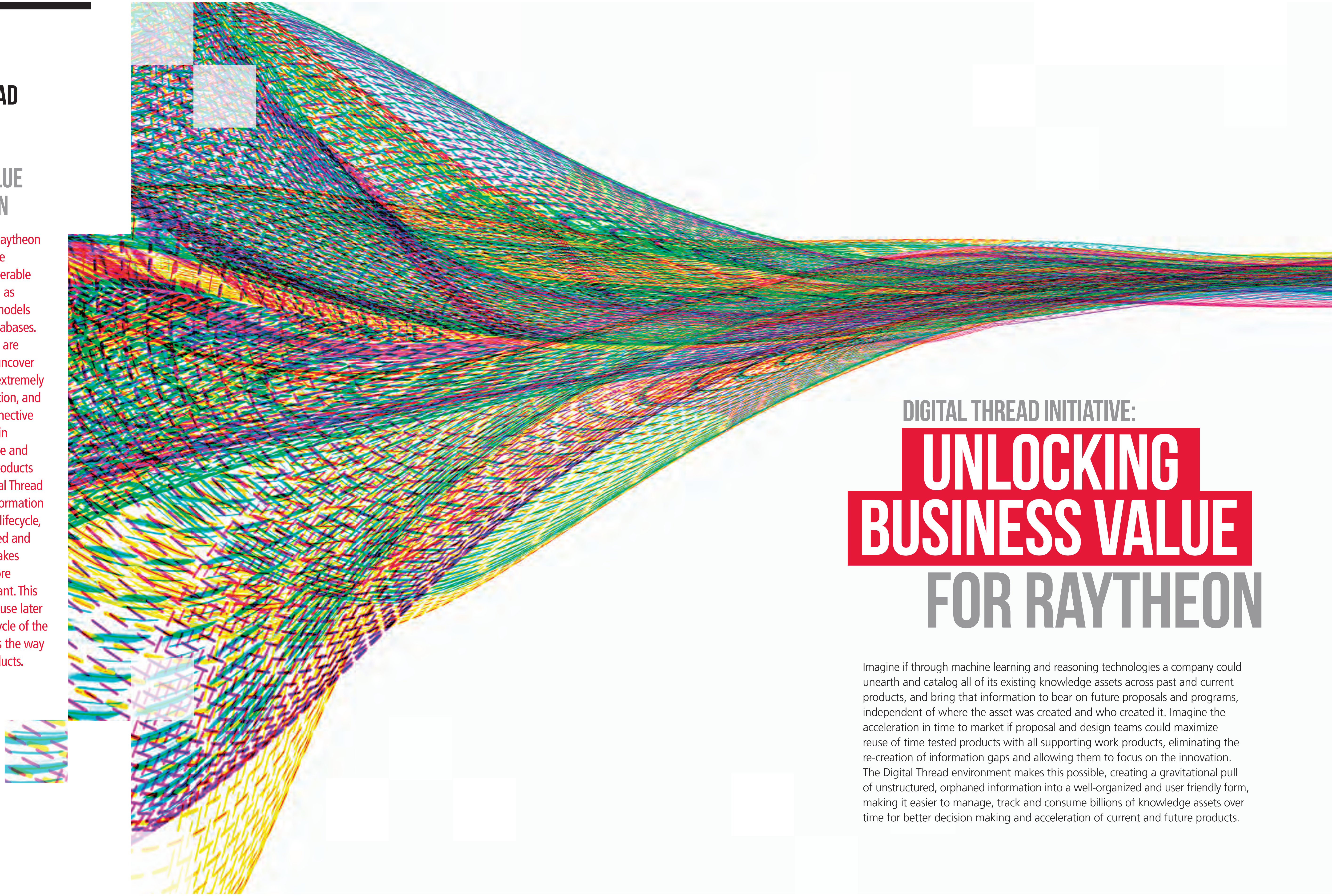
Asked what advice she would offer new employees in the manufacturing engineering field, Spalt explains: "Continuous process improvement. Always question how a process can be made better, and then do just that."

Spalt is currently the Operations representative for the Raytheon Missile Systems Integrated Process Development System (IPDS) Control Board and the Design for Manufacturing and Assembly Council. She holds a bachelor's and master's degree in Mechanical Engineering from Arizona State University, and she is a certified Manufacturing Readiness Level Assessor.

FEATURE

DIGITAL THREAD INITIATIVE: UNLOCKING BUSINESS VALUE FOR RAYTHEON

Corporations such as Raytheon have accumulated large amounts of non-discoverable knowledge assets such as content files, isolated models and single purpose databases. Emerging technologies are providing a means to uncover and re-assimilate this extremely rich bounty of information, and then link it into a "connective tissue" to place it within context of the hardware and software deliverable products they support. The Digital Thread approach of linking information across the full product lifecycle, in context to the defined and controlled products, makes this information far more discoverable and relevant. This not only maximizes its use later in the program or lifecycle of the product, but also paves the way for reuse in future products.



DIGITAL THREAD INITIATIVE:
UNLOCKING BUSINESS VALUE FOR RAYTHEON

Imagine if through machine learning and reasoning technologies a company could unearth and catalog all of its existing knowledge assets across past and current products, and bring that information to bear on future proposals and programs, independent of where the asset was created and who created it. Imagine the acceleration in time to market if proposal and design teams could maximize reuse of time tested products with all supporting work products, eliminating the re-creation of information gaps and allowing them to focus on the innovation. The Digital Thread environment makes this possible, creating a gravitational pull of unstructured, orphaned information into a well-organized and user friendly form, making it easier to manage, track and consume billions of knowledge assets over time for better decision making and acceleration of current and future products.

A Digital Thread is a weave of information and services that contains all the information about a particular system over the life of that system, from conceptual design through end-of-life. This includes the original proposal, design trades, analysis, models, drawings, software, manufacturing notes, any changes made on the production floor, and all services that the system has undergone. A Digital Thread is unique to every delivered product and is linked to the Digital Threads of other "like" products to ensure that information associated with actions performed on any one product in a family of products is available to the entire product family. Additionally, sensed state changes from fielded products can be compiled along with the design analysis and production information, and be readily available to help diagnose and improve system performance in the field. Throughout the lifecycle of a product, the availability of this amount of historical and current knowledge contributes significantly to lower lifecycle costs, improved maintenance practices and more efficient system updates and upgrades.

