



Avoiding Technology Surprise for Tomorrow's Warfighter--Symposium 2010

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avoiding technology surprise for tomorrow's warfighter— symposium 2010

Committee for the Symposium on
Avoiding Technology Surprise for Tomorrow's Warfighter—2010

Division on Engineering and Physical Sciences

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Preface

The symposium described in this report was the second annual gathering of this type, representing a new venue for the ongoing engagement between 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 TIGER's sponsor, the Defense Warning Office (DWO) of the Defense Intelligence Agency (DIA), intends that the personal interactions that occurred throughout the symposium, this report, and similar products of future sessions will help to systemically strengthen U.S. S&TI capabilities.

The chair and vice chair express their appreciation to the members of the Committee for the Symposium on Avoiding Technology Surprise for Tomorrow's Warfighter—2010 for their earnest contributions to the generation of this report. We are also grateful for the active participation of many members of the technology community as well as to the sponsor for its support. Likewise, we recognize the substantial contribution made by the staff of the Lockheed Martin Center for Innovation in supporting the conduct of this symposium at the facility in Suffolk, Virginia. The committee would also like to express sincere appreciation for the support and assistance of the NRC staff, including Daniel Talmage, Carter Ford,

¹The preceding symposium is described in National Research Council, 2009, *Avoiding Technology Surprise for Tomorrow's Warfighter: A Symposium Report*, Washington, D.C.: The National Academies Press. Available at http://www.nap.edu/catalog.php?record_id=12735.

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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 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:

James J. Carafano, The Heritage Foundation,
Lawrence J. Delaney, Titan Corporation (retired),
Stephen W. Drew (NAE), Drew Solutions LLC,
Allison A. Hickey (USAF, retired), Accenture National Security Services,
Larry G. Lehowicz (USA, retired), Quantum Research International, and
Gregory S. Martin (USAF, retired), GS Martin Consulting.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Robert J. Hermann (NAE). 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 authoring committee and the institution.

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Acronyms and Abbreviations

COCOM	combatant command
COD	currency of development
DIA	Defense Intelligence Agency
DoD	Department of Defense
DWO	Defense Warning Office
EMP	electromagnetic pulse
FOIA	Freedom of Information Act
IC	intelligence community
JFCOM	United States Joint Forces Command
NRC	National Research Council
ORD	Office of Research and Development
RCAs	riot control agents
R&D	research and development
S&T	science and technology
S&TI	scientific and technical intelligence

TFP	total factor productivity
TIGER	Technology Insight—Gauge, Evaluate, and Review
TQM	total quality management
USJFCOM	United States Joint Forces Command
WoW	World of Warcraft

1

Motivation for the Symposium

INTRODUCTION AND STUDY ORIGIN

This report summarizes key themes identified during the course of the second annual Symposium on Avoiding Technology Surprise for Tomorrow's Warfighter, a two-day event held at the Lockheed Martin Center for Innovation in Suffolk, Virginia, on April 28 and 29, 2010. Both the symposium and this summary report were produced under the auspices of the National Research Council's (NRC's) Committee for the Symposium on Avoiding Technology Surprise for Tomorrow's Warfighter—2010, sponsored by the Defense Intelligence Agency's (DIA's) Defense Warning Office (DWO). The ad hoc committee was composed of several members of the Standing Committee on Technology Insight—Gauge, Evaluate, and Review (TIGER).

This symposium represented a continuation of the relationship between the TIGER standing committee and the intelligence community (IC) and the growth between them, with the goal of perpetuating and strengthening a dialogue between warfighters and members of the IC on ways to minimize surprise from either the unexpected appearance of novel technological capabilities or innovative adaptations of existing capabilities, or both. The 2005 publication *Avoiding Surprise in an Era of Global Technology Advances: A Symposium Report* introduced a methodology for gauging the potential impact of emerging technologies on national security, which served as the foundation for the symposium in 2010.¹

¹NRC. 2005. *Avoiding Surprise in an Era of Global Technology Advances: A Symposium Report*. Washington, D.C.: The National Academies Press. Available at http://www.nap.edu/catalog.php?record_id=11286. Accessed August 30, 2010.

In fulfilling their roles, the ad hoc committee and the symposium attendees alike required access to classified national security information and other information exempt from public disclosure under the Freedom of Information Act (FOIA).

This report summarizes the key themes from the symposium and the views expressed by participants. Although the NRC committee is responsible for the overall quality and accuracy of this report as a record of what transpired at the symposium, the views described are not necessarily those of the committee; rather, the report is an attempt to fairly represent the discourse that emerged from the presentations and associated dialogue. Box 1-1 provides the study statement of task.

OBJECTIVE

The Symposium on Avoiding Technology Surprise for Tomorrow's Warfighter—2010 was originally conceived by the DIA as a forum for warfighters who consume scientific and technical intelligence (S&TI) and for members of the IC to exchange perspectives on potential sources of surprise in the near- and long-term future. While this future was not strictly bounded by a number of years (such as “out to 20 years”), it assumed current and emerging technology and intentionally allowed for the possibility of new physics and/or very advanced applications that are not present today in mainstream science and engineering. The purpose of this annual event, this being the second, is to promote dialog between the two groups to elucidate trends that can be used to improve the Department of Defense's (DoD's) technology warning capability.

This symposium represents an important part of DWO's ongoing efforts to engage warfighters and intelligence analysts in a discussion of potential threats posed by disruptive innovations and their impacts on national security. These efforts have been successful and are expected to produce even more benefits with continued engagement, including meetings such as this one. The first symposium, held in 2009, opened initial channels of communication between DWO and the combatant commands (COCOMs) and raised awareness of the need for collaboration.

The 2010 symposium built on the achievements of the first symposium by eliciting greater participation from COCOMs, largely through the greater support of the United States Joint Forces Command (USJFCOM). The event took place at Lockheed Martin's Center for Innovation, a high-tech networked facility that uses collaborative software tools to enable real-time virtual interaction between members of the committee, members of the audience, facilitators, and presenters. These tools allowed the continuous collection of data from participants throughout the symposium, including the symposium committee, resulting in a higher overall level of knowledge exchange than in the live panel discussions held in the 2009 symposium.

BOX 1-1
Statement of Task

An ad hoc committee will plan and convene a two-day symposium themed "Avoiding Technology Surprise for Tomorrow's Warfighter 2010." This event will feature invited presentations and panelists and include discussions on various related S&T topics. The committee will:

- Attend and participate in all symposium sessions;
- Capture comments and observations from the panel discussions, and elucidate any trends presented in the discussions; and
- Produce a report that summarizes the themes of the symposium, with specific emphasis on challenges to U.S. warfighters involving technology surprise covered in the presentations and discussions.

The symposium opened with a keynote speech by Lieutenant General Keith Huber, Deputy Commander of the USJFCOM, followed by presentations highlighting cutting-edge technology topics selected by the DIA sponsor, including nonkinetic weapons, the death of privacy, Human 2.0, and energy.

These drivers and the technology areas that pertain to them are presented in detail in Table 1-1. While they are unlikely to be the source of technological surprise in current conflicts, they are consistent with the sponsor's mission to try to anticipate surprise that could occur years to decades in the future. Appendix C contains individual summaries of each technology area. However, as noted in Chapter 2, discussions at the symposium evolved into a broader definition of surprise that included tactics involving novel use of widely available technologies and even unanticipated approaches arising from different cultures and value systems.

The second day began with a review of preliminary data from surveys carried out on the first day, continued with reflections by Admiral (ret.) James R. Hogg, and closed with presentations from DWO and USJFCOM's Future Joint Operating Environment Team.

SYMPOSIUM PARTICIPANTS

The more than 100 participants in this year's symposium included S&TI analysts or producers; consumers of S&TI from military, government, and non-government organizations; and the members of the ad hoc symposium committee. The relationship of the participants to S&TI—producer, consumer, or other—is

TABLE 1-1 Technology Areas Highlighted in Symposium Presentations and Their Associated Drivers.

Thematic Driver	Technology Area Presented
Nonkinetic weapons	Low observables and counter low observables Adaptive camouflage Nonlethal weapons Agile systems
Death of privacy	Miniaturized sensors Ultraprecision strike Quantum C4I Nanophotonics
Human 2.0	Virtual reality Enhanced cognition (nonpharmaceutical) Modeling, simulation, and games
Energy	Lightweight electrical systems High-energy-density materials Hypersonic flight Affordable space launch

summarized in Figure 1-1. A comprehensive list of the organizations represented at the symposium is included in Appendix B. The individual participants generally are not named.

