Future of Battlespace Situational Awareness: A Workshop Summary (2013)

DETAILS

28 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-28621-3 | DOI 10.17226/18353

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SUGGESTED CITATION

National Research Council 2013. *Future of Battlespace Situational Awareness: A Workshop Summary*. Washington, DC: The National Academies Press. https://doi.org/10.17226/18353.

Future of Battlespace Situational Awareness

A Workshop Summary

Daniel Talmage, Rapporteur

Committee for Science and Technology Challenges to
U.S. National Security Interests
Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, NWWashington, DC 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This study was supported by Contract HHM402-10-D-0036 between the Defense Intelligence Agency and the National Academy of Sciences. Any views or observations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

Limited copies of this report are available from the Division on Engineering and Physical Sciences, National Research Council, 500 Fifth Street, NW, Washington, DC 20001; (202) 334-2400.

Printed in the United States of America

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COMMITTEE FOR SCIENCE AND TECHNOLOGY CHALLENGES TO U.S. NATIONAL SECURITY INTERESTS

Preface

The workshop described in this report is the third in a series of three workshops held in early 2012 to further the ongoing engagement among the National Research Council's (NRC's) Technology Insight—Gauge, Evaluate, and Review (TIGER) Standing Committee, the scientific and technical intelligence (S&TI) community, and the consumers of S&TI products.[1] A restricted version of this report can be requested by contacting the Public Affairs Office of the sponsoring agency, the Defense Intelligence Agency, directly.

We express our appreciation to the members of the Committee for Science and Technology Challenges to U.S. National Security Interests for their contributions to the planning of this workshop. We are also grateful to the many members of the technology community who participated actively in the workshop, as well as to the sponsor for its support. The committee also expresses sincere appreciation for the support and assistance of the NRC staff, including Terry Jaggers, Daniel Talmage, Sarah Capote, Marguerite Schneider, Zeida Patmon, and Dionna Ali.

J. Jerome Holton, *Chair*
Edward Greitzer, *Vice Chair*
Committee for Science and Technology
Challenges to U.S. National Security Interests

[1]The first two workshops were summarized in the following National Research Council reports: NRC, 2012, *Big Data: A Workshop Report,* The National Academies Press, Washington, D.C., available at http://www.nap.edu/catalog.php?record_id=13541; and NRC, 2012, *Summary of a Workshop on the Future of Antennas,* The National Academies Press, Washington, D.C., available at http://www.nap.edu/catalog.php?record_id=13540.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Anita K. Jones (NAE), University of Virginia,
George A. Paulikas, The Aerospace Corporation (retired),
Thomas D. Romesser (NAE), Northrop Grumman (retired), and
Alton D. Romig (NAE), Lockheed Martin Aeronautics Company.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the views of individual participants, nor did they see the final draft of the report before its release. The review of this report was overseen by Lou Lanzerotti (NAE), New Jersey Institute of Technology. Appointed by the NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the author and the institution.

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INTRODUCTION

The workshop on Future Battlespace Situational Awareness was part of an ongoing series conducted by the National Research Council's Committee for Science and Technology Challenges to U.S. National Security Interests (see Appendix A for members' biographies). The first two workshops looked at individual technologies related to "big" data and future antennas and provided context for the topic addressed in the third workshop—the planning of a future warfare scenario. The statement of task for the overall project is given in Box 1-1. The objectives for the third workshop were to:

- Review technologies that enable battlespace situational awareness 10-20 years into the future for red and blue forces;
- Emphasize the capabilities within air, land, sea, space, and cyberspace.

The workshop was held on May 30-31, 2012, in Suffolk, Virginia, at the Lockheed Martin Center for Innovation (see Appendix B for the agenda and a list of participants). The sessions were not open to the public because they involved discussions of classified material, including data addressing vulnerabilities, indicators, and observables. These presentations and discussions are summarized below. Biographies of the presenters are provided in Appendix C.

This report has been prepared by the workshop rapporteur as a factual summary of what occurred at the workshop. The committee's role was limited to planning and convening the workshop. The views contained in the report are those of individual workshop participants and do not necessarily represent the views of all workshop participants, the committee, or the National Research Council. The presentations are summarized in the order shown in the workshop agenda. The presentations were followed by discussion periods during which questions were posed and answered and ideas were exchanged among the participants. These discussions are not captured in this report.

FUTURE BATTLESPACE TECHNOLOGY—PRESENTATIONS

Daniel DeLaurentis, School of Aeronautics and Astronautics, Purdue University

Daniel DeLaurentis, an associate professor at Purdue University, started the morning presentations with a discussion of issues related to aerospace vehicles and networked aerospace vehicles. He pointed out that within his area of expertise, there are three important items: collection, processing, and sense-making. He defined sense-making as how scientists seek to understand the uncertainty in state variables and what confidence levels are needed, particularly for time-sensitive requirements. Timeliness and confidence are critical. For red forces, he noted there are circumstances that can make timeliness and confidence intractable, including (1) the need to be able to detect information generation that is counter to state variable computation; (2) the need to be able to react so that the United States can do the state variable calculations in order to enable the sense-making; and (3) the need for a higher degree of autonomy in the state variable calculations. These circumstances cause a challenge in sense-making as the information context becomes critical. Machine learning integrated into the decision cycle that a human can deal with is probably a critical advancement that will help.

BOX 1-1

Statement of Task

An ad hoc committee will plan and conduct three workshops on the science and technology (S&T) fields noted below that have potential impact on U.S. national security.