As late as the 1980's, the major aerospace companies were still working with ink on mylar drawings. Although archaic by today's standards, there was an advantage to this simplicity, as you always knew the mylar drawing was the controlling master of the product's definition, while the blueprint was simply an uncontrolled copy. Since that time, the industry has experienced numerous technology explosions, due primarily to the exponential increase in computer power driving digital or model based solutions. This has resulted in the undesirable effect of perfectly mass replicating native authoring files, creating a tremendous amount of ambiguity on what constitutes the controlling master file as well as where it is located and how it's governed. Many companies today use single purpose, siloed databases and libraries tied to functionally specific authoring tools, along with other relevant product data that is completely disconnected from the product's definition in its Authoritative System of Record.

Additionally, digital formats are not naturally immutable, leading to a practice called "clone and own" between system owners, who modify the data and content in the system they own and don't push the changes back to the source systems. Before long, there is an inability to digitally trace information across isolated infrastructure systems. This creates a major data issue, defeating the automation of digital transactions and end-to-end traceability of information. While business automation and digitization can increase speed to market, reduce operational costs and contribute to margin growth, the required data cleansing and well-meaning point-to-point system integration can become a never ending and very expensive approach to creating a Digital Thread.

Product information should be treated the same as other company assets. It is important to understand how much there is, how healthy the information is, and how to use this information to create business value. Several themes should be addressed in a strategy to maximize the benefits of the Digital Thread, including a more holistic approach to solutions which avoids "path of least resistance" methods to accomplish near term tasks. Also, configuration management, content management and a common framework are necessary to ensure that information is traceable, native files are linked to the product they support, and data from trusted sources are available when and where needed. Finally, process visibility across product lines, systems and tools to support consistency in design, operation and production must be employed in order to troubleshoot the system and drive a reduced time to market.

The need to adopt a coherent product information strategy that is visible, automated and governed across the enterprise is paramount because of the growing volume, velocity and variety of information over time. A coherent approach enables accelerating the execution of all programs, improving speed to market. Eliminating the gaps in availability of this digital product information paves the way to systemically leverage emerging technologies such as Digital Automation, Model Based Engineering (MBE), Intelligent Business Process Management (iBPM), Internet of Things (IoT), Augmented & Virtual Reality (AR/VR) and Artificial Intelligence & Machine Learning (AI/ML).

Raytheon is engaged in "Digitizing the Business." This digital transformation has multiple aspects and focus areas. Digital control of the product definition and identifiers starts in the proposal phase and continues through operations, procurement from suppliers and customer support. From the system level down to the lowest element of a specific line of code or circuit card resistor, creation of a complete digital record has immediate benefit toward converting manual tasks to automated tasks, reducing errors, and establishing navigation lanes for core product digital information.

Knowledge asset creation is enabled through the enrichment of information brought into the proposal and design phase to speed up design convergence. The Digital Thread automates the collection, characterization and alignment of system and product information and associates these functional and performance attributes with existing product identifiers representing assemblies, modules and components for the purposes of search, selection, trades and eventual use/reuse in design solutions.

In order to effectively harness the vast wealth of information that has been created and digitized over the past 25 or more years, much of it in unstructured data types and objects, new technologies need to be developed, matured and/or adapted (Figure 1). One of these is Semantic Technology, which is the ability of a computing system to understand words based on their usage and context. Semantic Technology improves search accuracy by understanding a user's intent and contextual meaning. It uses Semantic Annotation and Tagging to categorize data assets by content and by relationship. Semantic Technology has been around for several years, and while it is easy to see how this technology could be very useful to the Digital Thread, it has been slow to develop and expensive to adopt until recently.

Graph Visualization and Modeling, a common modern analysis and machine learning technology, can contribute greatly to the Digital Thread. It enables the modeling of the data's logical connections to produce a physical model that allows connections to be visualized. Tying together the content with semantics allows for a two-directional flow of information that can be used to create Digital Threads.

Raytheon delivers many products to many customers. Initial studies and application of Digital Thread methods have shown significant potential for the quality and availability of system information to support improved design, development and delivery of these products. The goal of the Digital Thread Initiative and its associated product information management is to solidify the "connective tissue" between the vast amounts of information available, relative to product development, delivery and maintenance, in such a way that efficiencies in process time, energy and material usage across the product's lifecycle can all be improved. Digital Threads can provide insight into areas for product improvements that may not be readily apparent in some work environments. They can also be a catalyst for the next generation of Model Based technologies. Digital Thread solutions will be most effective when they are logical and compelling enough for even the occasional user to confidently and adequately capture, manage and retrieve the right information at the right time—setting the stage for future "Digital Business" and "Digital Twin" models where intellectual property and information are key assets for Raytheon, its products and its customers.

— David Slader, Greg Piper & Ron Williamson

TECHNOLOGY	BENEFIT TO DIGITAL THREAD
Semantic Annotation and Tagging	Machine assisted enrichment of core data assets with metadata that describes/characterizes the content (e.g. security labels, product category/domain, function, etc.). Provides the foundation for Semantic searches as well as large scale integration and reasoning on data both internally and with web enabled sources.
Semantic Search	Improved search capability and accuracy that considers user intent and contextual meaning, leveraging ontologies built using semantic standards such as Web Ontology Language (OWL), Resource Description Framework (RDF) and SPARQL as well as ontological triples (subject, predicate and object) that model relationships between and across domains.
Graph Visualization and Modeling	Translation of data's conceptual view to a logical and physical model amenable to visualization and baseline management.
Ontology Based Management/Development	The mechanisms and processes to govern quality and fidelity of ontologies that represent concepts and relationships within a domain or across multiple Raytheon knowledge hubs.
Data Analytics with Machine Learning (ML)	Automation of metadata generation and analytical model building for pattern, root cause and other ML-based analyses.

Figure 1: Technologies used to enhance Digital Thread capability

FEATURE

ROBOTICS IN THE FACTORY

Robots are changing manufacturing. And at Raytheon, robots are playing a key role in the development, optimization and proliferation of advanced manufacturing technologies across the enterprise. Advances in infrastructure, high technology production facilities and factory automation combine to drive productivity improvements and facilitate growth. This article discusses the fundamentals of these manufacturing advancements and the significant role robotics technology plays in Raytheon manufacturing automation.