METHODS FOR DATA GATHERING AND INTERPRETATION

This year's symposium differed critically from its predecessor in its use of technology to facilitate continuous discourse among attendees throughout the day. The result was a drastic increase in the efficiency and volume of communication—that is, the normal vectors of speaker-to-audience and peer-to-peer communication—whereby blogging among participants, including the speakers in post-presentation follow-ups, became the primary means of attaining a shared understanding of the issues. Participants were able to contribute to network logs (blogs) during the presentations and were encouraged to do so. Although there was at first a wide disparity in familiarity with this tool, it was generally observed that those unacquainted with real-time blogging were able to learn quickly, and good participation ensued. After each presentation, a focused and structured survey was presented to all participants, most of whom completed it. The combination of new data collection capabilities resulted in an increase in the quantitative data available for analysis from the surveys and in the qualitative data from the blogs. The quantitative data were analyzed by the hosting facility's

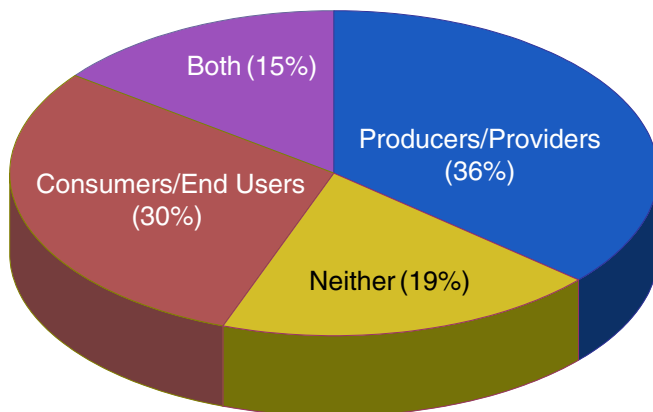


FIGURE 1-1 Distribution of symposium participants according to S&TI relationship.

team in accordance with guidance from the symposium committee. Together with the qualitative data distilled from the blogs, the quantitative data provided the committee with valuable insights into participants' attitudes, their claimed existing knowledge, and, in some cases, the evolution of the participants' knowledge and shared understanding of the concepts presented.

The committee observed that one benefit of using the collaboration tools was the increased participation of audience members. Users could participate openly or anonymously. The blogs contained responses to the presentations and to other bloggers' comments or questions, allowing the inclusion of topics of broader interest to the audience. The blogs also served as a means for all participants to contribute knowledge as they felt appropriate, and blogging enabled a level of involvement among participants not otherwise possible in workshops of this length, complexity, and size. Simply put, when many participants are able to participate fully in a dialogue without interrupting either the speaker or other listeners, the result is a much richer intellectual experience.

PRECISION OF SURVEYS

The symposium opened with a survey to collect demographic information and ascertain the current level of knowledge and use of S&TI products. Participants completed surveys after each presentation on a technology area. These "reaction surveys" asked participants to gauge the likelihood, based on their understanding of the topic and the presentation, that elements of the technology area would be used against U.S. national interests in various theaters of operation.

As mentioned above, questions in the reaction survey addressed a variety of dimensions of the topic under discussion, including the likelihood of encounter-

ing the capability in the hands of an adversary, making the technology perhaps better suited to offensive rather than enabling capabilities. The questions were very broad, which limited the ability of participants to express nuanced opinions on some of them. Additionally, participants interpreted some of the survey questions differently than had been intended.² In spite of these limitations, data from the surveys did a good job of presenting a high-level portrait of common understanding on the part of distinct demographic groups. Specifically, areas of shared cognizance could clearly mitigate the risk of surprise, whereas areas with a gap in the shared understanding of the technology's utility and significance represent opportunities for further engagement. The discussions and blogs suggested several ways to improve the granularity of the survey methodology for the next symposium. Figure 1-2 contrasts the results from surveys completed by the producers and the end users of the technologies during the symposium. The areas that showed the most difference between the two groups were cognitive neuroscience and virtual reality, as can be seen by comparing the consumer/end user line and the producer/provider line in Figure 1-2.

WORKSHOP TOPICS

S&TI analysts from the DIA loosely grouped the technology areas of interest discussed in the presentations into four potential drivers for future technology surprise: nonkinetic weapons, the death of privacy, Human 2.0 (including the use of cyber technologies to enhance human cognition and interaction), and energy. The technology areas that illustrate these drivers are listed in Table 1-1 and are represented in Figure 1-2.

REPORT STRUCTURE

This report summarizes the events of the symposium and highlights the four main themes selected by the DIA. The present chapter describes the origin and purpose of the symposium, the methodologies employed for data gathering, and the topics presented to stimulate discussion among participants. Chapter 2 discusses the concept of technology surprise. It explains that there is no contradiction between “surprise” and mature technologies—the harm of a surprise can come from the unanticipated, novel, or newly invented *application* of a mature technology or the *evolution of new processes* that enhance the utility and effectiveness of a mature technology, or from both. Chapter 3 highlights the main themes of the symposium and the discussions. Some of the challenges presented to the warfighter by technological surprise are outlined in Chapter 4. Appendix A contains

²This was determined through conversations overheard during the breaks and through explicit commentary made during the wrap-up sessions.

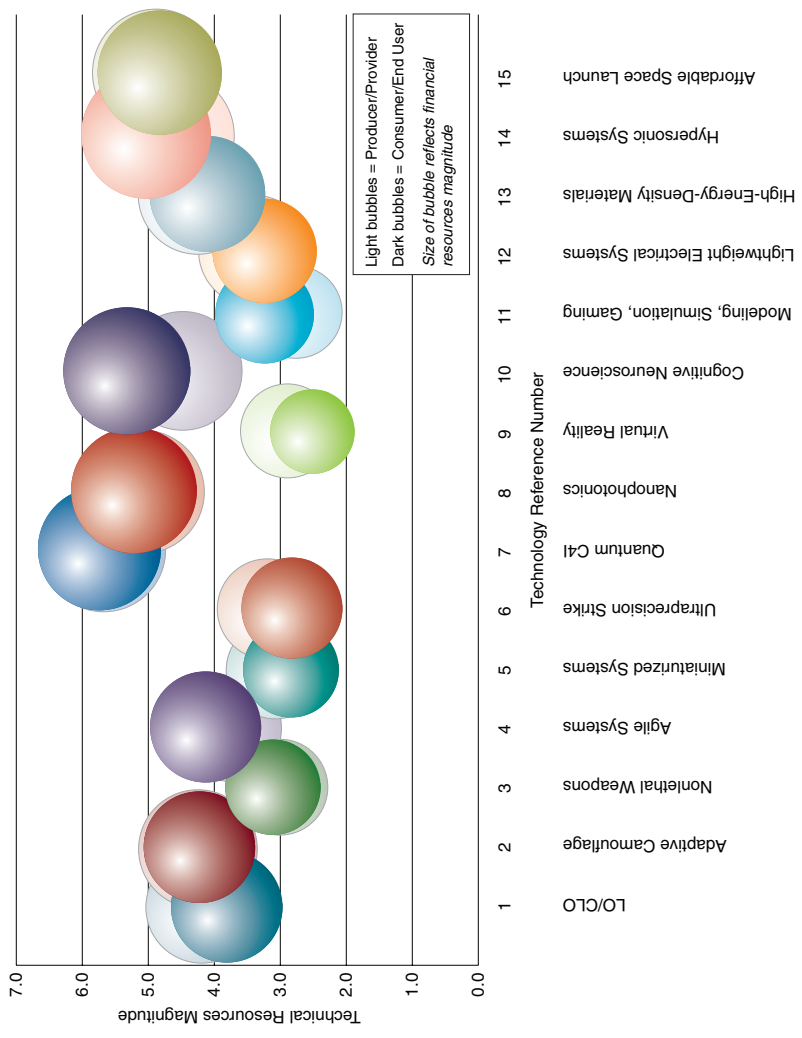


FIGURE 1-2 Comparison of survey results obtained from producers/providers and consumers/end users regarding the 15 technology areas highlighted in symposium presentations. LO/CLO, low observables/counter low observables.

committee biographies. Appendix B contains a list of participating organizations and an agenda, and Appendix C contains summaries of the sessions held on each of the two days of the symposium. Owing to the nature of some of the material covered, the summaries in some cases are very brief.

2

Considering Surprise

The technology surprises discussed at the 2010 symposium came from one of three sources:¹

- *Product and process technology breakthroughs.* These breakthroughs are enabled by experts in various areas of science and engineering. They are likely to be achieved by nations that are technological peers of the United States and that have comparable access to resources, or by non-state entities with specialized expertise in a specific technological area (e.g., cyber, nuclear, or biological).
- *New uses of existing technology.* Examples might be the innovative use of the Internet for mission planning or training purposes or the use of cellular phones to trigger improvised explosive devices. These innovative uses are generally accessible to individuals and small groups as well as to nation-states.
- *Unexpectedly rapid progression to the operational use of the technology.* Adversaries may acquire their technological capabilities or bring them into operation sooner than anticipated, whether through efficient acquisition systems, deception, or transfer from more technologically sophisticated patrons.

¹These categories largely mirror the types of technology surprise discussed in the first symposium report: (1) a major technological breakthrough in science and engineering; (2) a revelation of secret progress; (3) temporal surprise; and (4) innovative technology applications.

One important factor that may lead to surprise for the United States in each of these categories is that the intentions of an adversary may be misunderstood because evaluations were carried out on the basis of U.S. cultural biases and historical trends rather than the adversary's own culture, history, beliefs, and value systems. This concern was recognized in the report of the first symposium but became a major theme in this second symposium (see the text of Admiral Hogg's

BOX 2-1

Avoiding Technology Surprise for Tomorrow's Warfighter

Admiral James R. Hogg

I think we can agree that [avoiding technology surprise] is a terrific objective and an enormous challenge, both in importance and complexity. Especially so, given that we know little about avoiding Technology Surprise today, no matter how hard we try, let alone tomorrow. Yet, more so than others, this group is composed in a way that gives it a chance. We have here today Warfighters, Technologists, and Intelligence experts, joined together.