- Big Data—The workshop will review emerging capabilities in large computational data to include speed, data fusion, use, and commodification of data used in decision making. The workshop will also review the subsequent increase in vulnerabilities over the capabilities gained and the significance to national security.
- Future of Antennas—The workshop will review trends in advanced antenna research and design. The workshop will also review trends in commercial and military use of advanced antennas that enable improved communication, data transfer, soldier health monitoring, and other overt and covert methods of standoff data collection.
- Future Battlespace Situational Awareness—The workshop will review the technologies that enable battlespace situational awareness 10-20 years into the future for both red and blue forces. The workshop will emphasize the capabilities within air, land, sea, space, and cyberspace.

The committee will design the workshops to address U.S. and foreign research, why S&T applications of technologies in development are important in the context of military capabilities, and what critical scientific breakthroughs are needed to achieve advances in the fields of interest—focusing detailed attention on specific developments in the foregoing fields that might have national security implications for the United States. The workshops will each also consider methodology to track the relevant technology landscape for the future.

Each of the three workshops will feature invited presentations and panelists and include discussions on a selected topic including themes relating to defense warning and surprise. The committee will plan the agenda for the workshops, select and invite speakers and discussants, and moderate the discussions. Each event will result in a workshop summary that will be subject to appropriate institutional review prior to release.

DeLaurentis introduced a specific case and suggested that the challenge is data flow and determining the value of the information that can be obtained. The analysts have to make very quick computations on where to allocate resources and adapt the architecture, using multiple distributed systems (air, space, sea). He suggested the need for adaptive systems that mix humans and machines to leverage the best of both. One of the challenges is determining what to do when human operators and machine algorithms disagree.

Al Romig, Skunk Works, Advanced Development Program, Lockheed Martin Aeronautics Company

Al Romig, vice president and general manager at Lockheed Martin Aeronautics, started with a war analogy. He suggested that it was useful to think of where one has been, and then to think of where one wants to go. The American Civil War was a conflict that brought together modern industrialized warfare with tactics from the Napoleonic era. Dislocations between tactics and capabilities led to major carnage. This has happened time and time again on the battlefield. He noted that even though technology had evolved, fighters tried to use something new the same way they were using old technology. Instead, new technology needed new concepts of operation. The P-80 had to be flown differently than the P-51, and this is the same with newer planes. A person's natural inclination, however, is to employ new technology the way one used the old technology.

Romig stated that another example was the transition from the F-4 to the F-15. Each plane was completely different in how a crew member fired missiles, how one defended, etc. The improvements that had been developed by the air crews to optimize F-4 performance were transitioned to the F-15s, but that approach actually hindered performance. The air crews had to learn to forget the old ways and had to learn new ways: air crews and support staff had to go through new training for logistics, use of imagination, and leadership so that they would think differently.

He then pointed out that the newest fifth-generation plane is a flying computer and a flying sensor platform. Strategists need to learn to take advantage of the plane's capabilities. If U.S. pilots use fifth-generation planes the same way pilots used F-15s, they are relinquishing most of the new capabilities. Romig also discussed the additional challenge of how to integrate fourth-generation and fifth-generation aircraft with surface and sea platforms. Among the questions are how the United States might integrate all these together, sharing information. Warfighters of the future do not want to drown in data while starving for knowledge, and so they need to share and process data in an intelligent way.

David Vos, UAS & Rockwell Collins Control Tech, Inc. (retired)

David Vos, former senior director of unmanned aerial systems at Rockwell Collins Control Technology, titled his presentation "Automation and Autonomy: Impact on Future Battlespace Situational Awareness." He suggested that a key element for the future is a solution that is not intractable and is flexible enough to work. An example is achievement of high performance through simple algorithms: other examples are shown in Athena/Rockwell Collins videos on F-18 flight implementation that are available on YouTube.

Vos indicated that for the future the focus should be "what are we trying to accomplish, and how do we get there with simple, cost-affordable solutions?" It's easy to spend $100 on a solution but much more difficult to do the same thing for $1. The defense industry may be pricing themselves out of their own business argued Vos. DoD budgets are spiraling out of control. The United States should focus on how to achieve the $1 engineering space. This will provide the United States with an incredible advantage in the worldwide competition space.

Vos then went on to note that pretty much anything can be made unmanned today. The United States can do it, and so can many other countries and companies around the world. The resulting unmanned system can achieve high performance at low cost and can enter the arms market very quickly. Today, any country has this capability.

Vos noted that capabilities come from interesting places in other technology areas such as the seatbelt manufacturing area. In other words, there is a great deal of capability out there that can be repurposed. The United States can get distracted by reinventing capabilities for hundreds of dollars, when it could simply repurpose existing $1 capabilities.

Vos asserted that the United States needs to be careful to not trip up by losing focus on the fundamentals. For example, there are unmanned aerial vehicles that land themselves reliably and repeatedly but others for which landing is a problem. There is an untapped enormous commercial value to autonomous systems today. Market growth will be driven not only by military but also by commercial interests, including public and civilian interests. Autonomous systems are a worldwide capability. Vos said that ITAR (International Traffic in Arms Regulations) is not a solution in the unmanned field and may be incredibly unwise for competition. There is a potential for less abuse with autonomous systems than with manned systems. Aircraft have been the pioneering domain, but any vehicle can be made autonomous. Researchers need to expand their thoughts on how humans can be integrated with autonomous vehicles—e.g., use humans for what humans do best and let the system drive the boat.