Robots have a significant impact on today's manufacturing processes. Assembly automation can incorporate both vision systems and force sensing. As an example, vision can guide a robot to pick up a component from a conveyor, thereby reducing or eliminating the need for precise location. Visual sensing gives a robot the ability to rotate or translate one piece, fitting it with another piece. Force sensing is used in part assembly operations like insertion, giving the robot controller feedback on how well parts are going together or how much force is being applied. Together, these sensing technologies make an automated production line cost effective for even relatively short production runs. As depicted in Figure 1, robots are often used to perform duties that are dangerous, or unsuitable for human workers, such as repetitious work that could lead to injuries due to poor ergonomics. The assembly robot shown has the flexibility built into the design to handle variants of a product family, even from cycle to cycle, when equipped with vision and/or other sensors, and it is quickly and inexpensively reconfigured with product design changes.

ROBOTICS IN THE FACTORY

Figure 1: Robots are working hand-in-machine with Raytheon engineers to build powerful radars for U.S. and allied militaries

Three distinct types of robots, industrial, collaborative and material handling, have become key to achieving higher efficiencies and quality across all Raytheon manufacturing sites.

Industrial robots are automated, programmable and capable of movement on two or more axes. They can be programmed to perform dangerous, difficult and/or repetitive tasks with reduced waste and consistent precision and accuracy. In Figure 2, a robot utilizing an end of arm tooling (EOAT) attachment can hold and manipulate either the tool being used in the process or the piece being worked on in the process. In this 'dual-robotic' configuration, the smaller robot controlling the EOAT attachment is mounted on top of a tray, which is attached to a larger robot for movement and positioning. The dual robot solution provides a smaller footprint of manufacturing space. The larger robot allows flexible autonomous installation at large envelopes while the smaller robot provides the high precision of assembly.

Collaborative robots (Cobots) enable rapid deployment and provide the flexibility necessary to allow Raytheon engineers to integrate robotic functionality across multiple product lines and applications. These robots execute tasks (Figure 3), operating side by side with their human counterparts, without a need for additional safety devices. Based on proven sensor technology, the force sensors and safe contact stops are able to immediately halt a collaborative robot's current task whenever the possibility of collision with a human person or fixed object is detected. Operators can guide the robot and/or train it to assist in assembly, pick & place, adhesive application, verification, machine tending, and material manipulation. Collaborative robots allow the user to work

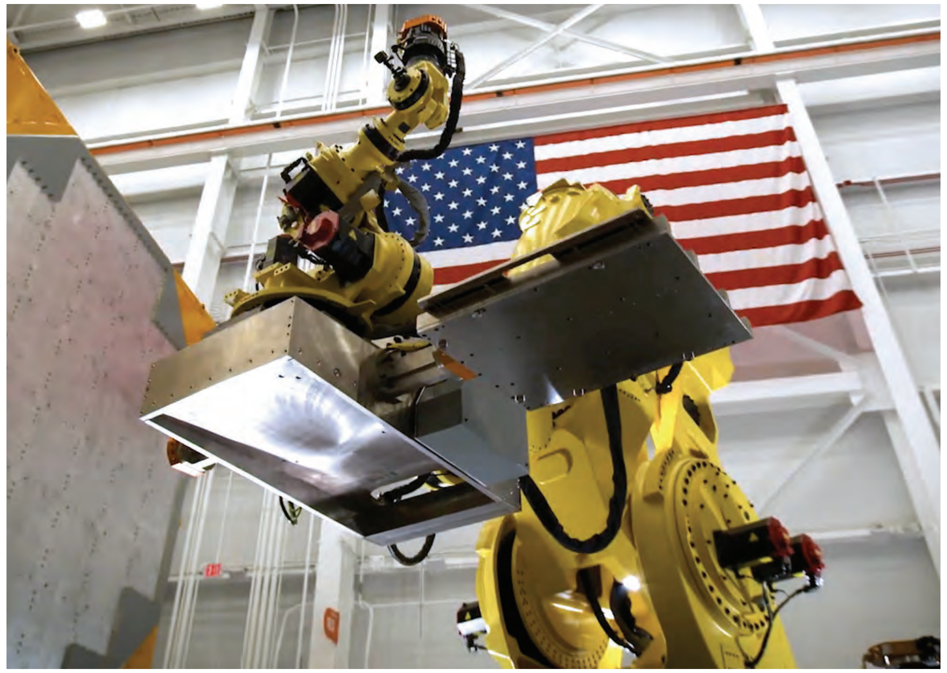


Figure 2: A "dual-robotic" system for radar array assembly

cooperatively with the system, increasing operator productivity and product quality while reducing waste.

Material handling robots or Automated Guided Vehicles (AGVs) are portable robots that utilize vision, magnets and/or lasers for navigation. AGVs are used to consistently and predictably transport material loads in areas that might otherwise be serviced by fork lifts, conveyors or manual cart transport. They are particularly useful where high volumes of repetitive movements of material are required, but where little or no human decision making is needed to perform the movement. AGVs assist in material handling logistics to optimize the flow of materials within production systems that focus on the reliability, traceability and efficiency of moving product (Figure 4). Raytheon employs two types of AGVs within its manufacturing facilities, autonomous navigation and laser navigation. Both are integrated into the Enterprise Resource Planning (ERP) and Supervisory Control and Data Acquisition (SCADA) systems for a fully integrated automation solution.

Autonomous navigation AGVs have built-in sensors, cameras and sophisticated software. These autonomous robots can identify their surroundings and take the most efficient route to their destination, safely avoiding obstacles and people. Without the need to alter the facility with expensive, inflexible wires or sensors, autonomous robots can safely maneuver around people and obstacles, through doorways, and in and out of elevators.

Figure 3: A collaborative robot works side by side on a workstation with an operator to complete a component build

Laser navigation AGVs have many tons of load capacity and can pick up a radar which is sitting on a mobilizer, a structure that interfaces with the AGV. The laser navigation AGV locks into the mobilizer and uses laser navigation throughout the facility to navigate autonomously and position itself within 3 millimeters of its target in just minutes. Historically, arrays were placed on air pallets that required precision and accuracy performed by human hand, utilizing lasers. That effort took days to complete and now, through automation, takes just minutes to complete, with significant cycle time reduction, increased repeatability, and minimal support.

Figure 4: An Operations Engineer programs an automated guided vehicle to bring parts and tools to a robotic arm that helps build radars in Raytheon's new state-of-the-art radar development facility

In addition to internally developed technologies, Raytheon leverages advancements in the commercial sector. One of these opportunities is Manufacturing USA®, an initiative of the Advanced Manufacturing National Program Office (AMNPO) that connects people, ideas and technology across manufacturing, government and academia. As a member of the Advanced Robotics in Manufacturing (ARM) institute of Manufacturing USA, Raytheon's engineers connect with public-private partnerships to support promising early stage research to propel new products to market. A key objective in these partnerships is to identify gaps in robotic applications within the commercial industry and develop solutions utilizing cross business and cross functional teams.