Among you, we need linguists. Linguists who understand the cultures of the ethnic groups whose languages they translate. So, a show of hands, please. How many of you are culturally aware linguists in the Muslim or Asian languages and dialects? Numbers are small. That's no surprise! And that explains a fundamental weakness in our Western approach to problem solving.

I say that because we will only be able to avoid Technology Surprise by thinking differently than what I will call the "Western norm." We will only do it by thinking the way a Muslim or an Asian thinks, not the way we in the West "think they think."

If we can't figure out how to get inside, way inside, their cultural mindsets, then for sure, we will not recognize Technology Surprise until it is too late. For example, how many of us in this room ever thought a large commercial passenger jet aircraft could generate Technology Surprise? Probably none of us. Let's just say few, if any. Why? Simply because Technology Surprise is generated by two things: disruptive technology and disruptive thinking or, even more challenging, a combination of the two!

I am going to focus now on disruptive thinking, because nations or radical groups that are incapable of developing disruptive technology will continue to "take us to the edge" through disruptive thinking. It goes like this: We in the West, in the main, tend to solve problems in a deductive manner, with precision, definition, and rule sets. This is prevalent among

presentation in Box 2-1). Indeed, while at the first symposium the notion of “surprise” was limited largely to technological surprise, participants in the 2010 symposium preferred to generalize the concept to include an adversary’s actions that would be surprising based on “Western norms” but might be anticipated with sufficient knowledge of the adversary’s culture, value system, and available resources.

engineers, for example, who are taught to “bound” problems in order to define and then more easily solve them. That makes sense.

Muslims and Asians, on the other hand, tend to approach problems in an inductive manner. With logic, based on ethnic and cultural beliefs, and without rule sets as we understand them. No rules. Anything goes! This inductive approach is amenable to continuous exploration. It is not bound by anything—in any way, in any dimension.

A rational conclusion is that a combination of the two is the best approach. To think inductively at first for exploration and discovery; then, to think deductively in order to come up with practical solutions. This sets up a balance between the open space that spawns creative thinking and the defined space that enables construction of solutions.

So, with all this in mind, and returning to the challenge of avoiding Technology Surprise, there is no immediate solution, but there is a way ahead. Every significant military command needs an “innovation cell” dedicated full-time to an inductive-deductive thinking process that is focused like a laser on Technology Surprise. By that, I mean Technology Surprise that might be generated by either disruptive technology or disruptive thinking. The composition of these innovation cells must be diverse in every possible way, including language and cultural skills. In addition, they must be netted, each a node in a DoD-wide web, ensuring seamless information flow and collaboration.

Over time, similar webs should be established in the Departments of State and Homeland Security, and across all agencies in the National Intelligence Directorate [Office of the Director of National Intelligence]. Let’s call this approach “Deep Red” for now. It’s a new way to organize, to think, to analyze, and to collaborate in order to anticipate and counter Technology Surprise during its developing stage and, absolutely, before its deployment.

PRODUCT AND PROCESS TECHNOLOGY BREAKTHROUGHS

Many of the presentations at the 2010 symposium (unclassified summaries are given in Appendix C) described cutting-edge research in such fields as biomedical engineering, nanotechnology, cryptography, quantum physics, communications, and electronics. Any potential threats emerging from these areas of research were generally thought to be longer-term concerns, i.e., not yielding surprising or disruptive applications for years, if not decades. This belief was articulated by many in the blog discussions, which posited that the nature of these research areas—which require sophisticated infrastructure and substantial funding, for example—makes them unlikely to be accessible to adversaries having only modest technological capabilities or resources, unless these are transferred, inadvertently or otherwise, by a more sophisticated patron. Further, many participants opined that concerted efforts to operationalize these research areas into deployable tools tend to be highly classified and fairly rare undertakings. The discussion thread went on to indicate that development efforts of this scope require a long time and are difficult to keep secret; the discussion captured the notion that this was true especially for complex technological undertakings, given that their human architects are derived from an increasingly globalized university-based research system, which is ever more tightly connected in its communication and other enduring relationships. Of course, if a breakthrough—one that transformed the seemingly impossible into the doable and operational—were to occur secretly, then the adversary would indeed possess a highly disruptive and surprising capability.

It is important to distinguish between product and process technologies. The products enabled by technologies (e.g., quantum computing) are tangible, whereas process technologies are methodological innovations (e.g., just-in-time logistics). In economic terms, process technologies are more often the source of innovation and productivity increases and can be brought into operation faster than product technologies. In sociological terms, process technologies generally require more coordination and generally leverage communication technology. For example, “blitzkrieg” could be considered a process technology innovation that was fairly effective at disrupting a then-traditional deployment of product technologies (the Maginot Line). Another example, total quality management (TQM), was hugely disruptive in the 1970s when it was applied to the car manufacturing industry.

NEW USES OF EXISTING TECHNOLOGY

Symposium participants noted that U.S. operational capabilities have been surprised or disrupted by available technologies in unexpected ways, and they suggested that it would be wise for the S&TI community, S&TI customers, or the operational community as a whole to contract for research focused on exploring ways in which technologies could be integrated to enable radical capabilities.

Many participants commented on this concept, including one who wrote

that the S&TI community frequently missed “the diabolic, innovative, and often simple repurposing of tech” to achieve an end goal. Another noted that real-time, functional brain imaging, for example, which was developed to improve understanding of the disruption of cognitive pathways and disease, was being repurposed to explore and assess how people from different cultures and educational backgrounds feel about themselves, the enemy, warfighting in general, risk, and evasion in theater operations.

The emergence and increasing penetration of virtual reality and augmented reality technology into daily life was recognized as a potential vector for technology surprise. New technology, combined with innovative uses, has “constructed” a new reality, whereby users can participate in a parallel “world” with varying levels of utility, fidelity, and realism. Of particular note in the behavioral discussion was the emergence of a common understanding of the significance of virtual reality as a tool for teaching or developing new behaviors. The discussion turned to the use of virtual worlds and alternate realities to develop surprising and innovative uses of technologies or new strategies. Additionally, the bridging of the virtual world into the real world through “augmented reality” frameworks could be a force multiplier across a number of markets, battlefields, and political landscapes. Finally, the inclusion of augmented reality in the discussion provided insight into an increasingly common technology that has seen broad applications by U.S. adversaries in asymmetric warfare.

SPEED TO OPERATIONAL USE OF TECHNOLOGY

Technologies that surprise and disrupt us could result from an adversary’s speed in developing or acquiring a technology newer than that used in the United States. The long time it takes to procure (or the long waits involved in procuring) new technologies in the United States was cited repeatedly, with several embarrassing examples given. The feeling among many participants was that such delays in acquisition gave adversaries a better opportunity to observe U.S. technological advances, including more time for them to counter—both offensively and defensively—new technologies before fielding them. Of even greater concern to many participants was the speed with which adversaries can catch up, and are catching up, by reverse engineering existing technologies, appropriating intellectual capital (as can happen when students are educated abroad and then return home), and even by simply acting more rapidly than U.S. bureaucracy can manage. The ideals of transparency and of open inquiry that the United States seeks to defend can, ironically, leave it vulnerable to adversaries who benefit from more agile, less democratic forms of development and acquisition. Moreover, there was some recognition on the part of participants that in many areas the United States no longer enjoys the technical superiority it once did, owing to the combination of less U.S. R&D funding, fewer U.S. graduate students, and the repatriation of foreign U.S.-educated students who create their own domestic university programs

and commercial enterprises to carry out research, development, and production, as well as to the now much more accessible global technology market. While all of these are significant, the greatest concern was the increase in S&T R&D investments and the rise of centers of S&T excellence worldwide.

During a lively discussion on how far behind in technology development certain adversaries are, one participant warned that “the 10-15 years [of lag behind the United States] is dynamic and the gap is closing.” Another went even further, writing, “We are giving most of it away (e.g., we educate them; they go teach their own [people] what they learned from us, then leap ahead of us)!” While such statements obviously reflect a U.S.-centric position, there were recurring discussions throughout the symposium on the unintended negative consequences of a globalized economy and the access to heretofore difficult-to-obtain technology and knowledge.

The adoption of a technology may also be more rapid in other countries by virtue of the price differences of labor. If 10 years can be reduced to 5 years in a foreign country in terms of the cost in U.S. dollars, then this needs to be considered. The discussion continued with several people recommending that analysts should look at the need to normalize measures to account for variations in labor costs throughout the world when estimating the resources required to develop a specific capability.

Speed of adoption, in general, is not the same in different countries, especially when they are not starting at the same point in time or from the same baseline. Because the United States is frequently on the cutting edge of defense technologies, the cost of early adoption places a premium on the time, the available supporting technology, and the supply of people/experts with an understanding of the field. When U.S. adversaries enter the same market years behind us, they can benefit from a number of factors that reduce the cost of acquiring a similar technology:

- Access to open research,
- Availability of a trained workforce,
- Cost-of-living (manpower-cost) differences among nations,
- Availability of supporting technologies at lower costs than in the original timeline,
- Ability to buy technology at “production rate” prices from other countries,
- Willingness to adopt technology without regard to legacy issues or complex environments, and
- Tolerance of higher failure rates and associated casualties to accomplish a particular end goal.