According to Vos there is a potential for abuse of these autonomous systems even with humans on board. Trusting that humans will make good decisions can reflect faulty logic. Not having a human on board may provide more security and more control. The country needs to break the cultural logjam that prevents it from fully realizing its potential. Some changes coming right now include unmanned civil aviation. The result will be better air traffic management, which Vos felt would enable, for example,

unmanned cargo flights around the world, unmanned air taxi service, unmanned postal service, etc, affording tremendous benefits for all. Interdiction of rogue users of airspace might actually be easier if designers paid attention to this capability during design of a system.

Vos also noted that cellular networks bring dramatic new connectivity options. Networking of vehicles gets easier, which enables autonomous-vehicle collaboration. One area that would be improved by such collaboration is traffic management and control, which would reduce the number of accidents and dangerous driving. This capability would be enabled by cryptography. On the other hand, networking improvements could enable the asymmetric enemy as well, but clever thinking can prevent or reduce the potential for abuse.

Microelectronics and sensing are continuing to improve rapidly (microelectromechanical systems, nanotechnology, higher performance, lower cost). Vos asserted that the improvements over the past decade have been amazing and that there is no foreseeable end in sight for the current improvement trends. Technologies continue to become cheaper as well. The volume of demand is driving the improvement of supply quality and cost.

The civilian world has an insatiable appetite for higher-performance digital imaging. Improvements in accuracy, resolution, spectrum, and size are astonishing. The electrooptical command, control, detection system in low-light conditions can give a really good image, and so it is not necessary to go to infrared, which has obvious applicability in battlespace awareness.

Vos concluded his talk by suggesting that less wealthy forces that are not friendly to the United States can use these low-cost solutions. The United States can always build something that is so expensive no one will buy it, not even the United States itself. The unfriendly forces can use the slightly less capable, but a "heck of a lot cheaper," commodity solutions to create a very "annoying" threat. For example, the 1976 Angolan war had missiles that used gyros with string to spin up on launch. This solution was low tech, low cost, and perfectly adequate for the short time period needed for the flight of the missile.

John Main, Intific

John Main, chief operating Officer, Intific, discussed the flood of sensors and data. In the past every soldier was a sensor, but today everyone is a sensor. In addition new sensors are being approved such as the Google autonomous vehicles being granted a driver's license in Nevada. Today everyone is a connected unit—kids text to each other all day long. Some of these conversations are "I'm alive," but a large part is passing actual information.

Micro-controllers are a key element. They are incredibly easy to use. They are basically the decision-making element in any sensor. One can easily use libraries to copy and paste programs to use them. Imagine what an individual could do with many micro-controllers working together. Main pointed out that fusion technology is going to proliferate. A key challenge is the flood of information coming from all different types of sensors from all different locations.

Brian Ballard, APX Labs

Brian Ballard, founder and CEO of APX Labs, made comments on how intelligence for the warfighter is disseminated from the ground and how to disseminate across the last tactical mile. The Army has a Forward Observation Base (FOB) focus to bring cell communications to provide massive amounts of data (not voice, but data) to soldiers at the edge. Ballard asked participants what ubiquitous communications will mean in 10-20 years. He suggested as an example that there will be a change in cellular systems—moving away from towers. Currently a call goes from phone to tower to switching center and back to tower to phone. Smarter towers eventually replaced by phones acting as repeaters means that phones will act as virtual, infinitely reconfigurable networks that cooperate for data delivery (voice or data).

He discussed how links between manned and unmanned systems will be enabled. These links will increase responsibilities and implications for rules of engagement. When a soldier has real-time access to intelligence, what responses are appropriate? Bad decisions, based on what is believed to be good intelligence, is a problem.

SCENARIO

Mark Jefferson introduced the workshop scenario to the participants. The scenario consisted of several discrete steps showing force action and reaction. Using visual screens, Jefferson introduced the participants to the premise of the scenario. The exercise facilitator guided the participants through a series of steps of both red and blue teams designed to elicit participant conceptionalization of potential operational strategies. These moves included deployment of weapons platforms and establishment of logistics support. The scenario was extremely robust in order to address the workshop planning committee's desire to cover multiple phases across the spectrum of operations, generating discussions about future technologies and deployment opportunities.

GENERAL DISCUSSION

One of the important themes evident in the discussion from some participants at the end of the workshop was an appreciation for how "sticky" normal is. "Normal" now is peer-level competition planning—the United States has aircraft carriers, other countries have aircraft carriers; the United States has submariness, other countries have submariness; and so on.

Appendixes

Appendix A

Committee Biographies

J. Jerome Holton, *Chair*, is a senior systems engineer with the Tauri Group, where he supports the BioWatch Systems Program Office within the Office of Health Affairs, Department of Homeland Security (DHS). He provides analysis, advice, and counsel to senior government decision makers on policy, technology, and operations issues related to weapons of mass destruction and their effects on civilian infrastructure, first responders, military forces, and tactical operations. Prior to this, he served in a variety of leadership positions for private-sector companies, spanning the gamut from scientific research start-up to large management consulting firm. Past clients include the Office of the Deputy Assistant to the Secretary of Defense for Counterproliferation and Chemical/Biological Defense, the Chemical Biological Defense Directorate of the Defense Threat Reduction Agency, the Chemical Biological National Security Program of the Department of Energy, and the DHS Science and Technology Directorate. His work extends broadly across the chemical/biological/radiological/nuclear/conventional explosives detection and countermeasures arena. For several years, he focused on the counterproliferation of, counterterrorism/domestic preparedness issues for, and the detection, identification, and decontamination of chemical and biological weapons. Recent accomplishments include fielding information operations tools and enhancing the intelligence, surveillance, and reconnaissance capabilities to detect and defeat improvised explosive devices as well as the development of applique armor solutions to counter explosively formed penetrators. Holton previously served on the NRC's Standing Committee on Defense Intelligence Agency Technology Forecasts and Reviews (TIGER), the Committee for the Symposium on Avoiding Technology Surprise for Tomorrow's Warfighter, and the Committee on Alternative Technologies to Replace Antipersonnel Landmines. He earned his B.S. in physics from Mississippi State University and holds M.S. and Ph.D. degrees in experimental physics from Duke University.