Raytheon and partners, QinetiQ North America, Massachusetts Institute of Technology, MassRobotics and General Electric were awarded one of the eight projects from the ARM Fall 2017 technology project, a *Robot-Assisted Wire Harness Installation*. This project centers on empowering human workers and reducing risk of injury in manufacturing environments through the development of a robot-assisted wire harness installation system. The system will augment human cognitive and physical abilities while eliminating errors and focusing on worker assist, rather than worker replacement. The project will engage a twin arm robot to hold, route and position a wire harness while using eye-safe laser pointers to indicate correct wire to terminal and connector pair locations. In addition to the technology advancement, the project will also feature a workforce development aspect that includes the creation of a training course for the new technology.

Raytheon understands the need to continually expand production automation capabilities, from initial engineering design through improvements to the speed and quality of its manufacturing processes. Robotics help establish a collaborative integrated system, assimilating with advances in information technology as well as modern manufacturing techniques, in order to automate the manufacturing infrastructure to achieve cycle time reductions and improved safety, quality and repeatability. ■

— Kristen Stone, David Miceli, Jayson Diaz & Blair Simons

Kristen Stone
Integrated Defense Systems

Kristen Stone began her career at Raytheon as an Industrial Engineering master's co-op in the Missile Systems business and was shortly thereafter selected for Raytheon's Engineering Leadership Development Program. She is currently a Senior Operations Engineer for the Operation's Modernization and Innovation (M&I) group at Raytheon's Integrated Defense Systems. Stone's role in M&I is one of extreme flexibility and adaptability, both in leading projects and providing technical expertise to Operations in numerous emerging technology areas such as Automated Guided Vehicles, Augmented Reality (AR) and Advanced Robotics. In addition to her daily responsibilities, Stone also supports many Independent Research and Development (IRAD) activities and has served as the Raytheon lead on multiple Manufacturing USA Institute and Small Business Innovation Research (SBIR) projects.

"Being a part of the M&I organization allows me the opportunity to experiment, grow and push the limits of my technical knowledge and leadership skills every single day," Stone affirms. "My passion is around solving problems, especially within teams—I believe that diversity of thought helps drive exceptional change."

One of Stone's recent projects involves the integration of AR Wearables in the factory, a capability that provides digital instructions to operators overlaid on the visual workspace while retaining full mobility.

"I am able to use creativity, imagination and innovation to help drive Operations to the next level," Stone states. "Operations and the M&I team are committed to providing our customers with world class solutions that not only meet the needs of today, but are also focused on tomorrow."

While pursuing her bachelor's degree, Stone played on a Division I women's lacrosse team. "I think that there is much to say about athletics and its relation to success within your career," she explains. "For example: team building, communication, leadership and time management. Athletics provides a safe environment to fail, but fail fast, re-evaluate and re-attack. You will always face small failures within your journey, but the overall victory, the ability to get a win is what ultimately matters."

For new employees starting out at Raytheon, Stone offers the following. "Always strive to learn, keep a strong work ethic, and apply for the stretch opportunities… Treat every day and every task as an opportunity to grow and prove yourself."

Stone holds a bachelor's degree and master's degree in Industrial and Systems Engineering from the State University of New York, Binghamton.

FEATURE

SUSTAINABILITY
IN RAYTHEON FACTORIES AND BUILDINGS

Raytheon's sustainability program aligns employees, customers, suppliers and communities around a single goal — to engineer a sustainable future through environmental stewardship and the conservation of natural resources.

Raytheon's sustainability principles extend across the company and influence everything from the operation of manufacturing plants to engineering products. Integrating these principles of sustainability throughout Raytheon operations drives an innovative approach to problem-solving that yields solutions with co-benefits to both the environment and the business.

The Raytheon Sustainability program is founded on several distinct and easily understood goals, including decreasing energy consumption, decreasing water usage and reducing greenhouse gas emissions, that help drive green manufacturing practices in company buildings and in operations. At the Raytheon Missile Systems (MS) site in Tucson AZ, the facilities organization is leading an initiative to build a Smart Campus by integrating a network of sensors, meters, data loggers and controls that provide powerful capabilities to visualize and analyze building performance. Building automation system upgrades and integration into the Smart Campus platform has been completed for more than 50 buildings at the site with energy performance data available in real time. The Smart Campus platform is an aggregate solution, consisting of commercial automation software and a variety of building automation tools, monitoring systems and analysis components, that provides a seamless energy and water usage/control capability. The system sends fault alerts when equipment, such as a heating, ventilation, and air conditioning (HVAC) unit, is not operating optimally, and displays the cost of each fault in order to prioritize repairs and elevate performance.

Raytheon facility in Tucson AZ

In some areas, such as the larger machine shops, each piece of factory equipment is also metered, showing the energy draw of all machines whether they are in-use or idle. This provides the ability to perform data analyses such as comparing equipment run time against energy draw. This information is then used to drive efficiencies by reducing idle time, forecasting operational hours, and turning off office equipment when not in use. Similarly, water meters are being installed on cooling towers and other related infrastructure to track water usage more closely. This allows equipment operations, such as cooling tower cycle times, to be modified for maximum efficiency.

Adopting this smart technology at Tucson and other Raytheon facilities has the benefit of conserving energy, reducing maintenance costs, increasing equipment life, improving productivity, and minimizing each building's environmental footprint; demonstrating that integrating sustainable practices into business operations has dual benefit to a company's bottom line by reducing both utility and maintenance costs.

SUSTAINABILITY IN RAYTHEON FACTORIES AND BUILDINGS

Figure 2: Xeriscape with native vegetation around the soccer field at the Raytheon Tucson facility

As an example of how smart technology is leveraged in new construction, consider a data center building designed for direct cooling using chilled door technology. Chilled doors are a recent technology that offers the ability to cool individual data system racks through the use of chilled water coils in the rack door. Also at this facility, "multilevel" monitoring is visualized through the Smart Campus platform's Power Usage Effectiveness (PUE) dashboard, and the Fault Detection and Diagnostic (FD&D) function is used to maintain optimal operation and energy efficiency.