THE EFFECTS OF CULTURAL VALUES ON SURPRISE

Surprise may come from the use of tactics or disruptive behaviors that are not typically sanctioned by Western norms, such as the use of commercial airliners as weapons in the 9/11/2001 attacks or the emergence of suicide bombing as a common tactic in asymmetric warfare. Such behaviors may be employed by individuals, small groups, or nation-states and do not necessarily involve technology per se to create surprise.

There was a rich and continuing discussion of what constitutes—or may constitute—“ethics and culture” in this context. Many participants believed that the different values of different cultures should not be labeled “right” or “wrong” or even “pathological.” On the other hand, there was widespread disagreement about the extent to which other countries conduct research on human beings that would not be ethical in the United States.

In some parts of the world, S&T research is carried out under constraints that differ dramatically from those in the United States. Specifically, the issue was broached of how different ethical or cultural standards might permit varying approaches to technology development. This topic was raised in the discussions on advances in technology and applications for the neurosciences and in virtual reality. One participant noted that the development of brain interfaces would be more advanced in some other countries because they did not have the restrictions surrounding research that apply in the United States, giving those countries a research advantage.

Another participant observed that, from the perspective of U.S. research into behaviors and innovations, the use of virtual worlds such as World of Warcraft (WoW) and Second Life² is often constrained by ethical considerations derived from the real world. One symposium participant noted that it turns out that the players in virtual worlds take the experiences in them so literally that the same ethical constraints regarding real-world research tend to apply in virtual worlds.³ Nonetheless, many participants said in their blogs that the set of norms that appear in the virtual world are very broad because people understand that such a world is not real. Although most people act in virtual reality gaming as they would in real life, a few intentionally deviate because reprisals are less severe and there is no enforcement. Clashes among cultures can be seen both in the virtual world and in

²Second Life is a product of the Linden Lab that allows participants to create avatars (digital representatives of each participant customized to personal preferences) and conduct interactions between them. As such, it constitutes a virtual world in which participants are able to act out ideas and alternative lives and even to interact emotionally.

³Assuming some consistency in human behavior across cultures, this implies that observation of the self-imposed constraints by virtual world players in foreign cultures and other groupings may yield insight into their real-world constraints or lack thereof. It is cautioned that these interpretations are not simple, because virtual-world behavior, like real-world behavior, may be contaminated by noise from culturally independent fanaticizing, psychopathology, or other psychological deviations. The behaviors displayed may also include purposeful deception.

the message groups and conversations taking place in the “real” world. The differences, which are instructive and important, can be modeled by the intelligence community (IC) to avoid surprise.

Asymmetry in research and development caused by different ethical and legal constraints worried another symposium participant, who noted that, while he did not advocate careless research, he nevertheless felt that current regulations and their associated cost put the United States at a huge disadvantage and were forcing research to move offshore.

Research advances achieved through processes not subject to the same ethical and policy standards that constrain U.S. research were said to have placed the United States at an increasing disadvantage, not only in terms of the availability of specific research opportunities but also in terms of hindering a better understanding of the potential of certain emerging technologies. For example, one participant opined that “the nation that best leverages exploring understanding of the mind will dominate the future,” and went on to express concern over research investment strategies in the United States.

FINAL REMARKS

In avoidance of surprise, understanding behaviors and their effects is at least as important as anticipating technology breakthroughs. Such behaviors range from turning benign technological advances into threats and being willing to accept more risk by deploying new capabilities more rapidly, to emphasizing greater agility in acquisition and deployment, to acting according to differing values that eliminate constraints on the conduct of research and exploration. Thus, surprises and disruption cannot be forecast solely on the basis of anticipating technological breakthroughs, as Admiral Hogg noted in his remarks on disruptive thinking.

3

Discussion, Analysis, and Key Themes

The manner in which the workshop was conducted was conducive to rich discussions in group-enabled forums, which often spilled over into conversations during the breaks. All observed discussions converged into four main thrusts, which can be summarized as follows:

- The lack of shared understanding of new technologies on the part of S&TI producers and consumers often leads to surprise.
- Understanding the effects of an adversary's compulsions and constraints, or "currency"¹ of development—that is, the factors that impede or accelerate progress—is crucial for effective planning.
- In considering the potential of an adversary to produce surprise, it is essential to understand the cultural (geopolitical, demographic, moral/ethical value-system-related) context in which an adversary operates.
- It is now easier to gain access to potentially disruptive technologies or to component technologies that can be combined to create disruptive technologies; more difficult to monitor the increasing number of technology developments that could lead to surprise; and nearly impossible to anticipate the growing number of new uses for older technologies and tools.

Each of these thematic areas emerged in workshop discussions as a potential contributor to surprise or disruption. The challenge of shared understanding

¹In this context, the term "currency" refers to the mix of both tangible factors (resources, people, infrastructure, etc.) and intangible factors (ethics, nationalism, willingness to sacrifice to achieve a goal) that can result in the emergence of surprising behaviors or technologies.

focused on the lack of common definitions and clarity regarding the potential of various technologies to produce surprise—not only among symposium participants but also, by extension, among military strategists and planners. The currency of development refers to the various elements of a country's culture that could accelerate or decelerate the speed of technological progress. Cultural impacts also play a role in the acceptability of a technology and affect which areas are selected for development. Finally, commercially driven development, increasingly carried out by multinational corporations responding to global market demands, could be unpredictable, complex, and subject to repurposing. These areas are all discussed more fully in the following sections of this chapter.

LACK OF SHARED UNDERSTANDING OF NEW TECHNOLOGIES

Symposium participants' differing perspectives on which technologies were on the cutting edge of development stimulated discussion regarding the significance and consequences of the featured technology topics and the relevance of their emergence in adversarial circumstances. The lack of a shared understanding of potential uses also proved to be a source of widely varying perspectives among participants, particularly in the case of exotic technologies such as quantum computing. It was a generally held belief that some applications of these not-widely-understood technologies could be debilitating to U.S. defense strategies.

For example, a debate emerged in the blogs about what to watch for in the development of chemical weapons. It became apparent as the debate moved forward that the symposium participants were basing their opinions on different definitions. This kind of confusion in communication could be problematic both for indications and warning and for operational intelligence. In another example, it became apparent during a discussion on the use of electromagnetic pulses (EMPs) as nonlethal weapons that many participants were unaware of recent research showing that EMPs, even when used with benign intent, could have lethal effects. Another discussion mentioned the need for senior officers and decision makers to be advised by one or more technologists who are well informed on the current state of the science and are adept at translating technological advances into operational impact when planning defensive strategies and capabilities.

Additionally, different perceptions emerged that reflected lack of a clear, shared understanding of how technologies, even well-understood technologies, might be used. One participant suggested that perhaps we think too much in terms of the legacy platforms we so abundantly have versus future options an adversary might pursue. Another participant opined that we perhaps have become complacent in some technological areas by virtue of having been so dominant in air superiority for 30 years. The discussion became fairly pointed with respect to quantum computing, with one participant stating flatly that it's a red herring and others noting that there is an amazingly large investment globally for such a

“red herring”—one sign of a gross disparity in understanding that could create vulnerability and open the way to future surprise.

One participant noted that popularized information channels were not a reliable enough source of information to inform high-regret decisions, specifically stating that we need to be very cautious about making policy and military decisions based on hype (science fiction, marketing, movies, news). Another symposium participant responded that it would be important to search actively for the unusual—not a wish for hype, but for understanding the nature of the technology in order to anticipate how the technology could be combined in unique ways to create true surprise. Yet another participant countered that a new field such as detection deception might appear to the uninformed as hype but to others as promising. The course of the discussion continued with the premise that even if these Star Trek-like devices (communicators, tablets, beam weapons, force fields) are considered hype today, they do challenge the S&T community to explore imaginative possibilities and are often the basis of long-term predictions, as discussed in the second National Research Council report on forecasting future disruptive technologies.² This discussion became a rich source of information and inspiration for some participants, with the record showing how opinions evolved as the online conversations continued.

A generational gap was noted in the use and appreciation of technologies. One participant observed how amazing it was that junior officers' ideas for using technologies were often resisted at first by their older commanders but then noted that when the junior officers demonstrated success, the general officers were willing to change their viewpoints.

During the discussions surrounding Human 2.0, virtual reality was presented as an enabler both for technology surprise and for behavioral development. In its application to training and visualization, virtual reality is well understood by many in the services and the relevant communities. In fact virtual reality has had a long-standing presence in large defense systems such as aircraft and naval systems, yet virtual worlds and simulation have been less common in the ground war (infantry/civil interaction) components of warfighter training. The U.S. government has made significant investments in this technology, but many in the audience questioned the effect of training soldiers solely via simulated encounters. One participant contended that there is no evidence that simulation can replicate the real stress that accompanies actual life. Without this critical piece, simulation will always be a poor substitute for reality, useful in particular niches like partial task training but not as a replacement for live training. Some members of the audience countered this argument, stating that although virtual reality might seem to be just an interesting experiment today, while it is still in its infancy, it might

²NRC. 2010. *Forecasting Future Disruptive Technologies—Report 2*. Washington, D.C.: The National Academies Press, p. 44. Available at <http://www.nap.edu/catalog/12834.html>. Accessed August 30, 2010.

be useful in the future if it spills into the real world, combining virtual combat environments with unmanned soldier systems. Another comment reminded the audience of the utility of systematic desensitization, given that some soldiers suffer posttraumatic stress disorder (PTSD) when they actually see, smell, and experience the blood and gore of real combat.