Edward M. Greitzer (NAE), *Vice chair*, is the H.N. Slater Professor, Department of Aeronautics and Astronautics at Massachusetts Institute of Technology. He received his A.B., S.M. and Ph.D. from Harvard University. Prior to joining MIT in 1977, he was with United Technologies Corporation, and, more recently, he was on leave at United Technologies Research Center as director, Aeromechanical, Chemical, and Fluid Systems. From 1984 to 1996 he was the director of MIT's Gas Turbine Laboratory, and from 1996 to 2002 was associate head, and from 2006 to 2008 deputy head, of the Department of Aeronautics and Astronautics. His research interests have spanned a range of topics in gas turbines, internal flow, turbomachinery, active control of fluid systems, university-industry collaboration, and robust gas turbine engine design; he was the MIT lead for the Cambridge-MIT Institute Silent Aircraft Initiative. He teaches graduate and undergraduate courses in the fields of propulsion, fluid mechanics, thermodynamics, and energy conversion, as well as the department's undergraduate project course. Greitzer is a three-time recipient of the American Society of Mechanical Engineers Gas Turbine Award for outstanding gas turbine paper of the year, the ASME Freeman Scholar Award in Fluids Engineering, the

International Gas Turbine Institute Scholar Award, and publication awards from the American Institute of Aeronautics and Astronautics and the Institution of Mechanical Engineers. He has received the Aircraft Engine Technology Award from the ASME International Gas Turbine Institute, the U.S. Air Force Exceptional Civilian Service Award, and the ASME R. Tom Sawyer Award. He has been a member of the U.S. Air Force Scientific Advisory Board and the NASA Aeronautics Advisory Committee, and he is an Honorary Professor at Beihang University (Beijing). Greitzer has published more than 70 papers and is lead author of the book *Internal Flow: Concepts and Applications*, published by Cambridge University Press. He is a fellow of AIAA and ASME, a member of the National Academy of Engineering, and an International Fellow of the Royal Academy of Engineering.

Brian Ballard founded and currently serves as the CEO of APX Labs, a software company focused on leading development into wearable augmented reality products at the nexus of computer vision, user experience, and see-through displays. Previously he served as the director of product development and vice president at Battlefield Telecommunication Systems (BTS), where he led the development of defense-oriented augmented reality and biometric data fusion applications. As part of his portfolio, he was also heavily engaged in developing mobile 3G and 4G networks, devices, and applications for tactical military employments. Prior to joining BTS, Ballard served as the CTO at Mav6, where he was involved in the development of emerging networking and embedded systems technologies for intelligence, surveillance, and reconnaissance (ISR) systems and applications in government and military. He is a highly experienced professional in the field of national intelligence systems and computer engineering. Employed for more than 10 years with the National Security Agency, he has dealt with all forms of data collection, dissemination, processing, and visualization. Ballard holds an M.S. and a B.S. in electrical and computer engineering from Carnegie Mellon University, and a master's of technology management from the University of Maryland. He is currently working on an MBA at the University of Maryland.

Kenneth I. Berns (NAS/IOM) is director and Distinguished Professor, UF Genetics Institute/Molecular Genetics and Microbiology, Medicine, University of Florida. He has served as a member of the Composite Committee of the United States Medical Licensing Examination, chairman of the Association of American Medical Colleges, president of the Association of Medical School Microbiology and Immunology Chairs, president of the American Society for Virology, president of the American Society for Microbiology, and vice-president of the International Union of Microbiological Societies. He is a member of the National Academy of Sciences and the Institute of Medicine. Dr. Berns's research examines the molecular basis of replication of the human parvovirus, adeno-associated virus, and the ability of an adeno-associated virus to establish latent infections and be reactivated. His work has helped provide the basis for use of this virus as a vector for gene therapy. Dr. Berns's M.D. and his Ph.D. in biochemistry are from the Johns Hopkins University.

Ann N. Campbell is director, Information Solutions and Services, at Sandia National Laboratories. Her organization develops and stewards a broad range of software applications and information systems for both internal (enterprise) and external customers to facilitate the delivery of effective national security technologies. At Sandia, she previously served as senior manager and deputy to the chief technology officer for cyber security S&T. In that role she was responsible for developing and implementing an institutional strategy for cyber S&T. She was recently acting director for Sandia's Cyber Security Strategic Thrust, leading the lab's activities to expand Sandia's cyber workforce and infrastructure, and strategies to provide increased support for Sandia's national security sponsors' cyber missions. Campbell has also served as deputy for technical programs for the Defense Systems and Assessments Strategic Management