THE RAYTHEON TUCSON FACILITY HAS BEEN USING THE SUN AS A NATURAL RENEWABLE ENERGY SOURCE. THIS CAMPUS HAS IMPLEMENTED 11 SOLAR PROJECTS, THE LARGEST BEING A GROUND-MOUNTED SOLAR PANEL SYSTEM

A holistic approach to sustainable operations is achieved through pairing the Smart Campus platform with building infrastructure upgrades that use cutting edge technology to take advantage of the conditions in a desert environment. In 2018, a central utility plant was completed to replace several air-cooled and water-cooled chillers located at a number of buildings at the Tucson facility. This project was urgently needed as the existing equipment was nearing the end of its service life. The new plant consolidated chilled water production from several buildings at a centralized location and implemented a number of district cooling innovations such as thermal energy storage, variable speed and direct primary chillers. Water is chilled at night when desert temperatures are lower and energy costs are less. The chilled water is then distributed during business hours to cool several buildings. Thermal energy storage provides chilled water production flexibility. It also improves reliability and takes advantage of lower nightly electric rate structures.

With Smart Campus technology and infrastructure upgrades lowering the energy load, renewable energy projects are even more impactful. Since 2008, another Raytheon Tucson facility has been using the sun as a natural renewable energy source. This campus has implemented 11 solar projects, the largest being a ground-mounted solar panel system located at one of the site's entrances (Figure 1).

Figure 1: A ground-mounted solar panel system greets employees at the entrance of a Raytheon Tucson facility

Raytheon collaborated with the United States Air Force to develop a photovoltaic system that converts sunlight directly into electricity to power the site. The 55 kilowatt system's solar panels, installed in 2012, are set at angles to optimally utilize the sun's power. Lights powered by this system improve employee safety by lighting large parking lots, pedestrian walkways, bus stops and signs. Solar power is used to heat water at the dining center and the on-site recreation center, and also supplements other natural gas-fired water heaters.

The value of water in the desert environment at the Tucson AZ campus is unmatched among the other natural resources. The campus landscaping has been converted to a unique Xeriscape™ (Figure 2) using native, drought-tolerant and low water-use vegetation. The last remaining green, the soccer field at the onsite gym, has been replaced with artificial turf. It is estimated that this project alone will save upwards of two million gallons of water annually in addition to the million currently being saved through xeriscaping.

In addition to traditional building infrastructure projects, green manufacturing opportunities are being evaluated within factory and lab processes. One of these areas of focus is the reduction of greenhouse gas emissions from chemical use. Chemical emissions are profiled projects that target the highest emitters first and provide upgrades for leak free delivery systems and installation of leak detection alarm systems. Other projects involve phasing out existing systems in favor of several low-to-no emission alternatives. Alternatives to canned air, for example, include plumbed shop air and an O2 Hurricane® duster system. The O2 Hurricane is a battery charged reusable duster that sprays filtered air with no chemical agent. Each of these alternatives eliminates the emissions and waste previously generated from canned air use. Other green manufacturing opportunities include chemical substitution options that favor low volatile organic compounds and greenhouse gas.

Innovations in sustainability are not only happening at the Tucson AZ facility, they are being implemented across the enterprise. In Fullerton CA, for example, a Raytheon site with a 1950 kW Tesla® battery system using PowerScope software is achieving significant reductions in both peak energy demand and annual energy costs. Companywide, new facilities are being designed and built to LEED® (Leadership in Energy and Environmental Design) standards. These facilities will include LED lighting, upgraded insulation and newer innovations such as variable refrigerant flow (VRF) refrigeration and in-row coolers in server rooms.

Across the enterprise, there were more than 80 active energy and water related projects in 2018 alone. Raytheon's sustainability program continuously focuses on the environment and the preservation of natural resources. Sustainability is an integral and innovative part of Raytheon business operations—expanding capabilities while reducing the environmental footprint. ■

— Nicole Sweeney

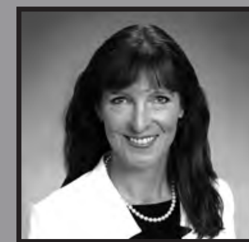
RAYTHEON OPERATIONS COUNCIL

KIM CARUSO, (CHAIR)
Vice President Operations
Raytheon Corporate

DIANE LAURENZI
Vice President Operations
Integrated Defense Systems

MARK KAMPF
Vice President Operations
Intelligence, Information and Services

ALLEN COUTURE
Vice President Operations
Missile Systems



TAY FITZGERALD
Vice President Operations
Space and Airborne Systems

TECHNOLOGY TODAY **SPOKE WITH OPERATIONS COUNCIL MEMBERS ABOUT TODAY'S EVOLUTION IN MANUFACTURING AND HOW ADVANCED MANUFACTURING TECHNOLOGIES, INNOVATION AND COLLABORATION COMBINE TO MEET TOMORROW'S DEMAND.**

TT: WHAT IS THE OPERATIONS COUNCIL (OC)?

KIM: The Operations Council consists of the Operations Vice President from each business unit and the Vice President of Corporate Operations within Engineering, Technology and Mission Assurance. The council meets regularly as a forum for cross business collaboration and alignment to achieve company goals and objectives. Leveraging the experience, expertise and resources of the enterprise, as a team we tackle operations challenges, initiatives for resolution and advanced manufacturing projects. We are also instrumental in adopting an enterprise lean strategy and driving the development and deployment of common tools, processes and metrics across all the businesses. The Operations Council schedules annual visits for the team to manufacturing facilities of several companies outside the aerospace/defense industry, which helps maintain a benchmark for Industry 4.0 initiatives and is a great opportunity to learn and share ideas and best practices.

TT: WHAT FUNCTIONS AND RESPONSIBILITIES ARE INCLUDED IN OPERATIONS?

DIANE: Operations is fundamental to our business. It is where technology and innovation intersect and synergize, enabling us to deliver cutting edge capabilities to our customers around the world. As a multifaceted organization, Operations has the responsibility of leading, developing and executing global manufacturing, continuous improvement and transition to production strategies. Developing effective solutions requires a collaborative enterprisewide team involving engineering, supply chain, operations and other critical support functions with representatives from all the businesses working together. This operational diversity empowers us to increase efficiency and reduce cycle time. Our teams also use advanced manufacturing technologies to drive competitive advantage and grow and evolve our capabilities to meet the rapidly changing customer demand.