Virtual worlds—from those that model large-scale persistent communities to the immersive games that are played in smaller peer nodes—were demonstrated to help in improving understanding of human behavior in a variety of ways. A symposium participant wrote that perhaps virtual worlds allow us to understand the implications of certain situations that we would not like to experiment with in the real world. (This idea is expanded later in this chapter—see the section “Impact of the Cultural Context on Technology Development and Use.”) Symposium participants observed that studying human behavior in instrumented virtual worlds could potentially provide a very rich set of behavioral data. This kind of research not only is possible but also is actually being pursued at research institutions around the world. Perception can be shaped. While virtual reality (e.g., *Second Life*³) could be used to promote dangerous ideologies, as one participant stated, it was exactly these behaviors that could be silently observed in a virtual environment and studied. Unlike in the natural world, virtual worlds provide a global reach that can uncover new combinations of cultural mixing, ideological distribution, and cultural behavior.

The symposium participants converged on understanding how virtual worlds were being used now and how they might be used (or abused) in the future. However, there seemed to be a dichotomy in the audience between those who saw a military relevance for virtual or augmented reality and those who thought it was overrated. One participant noted that augmented reality using synthetic visual generation and networked sensors could allow a warfighter to see what is on the other side of a wall; another disputed the idea, claiming that no evidence has shown real impacts from the use of immersive virtual environments. The lack so far of concrete, real-world examples of such technology successfully applied in military or intelligence environments is one reason that the technology is being evaluated for its potential to surprise. Simply put, no one has proved or disproved the utility of virtual reality technology.

³ See footnote 2 in Chapter 2.

UNDERSTANDING THE EFFECTS OF AN ADVERSARY'S COMPULSIONS AND CONSTRAINTS ON INNOVATION DEVELOPMENT

Among the many influences affecting S&T R&D development efforts in any country or organization, the committee observed that the following affect the ability to innovate:

- Time,
- Money,
- People, and
- Levels of risk considered acceptable.

Together these factors constitute the currency of development (COD), which should be taken into account when considering the relevance of the pace, direction, and origination date of the technology development effort. The COD incorporates the drivers and enablers of innovation in terms of the people, the timescale, and the resources (both tangible and intangible) necessary to bring about new behaviors and/or new technology. The COD also includes constraints or obstacles that economists might refer to as “negative incentives.” The combination of these elements constitutes a COD similar to Michael Porter’s total factor productivity (TFP).⁴ COD differs from TFP—COD captures the likelihood that a technology will develop in a specific context, whereas TFP focuses on the components of the productivity potential of an enterprise. However, metrics for COD need to be normalized across different countries to account for different labor costs, which appear in the cost of executing R&D as well as the cost of creating and maintaining the infrastructure to support the R&D enterprise.

This part of the discussion intrigued some of the symposium participants, and it became clear that the elements comprised by COD were neither well understood by the individuals present nor consistently definable by them. There was a concern that the intelligence community needed to understand COD much better and that such understanding would be critical to comprehending the development potential in specific situations. This understanding was discussed from both an observational and a diplomatic perspective, because it was from the latter perspective that elements of the currency component could be used to influence the technological capabilities of adversaries in certain areas.

⁴Michael Porter. 1990. *Competitive Advantage of Nations*. New York, N.Y.: Free Press.

IMPACT OF THE CULTURAL CONTEXT ON TECHNOLOGY DEVELOPMENT AND USE

Cultural issues were of significant concern to many of the symposium participants because of the perceived substantial impact on technology development and use. Cultural distinctions based on geopolitical context, demographics, and value systems were singled out for discussion. Culture was considered to have the following kinds of impacts:

- It makes some societies more susceptible than others to certain kinds of attacks,
- It makes some societies more likely to develop certain types of technologies, and
- It creates challenges in observing and interpreting other, different cultures.

Understanding the sources of cultural distinctions emerged as a multi-dimensional challenge that had not been fully considered by the participants.

Geopolitical Context

Geopolitical context is perhaps the most familiar source of cultural distinction because it is the one with which we are most familiar—people or groups from a distant region are different from “us” by virtue of their culture. As such, it was the first source of cultural distinction to warrant attention by the symposium participants. But once raised as a topic, geopolitically based cultural distinctions turned out to be replete with nuance. In this connection, microcultures (cultures within other dominant cultures) were discussed along with fused cultures resulting from population migration. Fundamentally, however, lack of appreciation of other cultures was seen as a weakness in U.S. intelligence efforts. One participant noted that Americans speak few foreign languages, do not travel abroad widely, and do not have a good understanding of foreign cultures. The premise was that the more people are exposed to foreign ways of thinking, the better they are able to understand other points of view and the less myopic their outlook will be. One example given was the number of Chinese students studying the English language and American culture compared to the number of Americans studying Mandarin and the Chinese culture. Another participant, agreeing, said that cultural competence was expensive in terms of time and money, going on to note that the few people who have that competence are usually fully engaged in current operations. This thought was developed further in a cost-benefit discussion, which suggested that significantly broadening cultural competence DoD-wide would be challenging, time-consuming, expensive, and difficult to defend given the current climate of shrinking resources and increased competition for those resources—raising cultural awareness might even have to be supported from S&T funding.

Not knowing where cultural distinctions come from can be a weakness in defense planning, where actions are undertaken to achieve a desired outcome. The weakness may be exacerbated if there is a lack of training and familiarization with such issues and their interpretation, which is quite likely, given the subtlety and sophistication of cultural nuances and their interpretation. The importance of culturally sensitive analysis was described by one participant as critical to seeing correctly through an adversary's eyes—for example, a Western thinker, asked to select two from among a banana, a monkey, and a panda, might choose the monkey and the panda since they are animals. Alternately, an Asian thinker might choose the banana and the monkey since a monkey eats bananas. Another participant noted that even among cultures that might seem to be very similar, important differences in perspective can exist. This participant spoke of conducting a research project years ago that examined differences between U.S. and UK training and technologies using Navy officers conducting combat operations. The results showed that there were critical differences in the heuristics used in their decision making. This difference in thinking exemplifies the impact of cultural differences and educational differences even among people who share the same language.

One symposium attendee warned that addressing the problem of cultural nuance is not easy from a personnel perspective and commented that to be effective requires personnel who can internalize the values of adversaries while faithfully bearing allegiance to the United States. Unfortunately, these people can and do have career disadvantages within U.S. culture; hence, they are kept out of the mainstream. Another attendee cautioned that understanding culture is important and noted the great temptation to apply a solely American perspective to U.S. international efforts, as well as the increased likelihood of failure in those efforts if we indulge in an exclusively American-centric strategy. Put another way, on the international stage, what the United States intends is often not what is inferred, many times for no other reason than a culturally uninformed choice of words or gestures to which we ascribe little meaning but which have great significance for the observer.

Demography

A more subtle cultural distinction comes from demography—younger generations are increasingly more immersed in network-enabled entertainment and productivity than older generations and, therefore, have a very different appreciation and interpretation of what is *virtual* in culture and games and what is *real*. This cultural distinction transcends geography and geopolitical boundaries and fosters the emergence of subcultures that span the globe. The denizens of these subcultures have different expectations of what is allowable, what is possible, and what is appropriate, particularly when it comes to behavior in cyberspace. This culture is more dynamic than mainstream culture—it has norms that evolve at a

much more rapid pace, is more driven by advances in technology and assimilation of those advances, and is less encumbered with the burdens of communicating to other cultural groups that don't have the context to understand the *reality* embodied in their *virtual world*.

The impact of cultural nuances based on demographics is grasped only poorly, if at all, by older generations. One participant noted that the youth of today have different expectations, saying that for many under-25-year-olds, their virtual friends are more real than their "physical" friends. Look at Facebook for example. For many of that generation, virtual interaction *is* human interaction. If we think about virtual teams and a virtualized workforce, cyberinteraction and social skills in cyberspace may be more important socially, politically, and economically than "local" interactions.

Another participant noted that demographic cultural differences also exist within geographically defined cultures, including in the United States, where, according to one observer, young army officers who use these new technologies to increase their agility showed all of "us old guys" how technology should be integrated into the Army. As mentioned above, one observer expressed amazement that junior officers' ideas to use technologies were initially so resisted by their older commanders, whereupon another attendee offered having witnessed one senior officer refer to those technologies as "destructive to the chain of command."