Unit (DSA SMU). In that role she advised the DSA vice president regarding the unit's national security programs, was responsible for strategic planning and the investment strategy for the DSA, and assisted with implementation of the laboratory's cyber strategy. From 2003 to 2007, Campbell led the Assessment Technologies Group in Sandia's Information Systems Analysis Center. She was responsible for development, coordination, and oversight of programs focusing on vulnerability assessments and development of national security solutions in information technologies for multiple government sponsors. From 1999 to 2003 she was manager of the Microsystems Partnerships Department, which assessed and addressed microelectronics vulnerabilities for a variety of government sponsors. In that role Campbell led Sandia's program to support the DoD Anti-Tamper Initiative. She joined the technical staff at Sandia in 1985 and had assignments in the Materials and Process Center and the Microsystems Science, Technology, and Components Center. She conducted research on the microstructure and physical properties of advanced materials, the physics of microelectronics failures, and the development of advanced microelectronics failure analysis techniques. Campbell serves on the National Academies' Standing Committee on Technology Insight–Gauge, Evaluate and Review (TIGER). She is a senior member of IEEE and served as vice president of membership for the IEEE Reliability Society and on the Management Committee and board of directors for the IEEE International Reliability Physics Symposium. She has more than 20 publications and several patents. She holds a B.S. degree (1979) in materials engineering from Rensselaer Polytechnic Institute and M.S. (1980) and Ph.D. (1985) degrees in applied physics (materials science concentration) from Harvard University.

Dean R. Collins recently retired as a deputy director of DARPA's Microsystems Technology Office (MTO); as a chief scientist he was responsible for the monitoring, analysis, and evaluation of research projects directed by MTO program managers and also participated in the concept planning for leading MTO into new programs beyond the current state of the art in electronics, photonics, microelectromechanical systems (MEMS), component architectures, and algorithms. He managed the MTO program on integrated circuit cybersecurity. Prior to joining DARPA, Collins was director for advanced research and development activity in information technology (ARDA). ARDA functioned as a joint activity of the intelligence community and the Department of Defense, addressing high-risk/high-payoff information technology problems that had broad impact across both supporting communities. Collins initiated ARDA's key cyber security effort. He was also a member of the intelligence community Advanced Research and Development Committee and managed the ARDA quantum information science effort. Prior to joining ARDA, Collins was with the National Institute of Standards and Technology (NIST), where he was chief of the High Performance Systems and Services Division, the largest division at NIST. This position focused on information technology with a strong commercial bias, and the topics investigated ranged from biometrics to electronic books. Previously, Collins was with Texas Instruments, as director of the System Components Lab, which was responsible for all research on III-V devices, nanoelectronics, photonics, and neural networks. Prior to that, he was director of the Interface Technology Lab, which was responsible for all sensor and display research, including LCDs, DLPs, and CCDs. Collins is a fellow of the IEEE, a member of the American Physical Society, and a registered professional engineer. He has published more than 40 refereed articles and has ten issued U.S. patents.

Sharon C. Glotzer is the Stuart W. Churchill Collegiate Professor of Chemical Engineering and a professor of materials science and engineering at the University of Michigan (UM), Ann Arbor, and is director of research computing in the UM College of Engineering. She also holds faculty appointments in physics, applied physics, and macromolecular science and engineering. She received a B.S. in physics from UCLA and a Ph.D. in physics from Boston University. Prior to

joining UM, she worked at the National Institute of Standards and Technology. Her research focuses on computational nanoscience and simulation of soft matter, self-assembly and materials design, and computational science and engineering and is sponsored by the DoD, DoE, NSF, and the J.S. McDonnell Foundation. Glotzer is a fellow of the American Physical Society and of the National Security Science and Engineering Faculty, and she was elected to the American Academy of Arts and Sciences in 2011. She has served on the National Academies' Solid State Sciences Committee; Technology Warning and Surprise study committee; Biomolecular Materials and Processes study committee; Modeling, Simulation, and Games study committee; and Technology Insight–Gauge, Evaluate, and Review (TIGER) Committee. She is involved in roadmapping activities for computational science and engineering, including chairing or co-chairing several workshops, steering committees and pan-agency initiatives, and she serves on the advisory committees for the DOE Office of Advanced Scientific Computing and NSF Directorate for Mathematical and Physical Sciences. Glotzer is also co-founding director of the Virtual School for Computational Science and Engineering under the auspices of the NSF-funded Blue Waters Petascale Computing Project at the National Center for Supercomputing Applications.

J.C. Herz is chief executive officer at Batchtags, LLC. She is also a technologist with a background in biological systems and computer game design. Her specialty is massively multiplayer systems that leverage social network effects, whether on the web, mobile devices, or more exotic high-end or grubby low-end hardware. She currently serves as a White House Special Consultant to the Office of the Secretary of Defense (Networks and Information Integration). Defense projects range from aerospace systems to a computer-game-derived interface for next-generation unmanned air systems. Hertz is one of the three co-authors of OSD's Open Technology Development roadmap. She serves on the Federal Advisory Committee for the National Science Foundation's education directorate. In that capacity, she is helping NSF harness emerging technologies to drive U.S. competitiveness in math and science. Hertz was a member of the National Research Council's Committee on IT and Creative Practice and is currently a fellow of Columbia University's American Assembly, where she is on the leadership team of the Assembly's Next Generation Project. In 2002, she was designated a Global Leader for Tomorrow by the World Economic Forum. She is a member of the Global Business Network; a founding member of the IEEE Task Force on Game Technologies; a term member of the Council on Foreign Relations; and a member of the advisory board of Carnegie Mellon's ETC Press. Hertz graduated from Harvard University with a B.A. in biology and environmental studies, magna cum laude, in 1993. She is the author of two books, *Surfing on the Internet* (Little Brown, 1994), an ethnography of cyberspace before the web, and *Joystick Nation: How Videogames Ate Our Quarters, Won Our Hearts, and Rewired Our Minds* (Little Brown, 1997), a history of videogames which traces the cultural and technological evolution of the first medium that was born digital, and how it shaped the minds of a generation weaned on Nintendo. Her books have been translated into seven languages. As a *New York Times* columnist, Hertz published 100 essays on the grammar and syntax of game design between 1998 and 2000. She has also contributed to Esther Dyson's Release 1.0, *Rolling Stone*, *Wired*, *GQ*, and the *Calgary Philatelist*.