TT: WHAT EFFECT HAVE INDUSTRY 4.0 AND DIGITAL MANUFACTURING HAD IN SHAPING THE OC'S MISSION?

ALLEN: With Industry 4.0 has come the maturation of new technologies and processes including common test platforms, collaborative robots, automated guided vehicles and data analytics, all of which help to increase efficiency, facilitate employee workflows, reduce variation and identify opportunities for further process optimization. The Operations Council collaborates across the businesses and with commercial industries on these and other Industry 4.0 technology and concepts. This has shaped our mission to prioritize key technology pursuits such as cyber resiliency, which is fundamental to ensuring our factories' systems remain secure, and data analytics, which are enabled by the increase in information from devices, sensors and processes that support migration from reactive factory management to a more proactive and predictive approach.

TT: WITH TODAY'S RAPID TECHNOLOGICAL ADVANCEMENTS, WHAT ARE THE BIGGEST CHALLENGES FACING OPERATIONS?

TAY: Rapid technological advancement is requiring manufacturing operations to adapt organizationally, culturally and technically. The close integration of IT (Information Technology) and OT (Operations Technology) systems in modern manufacturing, combined with automation and data science, requires us to look at new skills and organizational dynamics in manufacturing. Fundamentally, technology in manufacturing is a human-machine system, and we must place emphasis on the human experience and cultural change dynamics with these new advancements. Lastly, Industry 4.0 advancements require new disciplines in modern organizations, including data science, systems engineering, materials science, robotics, machine learning and cybersecurity. Our challenge is to foster and recruit these disciplines as well as Lean experts who are prepared to embrace the new technical advances in manufacturing.

TT: HOW DO YOU CREATE AND NURTURE INNOVATION IN OPERATIONS?

DIANE: Innovation goes far beyond the cultivation of new ideas. It is a critical component of Operations that helps drive efficiency, safety and reliability, along with cost and cycle time reductions. As leaders, we set the tone for innovation and establish it as a strategic imperative. Using grass roots initiatives, we encourage ideas at all levels of our organizations, from cell leaders to the Vice President; we enable teams to research and pilot new technology; and we engage stakeholders and cross-functional partners to fine tune processes and act as thought leaders. Solutions come not only through internal collaboration but also result from our collaboration with academic institutions and consortiums. Manufacturing innovation is based on building a culture that is open to creativity and challenges the status quo, fostering cutting edge ideas to develop the best technology solutions for Operations.

TT: HOW DO THE OPERATIONS TEAMS COLLABORATE ACROSS THE BUSINESSES?

MARK: There are a number of collaboration efforts regularly occurring between the four Operations organizations. With technologists from each of the businesses participating, these focused efforts target specific technologies and capabilities to support needs across the enterprise. A recent Circuit Card initiative is a great example of this, where we are continually investigating and implementing efficiency measures to reduce defects and improve costs. The Operations Council funds a number of cross business team initiatives to do initial research in areas such as Model Based Work Instructions, Remote Maintenance via Virtual Reality, and Wearable Device Integration.

TT: WHAT EXCITES YOU ABOUT OPERATIONS TODAY AT RAYTHEON?

ALLEN: As we leverage advanced technologies to provide our customers with the best performing systems at the lowest possible cost, we are shaping a new and exciting future for Operations. As our customers' needs evolve to address new mission areas, product technologies and manufacturing processes are also evolving. Operations is engaging early in the product development lifecycle, partnering with design teams to develop producible designs, execute development, and transition advanced new products into full-scale production. We are leveraging emerging technologies such as composability, additive manufacturing and the Digital Thread in our designs to provide flexibility in manufacturing and streamline the transition to the factory. More than ever, we are in an environment where Operations is empowered and expected to make a positive impact to the bottom line, and our people are focused on promoting the best of themselves to deliver a quality product.

TT: ALONG WITH INDUSTRIAL DIGITIZATION COME BIG DATA REQUIREMENTS. WHAT REQUIREMENTS HAS THIS PLACED ON OPERATIONS AT RAYTHEON?

TAY: As the world evolves from a product- and tool-based society to a data-centric society, so does manufacturing. Creating systems that can access, assimilate and rapidly transform data into useful information requires new ways of thinking about data and computing architectures in manufacturing. For example, a single automation cell for a complex aerospace assembly can perform more than 4,000 operations per unit build. The numerous digital collects, image captures, and records per operation from the build, along with additional data from the products' sub-components, can produce digital records that grow exponentially. Similarly, smart building systems crunch data from over 100,000 edge sensors monitoring energy and the health of critical systems. Data science and algorithmic expertise are required to extract value from this vast amount of information. Also, a lean manufacturing philosophy helps ensure that we solve the right problems with these analytics and communicate them in a way that is understood by anyone from operator to Vice President.

TT: HOW DOES AN EMPLOYEE PROVIDE IDEAS AND SUGGESTIONS TO RAYTHEON OPERATIONS?

KIM: Across our manufacturing facilities, the Total Employee Engagement program empowers and encourages every employee to submit innovation ideas ranging from safety to process and product improvement to cost savings. Through Corporate Technology and Research, there are programs to fund innovative project ideas, in which a Manufacturing Technical Area Director (TAD) is involved to help vet those specific to Operations. The Operations Council is also a venue where employees can submit project ideas that have cross business applications.

NEW MIRROR TECHNOLOGIES TO SUPPORT RAYTHEON'S ADVANCED ELECTRO-OPTICAL AND INFRARED SYSTEMS

Raytheon has enterprisewide technology networks established to communicate and coordinate technology needs and developments across the company. These networks help ensure discriminating technologies are available to our system solutions that, in turn, provide our customers with the highest performance capability at the lowest possible cost.

One particular technology network is the Multifunction Electro-Optical Systems Technology Network (MEOSTN) whose charter is to foster the advancement of electro-optical and infrared (EO/IR) technologies and promote enterprisewide communication, synergistic product development and technical reuse within the field. Mirrors play an important role in many EO/IR systems, both in the precise redirection of light and in component size and weight reduction. This article discusses two new Raytheon technologies in this area currently entering initial deployment with clear paths to expanding future roles across the company.