Values

The United States has learned, painfully, that certain values considered by our citizenry to be abhorrent and even prohibited in our own culture are nonetheless fully accepted as appropriate, or at least permissible, in the cultures of some of our adversaries. By their own standards, these adversaries consider themselves to be highly structured, altruistic, and moral. This leads to several potential cultural conflicts. The first arises from the development of culturally abhorrent technologies, where the abhorrence could stem from either the end use or the development process itself. Such circumstances could result in a perceived need for the United States to develop defensive technologies to counter the perceived threat, which in turn could imply a need to go against our cultural values. Another arises in the challenge of teaching right from wrong to the next generation of warfighters. Further, the value gradient may be gradual rather than discrete, possibly allowing for an extended and irresolvable debate. One participant pointed out that chemical and

biological weapons are banned as a method of warfare, which is why the United States doesn't use riot control agents (RCAs) in offensive operations like building clearing. Conversely, RCAs are permitted in police actions. Police actions are defined by each nation-state—for instance, the United States uses RCAs for detainee operations, but the United Kingdom does not. During the 2002 Moscow theater crisis, fentanyl was deployed by the “police”—regulations governing the use of chemical and biological weapons provide little guidance on what a country may use or develop for use against its own people.^{5,6}

These issues are not new—consider the impetus for the Geneva convention—but continue to be of concern, particularly in the area of advanced human-based technologies, which require careful consideration. Additionally, there are significant intelligence challenges, because “values” are culturally dependent, and we cannot, in principle, appreciate them fully from other perspectives. Many participants felt that disciplines such as cultural anthropology, sociology, and psychosocial pathology are extremely important to warfighters, particularly in today's world and going forward.

It was noted at the symposium that understanding takes effort. To paraphrase one exchange from the blogs, we are surprised by female suicide bombers, not because we have *no* knowledge of our enemy and their thinking, but because we have only a superficial, cookie-cutter understanding of that culture and thinking. The blog contributor closed that particularly poignant dialog by stating that, with people at least, there may be nothing new in interpersonal interaction the world over, but there is a lot of “new to me.” As the symposium proceeded, a great many participants echoed this sentiment.

GROWING EASE OF ACCESS TO POTENTIALLY DISRUPTIVE TECHNOLOGIES AND INCREASING DIFFICULTY OF MONITORING

Commercially Driven Emergence of Disruptive Technologies

The potential for surprise arising from commercial development efforts was considered from several angles. One was the speed with which commercial development can occur, particularly as contrasted with the pace of U.S. defense procurement. Another was the potential for incursion into what has traditionally been state-sponsored research and development, such as for space-related R&D. One participant commented that space was already a “playground” for billion-

⁵P.M. Wax, C.E. Becker, and S.C. Curry. 2003. Unexpected “gas” casualties in Moscow: A medical toxicology perspective. *Annals of Emergency Medicine* 41(5):700-705.

⁶NRC. 2008. *Emerging Cognitive Neuroscience and Related Technologies*. Washington, D.C.: The National Academies Press. Available at <http://www.nap.edu/catalog/12177.html>. Accessed August 30, 2010.

aires, highlighting *SpaceX* as a demonstration of what smart, creative engineers can do with relatively little money.

The potential for impacts from commercial development is particularly apparent in the biotechnology and medical areas. As one participant noted, the commercial drive for some research, particularly medical and pharmaceutical research, might lead to alternative uses that are not readily observable but that could be surprising. For example, medical research for conditions like Alzheimer's disease and Parkinson's disease will continue to advance and drive research on brain interfaces in the United States, but the notion of using it for other applications is wide open. The research on and commercial application of neurological treatments elicited a robust discussion when it was collectively realized that cognition-altering drugs can be used for many purposes beyond those originally intended, such as memory enhancement or suppression, the maintenance of alertness, or the simulation of pleasure. One participant felt that given the profit potential of treatments for neurological disorders in the aging populations of richer countries, it is likely that the rapid pace of development of these technologies by the commercial sector will continue to accelerate. Another participant pointed out that genetic engineering combined with brain interface development may enable advances in behavioral control, with the resulting potential for creating a new class of engineered humans of particular use as "cyberwarriors."⁷

Concern was expressed about the potential for benign, highly profitable technologies developed by the commercial sector to be converted or "frankensteined" into offensive technologies. This concern arose most often when the discussion turned to biotechnology, virtual reality, social computing, or space exploration. While there was some discussion about the barriers to entry for new technologies (from the standpoint of both the required technology base and the necessary resources), the point was made repeatedly that such barriers applied only to initial entrants and became much lower over time as the technology pervaded the marketplace.

A specific area of concern was in the area of health research, where commercial enterprises working at the DNA level are beginning to market health protocols, including drug treatments, based on genetic engineering and chemical interventions into normal human processes. The fear was that the maturity of the research base required to achieve this level of sophistication in health treatments need not be replicated by adversaries desiring to create an offensive capability; for example, effort toward the genetically specific targeting of populations or the use of chemicals to influence mental processes might leverage open-source knowledge and widely available "best laboratory practices" in conjunction with commercially available equipment, as opposed to investment in an expensive,

⁷For more information, see NRC, 2008, *Emerging Cognitive Neuroscience and Related Technologies*, Washington, D.C.: The National Academies Press. Available at <http://www.nap.edu/catalog/12177.html>. Accessed August 30, 2010.

general-purpose research-grade enterprise. This fear as expressed by some symposium participants was compounded by the realization that there is a much higher potential for maintaining secrecy regarding such development efforts in the case of a legitimate commercial enterprise (versus a state actor) whose primary-purpose technology or treatment was being turned into a product to fill an existing market niche, such as a genetic screening test for a condition common to a particular ethnic group, since investments, staff, and products for executing the advertised objective would match those required for the clandestine objective. This situation could potentially make the detection of such capabilities for nefarious purposes almost impossible.

Another area cited by participants as one in which commercial R&D predominates is that of small sources of power, especially batteries. Although Napoleon is quoted as having said that an army travels "on its stomach," it is the case that a modern army travels on electric power, primarily batteries and small generators. This power is needed for the equipment soldiers carry as well as for robots; for these applications, combustion engines are inadequate, unavailable, or inappropriate. Indeed, it was stated at the symposium that a major challenge to the evolution of small robots—for land, sea, and air operations—was the lack of power sources with energy densities comparable to those available for large platforms. It was pointed out that while most of the R&D on advanced batteries takes place in the United States, most battery manufacturing is in Asia (mainly China), and that U.S.-based production facilities have been closed or sold to foreign owners. Other participants countered by saying that several new start-ups in the United States are planning to produce battery packs for electric cars, implying that this situation might improve.

Discussion of the commercialization of space and its impact on security elicited different views. Some thought that entrepreneurial approaches would lower the cost of access to space and could be duplicated by non-state actors of sufficient means. Others were very skeptical that the cost would change much. People commented that the U.S. government was relinquishing its leadership in access to space to the private sector and other countries.

It was also pointed out that technologies developed by the commercial sector had often been repurposed for military uses; one example is the transfer of the combustion engine from cars to tanks. This observation led to a discussion of how military-use-only technologies could be distinguished from potential dual-use technologies.

A recurring theme during these discussions was whether technology surprise would be more likely to emerge as a result of commercial market forces or of state-sponsored development. This concern arose more often in discussions about the technology areas profiled in the symposium that were considered to have great commercial potential. It did not, for example, arise in discussions about highly specialized defense applications, such as precision targeting, but did arise

for application areas perceived to have a high probability of dual use, such as biotechnology, nanotechnology, and virtual reality.

Open-Source Development

The emergence of new technologies was also discussed in the context of open-source development. Several participants had strong opinions on the potential for surprise arising from applications of open-source knowledge, technology, and even intelligence, with one observing, “Now *there* is a disruptive *technology*.” Other contributors commented on the magnitude and diversity of computer code that is freely available to anyone with an Internet connection. Still others lamented that this topic wasn’t more specifically highlighted during the presentations at the symposium. This level of concern was seen as most relevant to technology being developed in connection with computer-enabled applications such as simulation, modeling, and communications but could easily be applied to ad hoc weapons designs (biological and chemical weapons, and improvised explosive devices and subcomponents).

The monitoring of open-source research was generally described as problematic. Discussion at the symposium explored the idea that when many different people from many different areas of expertise are contributing, keeping track of all that develops becomes increasingly difficult. Furthermore, the ability to fuse many open-source capabilities to create something new might dramatically reduce the time needed for research and development for technology applications. Clearly, not all technologies are amenable to open-source development. But of the ones that are, the combinatorial potential of the multitude of open-source efforts was seen as a troubling possibility. One participant declared that, at least for the technologies discussed at the symposium, there are few better examples of technology levelers for a non-state actor than exploitation of open-source technologies and expertise; the open and available nature of the Internet and open-source content offers clear and explicit instruction on how to do something and in some cases will nearly do it for you—you only need to hit “play.”

The Challenge of Keeping Up

In the various discussions about how surprising or disruptive technologies could emerge, there appeared a recurring question: Could such technology and expertise be discovered solely from the published literature? Because researchers, particularly those in academia, are so highly motivated to publish, does it stand to reason that the literature is an obvious source of information about new technology developments?

The literature is large and varied, and so identifying the potentially important advances from a large and increasing number of scientific articles requires a sophisticated approach as well as subject-area expertise. This sentiment was

widely shared among symposium participants, with one stating it explicitly when he asked a speaker for clarification of one of the presentation topics. In thanking the speaker for the informative answer, he said, "Cool. Thanks for the update. It's hard to keep up with the literature."

It was pointed out that keeping up with the literature entails more than simply counting papers, although it was noted that there is value in such observations, if only to uncover trends and to discern popular areas of published research. Also mentioned was the evolution of the literature to include Web publishing and blogging, which presents new challenges for tracking. To paraphrase many symposium participants, in order to extract knowledge from the published literature and obtain data on frequency of publication in a timely way, there would have to be ongoing collaboration with the academic community. The discussion continued, exploring the idea that facilitation of interactions between U.S. and non-U.S. scientists might be important in enabling the monitoring of technological advances and their uses, at least within academic organizations.