Kenneth A. Kress is a senior scientist for KBK Consulting, Inc., an affilate of Montana State University's Department of Physics, and a consultant for Booz Allen Hamilton, where he specializes in quantum information science and other technical evaluations and strategic planning for intelligence and defense applications. Some of his past clients include DARPA's Microsytems Technology Office, Noblis, Georgia Tech Research Institute, Mitretek Systems Inc., and Lockheed Martin's Special Programs Division. From 1971 to 1999 he worked in a series of positions at the Central Intelligence Agency's Directorate of Operations, Office of Development and Engineering, and finally Office of Research and Development (ORD); first as a research and development manager, later as a program manager, and finally as an ORD Office senior scientist

responsible for management support, the development of technical and strategic plans, and DOD inter-agency coordination for advanced technology. He is the inventor of the solid-state neutron detector, for which he won an award in 1981. He holds a Ph.D. in physics from Montana State University.

Darrell D.E. Long is the Kumar Malavalli Professor of Computer Science at the University of California, Santa Cruz. He holds the Kumar Malavalli Endowed Chair of Storage Systems Research and is director of the Storage Systems Research Center. He received his B.S. in computer science from San Diego State University and his M.S. and Ph.D. from the University of California, San Diego. His dissertation advisor was Jehan-François Pâris. He is a fellow of the Institute of Electrical and Electronics Engineers and of the American Association for the Advancement of Science. He is a member of the IEEE Computer Society, the Association for Computing Machinery, the American Society for Engineering Education, the Usenix Association, Upsilon Pi Epsilon, and Sigma Xi. He has broad research interests in many areas of mathematics and science, and in the area of computer science including data storage systems, operating systems, distributed computing, reliability and fault tolerance, and computer security. His research has been supported by the National Science Foundation; the Department of Energy (Office of Science and National Nuclear Security Administration); Lawrence Livermore, Los Alamos, and Sandia National Laboratories; the Office of Naval Research; and a number of industrial sponsors that include IBM, Microsoft, NetApp, Symantec, LSI Logic, Samsung, Hewlett-Packard, and Data Domain. He served as the vice chair and then chair of the University of California Committee on Research Policy. He has served on the University of California President's Council on the National Laboratories, and on the Science & Technology, National Security, and Intelligence committees. He currently serves on the Science & Technology committee for both Los Alamos and Lawrence Livermore National Laboratories. He previously served on the National Research Council Standing Committee for Technology Insight–Gauge, Evaluate and Review. He continues to serve on numerous committees and advisory panels for various federal government agencies.

Julie J.C.H. Ryan is an associate professor and chair of Engineering Management and Systems Engineering at George Washington University. She holds a B.S. degree in humanities from the U.S. Air Force Academy, an M.L.S. in technology from Eastern Michigan University, and a D.Sc. in engineering management from the George Washington University. Ryan began her career as an intelligence officer, serving the U.S. Air Force and the U.S. Defense Intelligence Agency. After leaving government service, she continued to serve U.S. national security interests through positions in industry. Her areas of interest are in information security and information warfare research. She was a member of the National Research Council's Naval Studies Board from 1995 to 1998. She has conducted several research projects and has written several articles and book chapters in her focus area.

Janet A. Therianos, a consultant, has 30 years of military experience. She is a U.S. Air Force Academy graduate with an undergraduate degree in aeronautical engineering; an MBA from Harvard Business School; and a master's of arts in air and space power strategy. She was a National Defense fellow and has executive education from Harvard Kennedy School of government, the Center for Creative Leadership, and the Intelligence Community Senior Leader Program. Therianos has flown several military aircraft and has served as a command pilot, flight examiner, flight instructor, and functional check pilot. She also holds an FAA Airline Transport Pilot rating. Her military career was grounded in operations, but she also had extensive higher-headquarters staff duties, including serving as senior military assistant to the Secretary of the Air Force. Her leadership experiences were threaded throughout her career, including several Commands. Her final military assignment was leading the Air Mobility Command's Directorate

of Intelligence, where she was responsible for organizing, training, and equipping the Air Force's global mobility intelligence units. Operationally she led the Command's daily Threat Working Group, which assessed threat levels for all global mobility flight operations.

Elias Towe is currently a professor of electrical and computer engineering and the Albert and Ethel Grobstein Professor of Materials Science and Engineering at Carnegie Mellon University. He was educated at the Massachusetts Institute of Technology (MIT), where he received the B.S, M.S., and Ph.D. degrees from the Department of Electrical Engineering and Computer Science. Towe was a Vinton Hayes Fellow at MIT. After leaving MIT he became a professor of electrical and computer engineering, and engineering physics at the University of Virginia. He also served as a program manager in the Microsystems Technology Office at the Defense Advanced Research Projects Agency (DARPA) while he was a professor at the University of Virginia. In 2001, he joined the faculty at Carnegie Mellon University. Towe is a recipient of several awards and honors that include the National Science Foundation Young Investigator Award, the Young Faculty Teaching Award, and an Outstanding Achievement Award from the Office of the Secretary of Defense. He is a fellow of the Institute of Electrical and Electronics Engineers (IEEE), the Optical Society of America (OSA), the American Physical Society (APS), and the American Association for the Advancement of Science (AAAS).