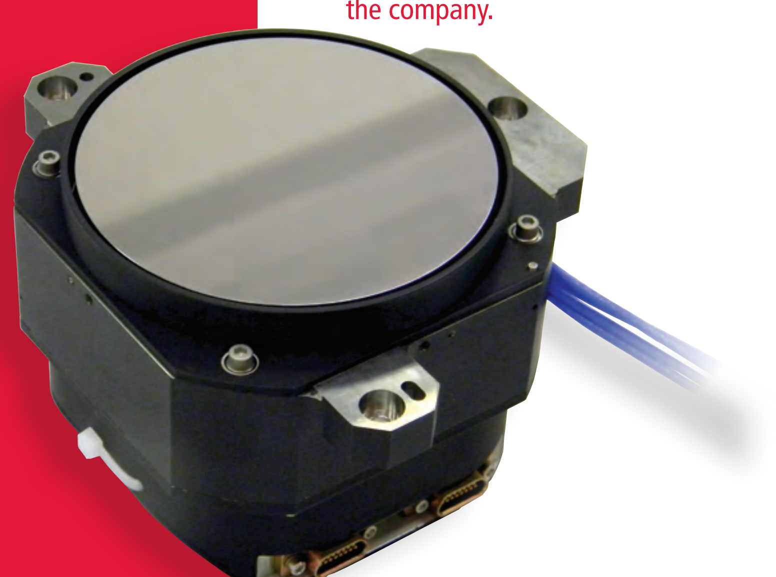


Figure 1: Complete housing and actuator mechanism for a Fast Steering Mirror

WIDE-FIELD STEERING MIRRORS

EO/IR turrets have become a standard feature on aircraft, providing magnified video images of the surface below for Intelligence, Surveillance and Reconnaissance (ISR) missions. They frequently require the ability to sweep large areas; for example, during rescue missions at sea when searching for survivors in life jackets on the ocean. Until recently, this required that the entire sensor turret slew to scan areas repeatedly, as well as have the ability to stabilize the optical images under conditions of shaking and vibration from the host aircraft. In fact, earlier generations of fast steering mirrors appeared in systems solely for image stabilization over small angles.

Raytheon has recently evolved the Fast Steering Mirror (FSM) beyond a single-task component into a multi-function scene scanning and image stabilization device (see Figure 1) able to sweep wide areas quickly, in much the same way as the human eye scans the page of a book without movement of the head.

The new breed of Raytheon FSMs are not only fast, but their integral position sensors make them precise, with low pointing noise and precise line of sight accuracy. As a result, EO/IR systems with this technology can produce sharp high resolution images of distant scenes free from jitter, while also having the ability to sweep large areas far more quickly than a practical imaging turret.

Raytheon's current generation of EO/IR detectors are as wide as several inches across. The size of FSMs has also increased, taking advantage of the capabilities of these larger optics to produce high resolution images at extreme range. To account for the associated increase in mass of the larger mirrors, the new actuator mechanisms are reaction compensated to eliminate forces they would otherwise impart on the optical turret, causing shaking in the other instruments.

Figure 2: Thixomolded MERLOT Mirror (less than 1½ ounces) showing the lightweight webbed structure and integral mounting points produced in the mold

Use in airborne or space environments requires that Raytheon's large diameter, wide field of motion mirrors be both rugged and reliable to support long duration missions under harsh conditions. These components are built to survive high accelerations and integrate with other systems having high operational reliability.

The practicality and effectiveness of Raytheon's current generation wide field of motion FSMs have made them a capability multiplier in many programs. Today, larger mirrors with wider range of movement devices are under development, offering expanded capabilities and a clear path for future growth of the technology.

MERLOT® ULTRALIGHT METALLIC MIRRORS

Multispectral Reflective Lightweight Optics Technology, known as MERLOT, is a new material and design methodology that leverages free-form diamond point-turning capabilities to create high-performance, low-cost and lightweight reflective metallic mirrors and optical assemblies. The core of this technology is a new mirror blank material and manufacturing method to replace conventional aluminum 6061-based optical systems.

Raytheon originally developed MERLOT to meet weight and performance requirements for handheld targeting systems. In these types of systems, weight, toughness, material stability, optical quality and cost are all highly constrained. MERLOT opened new design space, leaving conventional aluminum 6061 for a 35 percent lighter weight material better adapted to low cost production in large numbers and an improved mirror process patented by Raytheon. The resulting mirrors provide diffraction-limited performance for improved daytime imaging, laser ranging and night vision target acquisition.

The blanks for MERLOT mirrors are produced by a type of low temperature, low thermal stress injection molding called thixomolding. With thixomolding, the mold for the mirror can have extensive light-weighting features such as carefully designed webs and machined mounting transitions (Figure 2), yielding blanks with a very efficient geometry absent of machining stresses imparted to the material. Starting with thin walled, weight-efficient shapes allows MERLOT mirrors to be stiffer than CNC Machined mirrors. A thixomolded alloy, due to its extremely fine grain and lack of harder elemental inclusions, can be diamond-point turned into high quality reflective mirrors (Figure 3).

MERLOT is tailored for standard diamond-point turning processes and holds a distinct advantage over aluminum 6061 in terms of diamond tool wear. With aluminum 6061, diamond tool wear is significant, forcing constant tool adjustments that increase cost and create undesirable and often unpredictable process variability. With MERLOT, diamond tool wear is virtually non-existent, providing tremendous opportunity for cost savings, uniform parts and reliable volume production. Additionally, the alloy is proven to be optically stable over time. Given the benefits it brings to metallic mirrors, MERLOT is an effective alternative to aluminum in reflective optics or optical assemblies seeking weight and cost reductions.

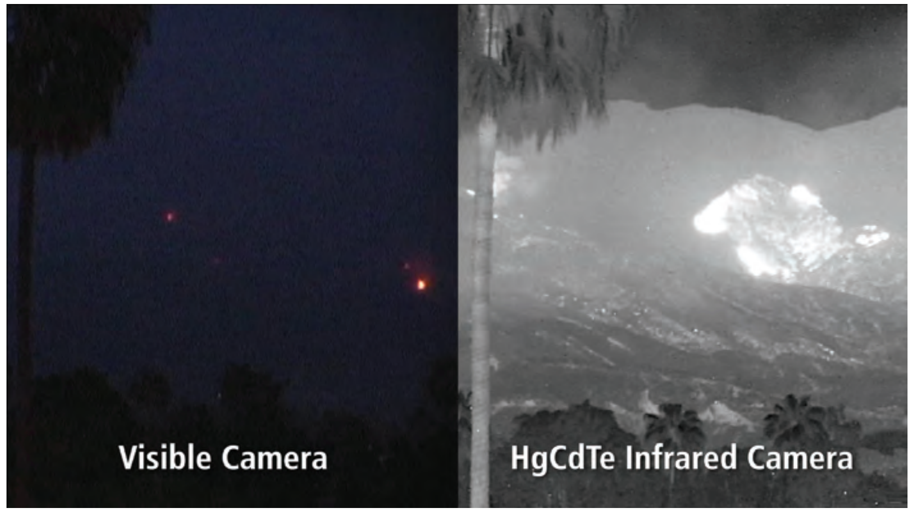
Figure 3: Single Point Diamond Turned and polished MERLOT Mirror with visible light quality figure and finish