4

Challenges of Technology Surprise for the Warfighter

There was robust discussion at the symposium regarding analysis of the surprising behaviors that permit or accompany the disruptive use of technology, the noteworthy result being the idea that cognizance and analysis of surprising behavior in addition to cognizance and analysis of technology alone represents an expansion of the contemporary community practice of addressing technology surprise. The views aired at the symposium explored the idea that predicting surprising behaviors requires more insight than can be derived from technical expertise alone. Participants noted that the widespread dissemination of scientific and technical knowledge and know-how could combine with the inherent cleverness of people everywhere to create an essentially unbounded set of possibilities for disruptive surprise based on technology *and* behavior. Several contributors noted that avoiding such surprise would probably require a multidisciplinary analytical approach that included country experts and societal specialists; such an approach might also need augmentation from selected psychologists, sociologists, political experts, religious specialists, and others. Concomitantly, it was noted that deep understanding and current knowledge of foreign cultures are rare among Americans, a view widely stated by symposium attendees.

It was pointed out that the suggested multidisciplinary approach to analysis that focuses on technology surprise faces many obstacles in addition to a paucity of potential participants within the intelligence community. For example, one participant posted the explicit question of whether technical experts should learn current cultural and country details so that they could produce more relevant sets of technology surprise predictions. Another participant commented that appropriately educating technical experts in cultural and country details requires a nontrivial investment of time and a high degree of motivation; the confluence

of the three—awareness of culture, country, and the associated potential for surprise—is currently “unusual” to the point of being nonexistent. Many participants discussed this issue, pointing out that resolving it is also exacerbated by the manner in which technical experts are managed and rewarded—time spent learning “soft” skills is not generally rewarded and may in fact detract from the time that might be spent writing a peer-reviewed paper, attending a conference, or making a technical breakthrough, all of which are generally highly valued in professional performance evaluations. Similarly, motivating country or societal experts to devote time and effort to understanding technology so that they are equipped to make optimal predictions and rankings is neither quick nor cheap, nor is it likely. Some pointed out that if improved and broadened prediction of technical surprise is truly desired, there may be no choice other than better educating the participants and/or including a broader range of actors, i.e., using collaborative teams made up of technologists as well as country experts.

As Admiral Hogg and the symposium attendees stated, the world is increasingly more complex and challenging, driven by globalization of resources and ideas as well as enabled by worldwide information and communication systems. This situation has given rise to new threats, new adversaries, and a changing environment that the United States has not defined (or redefined) in its doctrines of warfare and operations. The warfighter will still need to deal with the current traditional threats on the battlefield, including enemies who quickly start using technology that the U.S. military has just implemented. Surprise will come not only from the traditional areas but also from new enemies—some not declared—who adopt both available and new technology as well as improvise in its use. Because of these new challenges of surprise, the nature of warfare will likely change in the *very* near future.

Appendixes

Appendix A

Committee Biographies

J. Jerome Holton, *Chair*, is senior systems engineer with the Tauri Group, where he supports the BioWatch Systems Program Office in 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. Before that, he served in a variety of leadership positions for private companies, from scientific research start-ups to large management consulting firms. 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, the DHS Science and Technology Directorate, and the Joint Improvised Explosive Device Defeat Organization (JIEDDO). His work extends broadly across the chemical/biological/radiological/nuclear/conventional explosives (CBRNE) 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 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. Dr. Holton previously served the NRC as a member of its the Standing Committee for Technology Insight—Gauge, Evaluate, and Review (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.

Ruth A. David, NAE, Vice Chair, is president and chief executive officer of Analytic Services, Inc., a nonprofit research institute focusing on national security, homeland security, and public safety issues. She initiated a corporate focus on homeland security in 1999 and established the ANSER Institute for Homeland Security early in 2001; today the corporation operates the Homeland Security Institute, a federally funded research and development center sponsored by the Department of Homeland Security, in addition to the ANSER business unit. Before assuming her current position in 1998, Dr. David was deputy director for science and technology at the Central Intelligence Agency (CIA). As technical advisor to the Director of Central Intelligence, she was responsible for research, development, and deployment of technologies in support of all phases of the intelligence process. Dr. David currently serves on the National Academy of Engineering Council as well as on several committees of the National Research Council (NRC); she chairs the NRC Standing Committee for Technology Insight—Gauge, Evaluate, and Review (TIGER) and the Board on Global Science and Technology. She is a member of the Homeland Security Advisory Council, first established to advise the President, and now advising the Secretary of the Department of Homeland Security. She also serves on the National Security Agency Advisory Board, the Hertz Foundation Board, and the Wichita State University Foundation National Advisory Committee and is a member of the Draper Corporation. Previously, Dr. David served in several leadership positions at the Sandia National Laboratories, where she began her professional career in 1975. Dr. David received a bachelor of science degree in electrical engineering from Wichita State University, and a master of science degree and a doctorate in electrical engineering from Stanford University.

Brian Ballard is the director of product development and vice president at Berico Tailored Systems (BTS), where he leads the development of defense-oriented augmented reality and data fusion applications. As part of his portfolio, he is heavily engaged in developing mobile 3G and 4G networks for tactical military employments. Prior to joining BTS, Mr. Ballard served as the chief technology officer 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, Mr. Ballard has dealt with all forms of data collection, dissemination, processing, and visualization. As a field operations officer at the National Security Administration, he was a member and team leader in the Office of Target Reconnaissance

and Surveillance. Mr. 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.

Alan H. Epstein, NAE, is the vice president of technology and environment at Pratt & Whitney, where he is responsible for setting the direction for and coordinating technology across the company as it applies to product performance and environmental impact. Previously he was the R.C. Maclaurin Professor of Aeronautics and Astronautics and the director of the Gas Turbine Laboratory at the Massachusetts Institute of Technology. His responsibilities there included teaching and research in aerospace propulsion, power production, fluid mechanics, and microelectromechanical systems (MEMS). He was an active consultant to industry and government for more than 30 years on topics including gas turbine and rocket engines, MEMS, system testing, military infrared systems, and vehicle observable technology. Dr. Epstein is a fellow of the American Institute of Aeronautics and Astronautics and of the American Society of Mechanical Engineers. He is a former member of the NRC Air Force Science and Technology Board and of the DARPA Defense Science Research Council. He is currently chair of the NRC Board on Army Science and Technology. He received his B.S., M.S., and Ph.D. degrees from the Massachusetts Institute of Technology in aeronautics and astronautics.

John Gannon is president for Information Solutions at BAE Systems. He previously served as vice president for Global Analysis, a business area within BAE Systems Information Solutions. Dr. Gannon joined BAE Systems after serving as staff director of the House of Representatives Homeland Security Committee, the first new committee established by Congress in more than 30 years. In 2002-2003, he was a team leader in the White House's Transitional Planning Office for the Department of Homeland Security. He served previously in the senior-most analytic positions in the intelligence community, including as the CIA's director of European analysis, deputy director for intelligence, chairman of the National Intelligence Council, and assistant director of Central Intelligence for Analysis and Production. In the private sector, he developed the analytic workforce for Intellibridge Corporation, a web-based provider of outsourced analysis for government and corporate clients. Dr. Gannon served as a naval officer in Southeast Asia and later in several Naval Reserve commands, retiring as a captain. He holds a bachelor's degree from Holy Cross College in Worcester, Massachusetts, and master's and doctorate degrees from Washington University in St. Louis, Missouri. He is an adjunct professor in the National Security Studies Program at Georgetown University.

Christopher C. Green is assistant dean for Asia Pacific of the Wayne State University School of Medicine (SOM). He is also a clinical fellow and professor

in neuroimaging/magnetic resonance imaging in the Department of Diagnostic Radiology and the Department of Psychiatry and Behavioral Neurosciences of the SOM and the Detroit Medical Center (DMC). His medical specialties are brain imaging and forensic neurology, and his personal medical practice is in the differential diagnoses of neurodegenerative disease. He has served and continues to serve on many government advisory groups and private sector corporate boards of directors. Immediately prior to his current position, he was executive director for emergent technology research for the SOM/DMC. From 1985 through 2004 he was executive director, Global Technology Policy, and chief technology officer for General Motors' Asia-Pacific Operations. His career at General Motors included positions as head, Biomedical Sciences Research, and executive director, General Motors Research Laboratory for Materials and Environmental Sciences. His career with the CIA extended from 1969 to 1985 as a senior division analyst and assistant national intelligence officer for science and technology. His Ph.D. is from the University of Colorado Medical School in neurophysiology, and his M.D. is from the Autonomous City University in El Paso, Texas/Monterey, Mexico, with honors. He also holds the National Intelligence Medal and is a fellow in the American Academy of Forensic Sciences.