Alfonso Velosa III is research director for Gartner with a focus on sustainability, business ecosystems, and smart cities. He is also agenda manager for electronic equipment research at Gartner, concentrating on electronics and semiconductor supply chain research, with a particular focus on global trends for manufacturing, consumption, financing, and the key vendors in the market. Velosa has also written extensively about electronics, outsourcing of electronics manufacturing, electronic manufacturing services (EMS), original design manufacturing (ODM), and semiconductor consumption. He previously worked at or consulted for Intel Corporation, NASA Lewis Research Center and NASA Headquarters, Mars & Co., and IBM Research. Velosa graduated from Columbia University with a B.S. in materials science engineering; from Rensselaer Polytechnic Institute with an M.S. in materials science engineering; and from Thunderbird, the Garvin School of International Management, with an M.I.M. in international management.

Eli Yablonovitch (NAS/NAE) is an adjunct professor of electrical engineering at UCLA after having served as a full faculty member until 2007. He is currently a professor of electrical and computer engineering at the University of California, Berkeley. He graduated with a Ph.D. in applied physics from Harvard University in 1972, worked for two years at Bell Telephone Laboratories, and then became a professor of applied physics at Harvard. In 1979 he joined Exxon to do research on photovoltaic solar energy; in 1984, joined Bell Communications Research, where he was a Distinguished Member of Staff and also director of Solid-State Physics Research; and in 1992, joined the University of California, Los Angeles, where he became the Northrop Grumman Opto-Electronics Chair and a professor of electrical engineering. Yablonovitch's work has covered a broad variety of topics: nonlinear optics, laser-plasma interaction, infrared laser chemistry, photovoltaic energy conversion, strained-quantum-well lasers, and chemical modification of semiconductor surfaces. Yablonovitch's research focuses on optoelectronics, high-speed optical communications, nanocavity lasers, photonic crystals at optical and microwave frequencies, and quantum computing and communication.

Appendix B
Workshop Agenda and Participants

AGENDA

Workshop on the Future of Battlespace Situational Awareness

May 30-31, 2012

Lockheed Martin Center for Innovation

Suffolk, Virginia

Sponsor Welcome
Jim Nardone
Defense Intelligence Agency

Future Battlespace Technology Discussion
Daniel DeLaurentis,
School of Aeronautics and Astronautics
Purdue University

Al Romig
Skunk Works
Advanced Development Program
Lockheed Marting Aeronautics Company

David Vos
UAS & Rockwell Collins Control Tech, Inc. (retired)

John Main
Intific

Brain Ballard
APX Labs

Past Studies and Technology Exploration
Mark Jefferson
Lockheed Martin

Scenario Introduction
Adversary Capabilities: Technology, Blue Vulnerabilities

Strategic Warning Indicators Discussion
Mark Jefferson
Lockheed Martin

Cyber, Space, Air, Maritime, and Land Discussion
Brian Ballard
Committee Member

Strategic Surprise Discussion
Brain Ballard
Committee Member

Scenario Move 1 Discussion
Mark Jefferson (Facilitator)
Brian Ballard (Discussion lead)

Scenario Move 2 Discussion
Mark Jefferson (Facilitator)
Brian Ballard (Discussion lead)

Scenario Move 3 Discusison
Mark Jefferson (Facilitator)
Brian Ballard (Discussion lead)

Scenario Discussion Wrap-Up and Attendee Final Thoughts
Brian Ballard (Discussion lead)

PARTICIPANTS

Committee

Brian Ballard, APX labs
Julie Ryan, George Washington University

Staff

Daniel Talmage, Study Director

Facilitator and Speakers

Mark Jefferson, Lockheed Martin
John Main, Intific
Al Romig, Lockheed Martin
David Vos, Rockwell Collins Control Tech, Inc. (retired)

Guests

Defense Intelligence Agency
Department of Defense

Appendix C

Speaker Biographies

Daniel DeLaurentis is an associate professor at the System-of-Systems Laboratory, Aerospace Systems Research Area, at the School of Aeronautics and Astronautics at Purdue University in West Lafayette, Indiana. He leads the system-of-systems research laboratory and is an active participant in the College of Engineering's System-of-Systems Signature Area. He is the past chair of the AIAA Air Transportation Systems Technical Committee and co-chair of the IEEE Systems of Systems Technical Committee. He is an associate fellow of the AIAA. He earned his Ph.D. and M.S. in aerospace engineering from the Georgia Institute of Technology in Atlanta, Georgia. He received his B.S. in aerospace engineering from Florida Institute of Technology.

Mark "Mutt" Jefferson is director, Horizontal Integration, Aeronautics for Lockheed Martin Corporation. In this capacity, he is responsible for leading the aeronautics company thrust for advanced operational concept development and definition, and associated man-in-the-loop modeling and simulation and live experimentation for tomorrow's network-enabled warfighting environment. He integrates capabilities across aeronautics company programs and is the point of contact for the aeronautics company into the corporation for horizontal integration activities. Prior to joining Lockheed Martin, Jefferson served in a variety of increasingly responsible positions in the USAF, including Interoperability Joint Warfighting Capabilities Assessment Team Leader, U.S. Joint Staff, Washington, D.C.; deputy director, Combat Forces Requirements, U.S. Air Force Staff, Washington, D.C.; Combined Forces Air Component Commander, Operation Northern Watch, Incirlik, Turkey; deputy director, Defense Modeling and Simulation Office, Washington, D.C.; Commander 27FS, Langley AFB, Virginia; and numerous F15/F4 pilot/instructor pilot assignments in the United States, Europe, and the Pacific. Jefferson graduated from the USAF Academy in 1975 with a bachelor's of science in chemistry and from the University of Southern California in 1981 with a master's of science in systems management.