EO/IR devices and their associated mirrors, whether used as hand held instruments, seekers for missiles, imaging platforms on aircraft or sensors on spacecraft, are key to customers' mission success. The research, design and development, as well as manufacturing, deployment and support, of these assets continues at Raytheon as we develop practical solutions and decisive improvements in system capability and availability for our customers. ■

— Richard J. Wright, Andrew Bullard, John Anagnost, John P. Schaefer, Dan Vukobratovich, Scott Balaban

GLASSBLOWING IS IN THE GENES FOR KONRAD GLEISSNER

Konrad Gleissner, a Production Specialist at Raytheon Space and Airborne Systems in Goleta California, is an expert in glassblowing techniques. He uses these techniques to help in the production of important infrared (IR) sensor components. Mercury Cadmium Telluride (HgCdTe) night vision systems allow our customers to see through complete darkness, dust and sandstorms, and even into far away galaxies. They are employed in the U.S. military's optical targeting systems and night vision sights. HgCdTe is the only common material that can detect IR radiation in both accessible atmospheric windows. These are the mid-wave infrared window (MWIR) from 3 to 5 micrometers (μm) and the long-wave window (LWIR) from 8 to 12 μm. The advantage this capability provides is clear (see photo), but these systems are not easy to produce. While HgCdTe is very good at sensing IR light, it is a difficult material to work with, requiring material deposition on native substrates that are not widely available.



Comparison of a nighttime scene as observed through a visible camera (left) and an Infrared camera (right)

HgCdTe night vision systems are fabricated on Cadmium Zinc Telluride (CdZnTe) substrates. Because the substrates are not readily available, Raytheon had to come up with its own method to grow the substrate. The CdZnTe substrate fabrication process begins with the creation of a high purity quartz ampoule that varies in both size and shape. This is the device in which the three materials are then grown into a solid boule. The three materials comprising the CdZnTe are inserted into the ampoule, sealed off under vacuum and grown in a furnace for approximately one month. This process is performed using a Hydrogen and Oxygen torch flame and must ensure that no contaminants are introduced into any of the materials, as impurities that get into the substrate will impact sensor quality. The end result of the overall process is a single CdZnTe crystal boule with a very high success rate.

KONRAD'S MAIN RESPONSIBILITY IS TO MAKE THE CUSTOM GLASSWARE TO GROW THE CRYSTALS WHICH ARE THEN CUT INTO SUBSTRATES FOR THE SENSORS

It is at several steps throughout this activity where Konrad's skill as a master glassblower comes into play. His main responsibility is to make the custom glassware to grow the crystals which are then cut into substrates for the sensors.

Interestingly, Konrad's background in glassblowing comes from his father, Konrad Gleissner Sr., who himself was a master glassblower at Raytheon for more than 35 years. Konrad Sr. had a workshop in his garage where he did glassblowing as both a side job and hobby, and introduced Konrad to the craft at a young age. Watching his father create works of art out of glass fascinated the young Konrad, who was anxious to try his own hand at it. So, as he grew older, his father started him experimenting with several glassblowing techniques, and eventually he began working on projects, such as thermocouple wells, which then led to the more scientific applications of glass blowing.

Along with the scientific techniques, Konrad's father also had an artistic flair and would often create glass artwork figures. Konrad however decided he should stick with the technical applications when, in an attempt to duplicate one of his father's creations, he turned out a dolphin that more closely resembled a shark.

Konrad Gleissner shapes a tube used for growing crystals, which will later be sliced into sensor chips for imaging equipment

After 35 years with the company, when Konrad Sr. announced his retirement from Raytheon, Konrad Jr. was the natural choice for his replacement. Konrad has now been with Raytheon for 22 years. He continues to evolve his skills as a master glassblower, and is always exploring new ways and new directions to apply his talent.

Along with his responsibilities in the HgCdTe products, for which there is a constant demand, Konrad is also known to his fellow employees as the man who can make specialized equipment. His skills have been requested to make custom beakers, experimental equipment, specialized quartz boats for furnaces and other one of a kind apparatuses. As glassblowing is a dying art, required glassblowing equipment can be difficult to find, and often requires modifications or repair. As Konrad's skills remain in high demand in the Raytheon glassblowing arena, he is always able to complete the tasks at hand.

Konrad lives with his wife, Michelle, who prefers not to have a glassblowing workshop in the garage like Konrad's father had, since having liquid hydrogen in the house is not a good idea. While Konrad's son, Conner, has not yet shown interest in glassblowing, Konrad is hopeful that he might one day be the third generation of Raytheon glassblowing experts.

Konrad appreciates his value to the company and the importance of the skills he provides. "I love Raytheon," he states, "It's a wonderful company, and our products help our military be one of the strongest in the world." Raytheon employs many specialists from around the world, and glassblowing is an example of one of these exceptional talents. ■

— Lisa Hubbard

Demonstrating the artistic side of glassblowing: a dolphin and a ship in a bottle made by Konrad Sr.

PATENTS ISSUED TO RAYTHEON

At Raytheon, we encourage people to work on technological challenges to make the world a safer place and develop innovative commercial products. Part of that process is identifying and protecting our intellectual property. Once again, the U.S. Patent Office has recognized our engineers and technologists for their contributions in their fields of interest. We congratulate our inventors who were awarded patents from July 2018 through December 2018.

UNITED STATES

JOHN M. CONNOLLY
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SHUBHA KADAMBE, KIM A. PHAN, JASON SLEPICKA, BENJAMIN T. WRIGHT
3262530 Proactive emerging threat detection

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JOHN P. GIANVITTORIO
3275042 Expandable analog manifold

FREDERICK B. KOEHLER, WARD D. LYMAN
3283838 Shape memory alloy disc vent cover release

STEPHEN T. FASOLINO, BRIAN J. MERCER, JASON L. WHEELER
3304672 System and method for providing power from a standardized component without a power source output to an accessory component

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