John Main currently serves as chief operating officer at Intific, Inc. In addition to his operational responsibilities he leads the business development and preliminary design activities in the company. Prior to joining Intific he served as a program manager in the Defense Sciences Office of the Defense Advanced Research Projects Agency (DARPA), where he initiated programs in a broad range of technical areas, including biologically inspired materials, fast and efficient human-powered swimming, rapid rooftop access, small-scale power generation, and human exoskeletons for increased soldier endurance. In 2001 Main founded Precision Systems and Instrumentation, Inc., a company that designs, manufactures, sells, and supports two instrument systems used in spinal cord injury research. In 2008 Main was awarded the Office of Secretary of Defense Medal for Exceptional Public Service. Earlier in his career he also served as an associate professor of mechanical engineering at the University of Kentucky. Academic career accomplishments include more than 75 technical articles, three edited volumes, nine invited lectures, five awarded patents, and 32 externally funded research efforts. Before his academic work he served as a staff

engineer at both the Department of Veterans Affairs and the Westinghouse Nuclear Division. Main acquired his M.S. and Ph.D. in mechanical engineering from Vanderbilt University after receiving a B.S. in physics and mathematics from Western Kentucky University.

Alton D. Romig, Jr. (NAE) is vice president and general manager of Advanced Development Programs, Lockheed Martin Aeronautics. In this capacity, he sets the strategic direction for the capture of new business and leads the management of the world-renowned Skunk Works®, the pre-eminent seat of aerospace innovation for more than 65 years. Prior to joining Advanced Development Programs, Romig spent more than 30 years with Sandia National Laboratories, operated by Sandia Corporation, a Lockheed Martin Company. His responsibilities there included the leadership of development and engineering activities providing science, technology, and systems expertise in support of U.S. programs in military technology; nuclear deterrence and nuclear proliferation prevention; technology assessments; intelligence and counterintelligence; homeland security; and energy programs. During his time with Sandia he held a variety of management assignments, including chief technology officer and vice president for Science, Technology, and Partnerships. In that role, he was chief scientific officer for the Nuclear Weapons Program, accountable for Sandia's interactions with industry and academia. In addition, he was responsible for the Laboratory Directed Research and Development Program. Most recently, he served as the executive vice president, deputy laboratories director, and chief operating officer responsible for all aspects of laboratory business, including the science and technology base supporting all laboratory programs. Known for his pioneering work in materials science, engineering, and characterization, he has won numerous international prizes, including the ASM Silver Medal for Outstanding Materials Research (1992). As an engineer he worked on and led teams that designed, manufactured, and delivered numerous systems to the national security enterprise. Romig is an active member of the National Academy of Engineering and the Council on Foreign Relations. He has served on numerous influential government advisory councils and boards either through the U.S. government or the National Academies, including the Intelligence Science Board, an advisory body to the director of National Intelligence; the National Institute of Standards and Technology Visiting Committee on Advanced Technology, an advisory body to the director of the National Institute of Standards and Technology; Defense Science Board Summer Studies; the Air Force Studies Board; Standing Advisory Committee to the Special Operations Command; and the Standing Committee for Technology Insight—Gauge, Evaluate, and Review, an advisory committee to the intelligence community. Romig has served on several industrial boards, including for the Technology Ventures Corporation, a Lockheed Martin subsidiary dedicated to technology commercialization; and as a Lockheed Martin representative on the Atomic Weapons Establishment (UK) Board of Directors. He is a fellow of the American Association for the Advancement of Science, ASM International (American Society for Materials), and The Minerals, Metals and Materials Society. Romig is a senior member of IEEE, and he has served as chair of the United Way of Central New Mexico. He received his bachelor of science, master of science, and doctoral degrees in materials science and engineering from Lehigh University in 1975, 1977, and 1979, respectively.

David Vos is the retired senior director of Control Technologies of Rockwell Collins Control Technologies. He co-founded Athena Technologies, Inc., and served as its president, chief executive officer, and chief technology officer. Under Dr. Vos's leadership, Athena is an active contributor to the advancement of the United States' competitive position in math and science, as well as competitive sports and national pride. He has broad experience in analysis, synthesis, design, and development of mechanical systems, system dynamics modeling and simulation, guidance and control systems, passive and active vibration isolation systems, optimization algorithms and intelligent systems, internal combustion and turbo machinery modeling and control, and other estimation and control systems. He currently serves as director of Athena

Technologies, Inc. Vos is a pioneer in the area of unmanned aerial vehicles (UAVs). He developed a new mathematical approach for treating nonlinear, highly time-variant systems as if they were both linear and time invariant. He proved this approach and the resulting technology with the invention of the world's first autonomous unicycle. The riderless unicycle utilized sensors that could detect balance changes and a control algorithm that could interpret that sensor data and then issue adjustment instructions to a mechanical motor propelling the vehicle. With this success, he opened the door to an entirely new field of dynamics and control. Vos is the inventor and developer of Athena's core technology. He holds patents in nonlinear control systems, failure detection systems, optimal power control systems, and more. Vos holds a B.S. in engineering with honors in aeronautical engineering from the University of Stellenbosch, South Africa, an M.S. in dynamics and control from MIT, and a Ph.D. in estimation and control from MIT, in the Department of Aeronautics and Astronautics.