Diane E. Griffin, IOM and NAS, is professor and chair of the Department of Molecular Microbiology and Immunology at Johns Hopkins Bloomberg School of Public Health. She earned a degree in biology from Augustana College in 1962, followed by M.D. (1968) and Ph.D. (1970) degrees from Stanford University. She interned at Stanford University Hospital between 1968 and 1970 before beginning her career at Johns Hopkins as a postdoctoral fellow in virology and infectious disease in 1970. After completing her postdoctoral work, she was named an assistant professor of medicine and neurology. Since then, she has held the positions of associate professor, professor, and now professor and chair. She served as an investigator in the Howard Hughes Medical Institute from 1973 to 1979. Dr. Griffin's research interest includes alphaviruses and acute encephalitis. She is also working on the effect of measles virus infection on immune responses. Dr. Griffin is the principal investigator on a variety of grants from the National Institutes of Health and the Bill & Melinda Gates Foundation. She is the author or coauthor of more than 300 scholarly papers and articles, and the past president of the American Society for Virology, the Association of Medical School Microbiology Chairs, and the American Society for Microbiology.

Kenneth A. Kress is a senior scientist for KBK Consulting, Inc., 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 Microsystems Technology Office, Noblis, Georgia Tech Research Institute, Mitretek Systems, Inc., and Lockheed Martin 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 senior scientist responsible for management support, the development of technical and strategic plans, and DoD interagency 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.

Gilman G. Louie is a partner of Alsop Louie Partners, a venture capital fund focusing on the development of great technology entrepreneurs. Prior to this position he was president and CEO of In-Q-Tel, the venture capital group helping to deliver new technologies to the CIA and the intelligence community. Before helping found In-Q-Tel, Louie served as Hasbro Interactive's chief creative officer and as general manager of the Games.com group, where he was responsible for creating and implementing the business plan for Hasbro's Internet games site. Prior to joining Hasbro, he served as chief executive of the Nexa Corporation, Sphere, Inc., Spectrum HoloByte, Inc., and Microprose, Inc. As a pioneer in the interactive entertainment industry, Gilman's successes have included the Falcon, F-16 flight simulator, and Tetris, which he brought over from the Soviet Union. Louie has served on the board of directors of Wizards of the Coast, Total Entertainment Network, Direct Language, and FASA Interactive. He was an active member of the Markle Foundation Task Force on National Security and the Information Age.

Julie J.C.H. Ryan is associate professor of engineering management and systems engineering at George Washington University. She holds a B.S. 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. Dr. Ryan began her career as an intelligence officer, serving the U.S. Air Force and the U.S. Defense Intelligence Agency, working in a series of increasingly responsible positions throughout her career. 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. During a distinguished career she has conducted several research projects and has authored articles, book chapters, monographs, and a book in her focus area.

Appendix B

Participating Organizations and Agenda

PARTICIPATING ORGANIZATIONS

Air Force Research Laboratory
Central Intelligence Agency
Concurrent Technologies Corporation
Defense Advanced Research Projects Agency
Defense Intelligence Agency
Defense Threat Reduction Agency
Georgia Institute of Technology
In-Q-Tel
Institute for Defense Analyses
Joint Improvised Explosive Device Defeat Organization
Joint Warfare Analysis Center
Lockheed Martin Corporation
Martin Consulting
National Air and Space Intelligence Center
National Ground Intelligence Center
National Research Council
National Security Agency
Naval Surface Warfare Center
Naval Undersea Warfare Center
Office of the Chief of Naval Operations
Office of the Joint Chiefs of Staff
Office of Naval Intelligence
Pratt & Whitney

Sandia National Laboratories
 Science Applications International Corporation
 Stevens Institute of Technology
 United States Air Force
 United States Army
 United States Army Armament Research, Development and Engineering Center
 United States Army Materiel Command
 United States Army Research Development and Engineering Command
 United States Army Training and Doctrine Command
 United States Joint Forces Command
 United States Marine Corps
 United States Marine Corp Intelligence Activity
 United States Navy
 United States Transportation Command

AGENDA

April 28, 2010

07:30 Continental Breakfast, Registration
 08:15 Introduction, Dr. Ruth David
 08:30 Overview, FacilitatePro login
 09:00 Keynote Address, LTG Keith M. Huber, Deputy Commander,
 USJFCOM
 09:30 Break
 10:00 Presentations: Nonkinetic Weapons
 11:15 Break
 11:30 Presentations: The Death of Privacy
 13:45 Presentations: Human 2.0
 14:45 Break
 15:15 Presentations: Energy
 16:30 Reception
 18:00 Adjourn

April 29, 2010

07:30 Continental Breakfast, Registration
 08:00 Preliminary Survey Results
 09:00 Avoiding Technology Surprise for Tomorrow's Warfighter. Admiral
 James R. Hogg, USN (Ret.), Director, CNO Strategic Studies
 Group.
 09:50 Break
 10:00 Strategic Studies Group Day 1 Perspectives

- 10:15 Future Joint Operating Environment: Implications for Science and
Technology
- 11:00 Defense Intelligence Agency Defense Warning Office: Opportunities
for Persistent Engagement
- 11:30 Closing Remarks
- 11:45 Adjourn

Appendix C

Summary of Sessions

The symposium started with a keynote address by LTG Keith M. Huber. Each speaker then provided a very short summary of his or her presentation. These compressed summaries were designed to stimulate dialogue among those who had only limited subject-area knowledge and, it was hoped, allow them to recognize what might turn out to be red flags.

KEYNOTE ADDRESS: LTG KEITH M. HUBER

LTG Huber highlighted a number of challenges in avoiding technology surprise. Despite the inevitability of some technology surprise, he felt that communication skills were key to quickly developing a plan to deal with such surprise once it had happened. One challenge to be overcome was effective communication within the joint forces at a human level—specifically, the ability to share ideas among people with different levels of education. As a leader, he expected that the forces under his command would be diligent and motivated by a desire to benefit the next generation rather than a desire for personal advancement.

During the question-and-answer period, LTG Huber said he felt that his job entailed facilitating communication in several ways. He mentioned forcing communication between joint forces and command staff and actively using the 1.1 million-person resource pool to do this. He was also tasked with ensuring that the Washington and Norfolk contingents were in sync. He stated that as part of his job duties, he takes a capabilities approach by assigning staff to individual tasks and projects, depending on how well suited they are to the effort. He sets conditions and prioritizes his limited resources so that everyone can make a contribu-

tion. He also regularly provides information to the Secretary of Defense on the communications approach and on the collaboration efforts that he is enabling.

LTG Huber was also asked how JFCOM works with NATO and what the goals are. He replied that building trust between JFCOM and NATO through interagency cooperation is one key goal, as are sharing data and communicating regularly by means of status reports and meetings. He felt that a lack of communication would breed distrust.

NONKINETIC WEAPONS

Adaptive Camouflage

The presenter said that many different countries were actively researching camouflage technologies. Such technologies enable an object to blend in with its surroundings like a chameleon and to adapt to multiple, perhaps radically different environments.¹ Current hurdles to this research thrust involve the management of multispectral observables. Some of the techniques and materials involved in active camouflage were discussed.

Low Observables and Counter Low Observables

Low observable technologies and countermeasures were briefly discussed.²

Nonlethal Weapons

Three kinds of nonlethal weapons were discussed: pharmaceuticals, counter-personnel material, and ultra-short-pulse lasers. The presenter said that all three types of weapons could easily affect and disrupt large groups, including warfighters and mission planners, a danger posed by all of these weapons. Because advances are routinely published in academic research papers and in conference proceedings, much information on their status is openly available around the globe. The development of ultra-short-pulse laser technology is documented in the United States in papers that describe research and development in constructed systems. Additionally, the procurement of such high-power systems is also a matter of public record.

¹For more information, see NRC, 2001, *Opportunities in Biotechnology for Future Army Applications*, Washington, D.C.: National Academy Press. Available at http://www.nap.edu/catalog.php?record_id=10142. Accessed August 30, 2010.

²For more information, see NRC, 2006, *Future Air Force Needs for Survivability*, Washington, D.C.: the National Academies Press. Available at http://www.nap.edu/catalog.php?record_id=11743. Accessed August 30, 2010.

Agile Systems

The presenter described the utility of agile systems, which can vary their parameters *during* operation, perhaps in response to the operational environment (such as with polymorphous computing), or perhaps in response to an adversary (such as with frequency-hopping communications that prevent interception and variable radar or seeker modes that can counter electronic warfare). However, at this point the agile systems discussed were most compatible with nonkinetic weapons and devices, since they generally have control and/or telemetry systems that allow in situ or remote operation (kinetic weapons and devices generally have neither control systems nor telemetry systems).

DEATH OF PRIVACY

Miniaturized Sensors

Sensor technologies are progressing by leaps and bounds owing to the proliferation of devices (many of them wireless) that monitor our surroundings in ways barely imaginable a few years ago. A sensor is any device that can respond to a stimulus—heat, light, magnetism, or exposure to a particular chemical—by converting it into a signal. Emerging sensor technologies and trends were highlighted, including biosensors and sensors related to protein engineering, GPS, radio and TV signals, femtosecond lasers, and self-organizing, wireless ad hoc networks. The global sensor grid includes smart buildings and roads, military sensor networks, cell phones, minicameras, and smart appliances.

Ultraprecision Strike

The presenter highlighted the types of weapons that contribute to ultraprecision strikes and their effects. The composite warhead technology that enables the precision strike was discussed. Ultraprecision strike tools are being researched and developed by countries around the world.

Quantum C4I

The presentation focused on the progress being made in quantum information science. Quantum methodology was discussed. Quantum information science, quantum computing, and quantum cryptography continue to be part of U.S. research and development efforts and contribute to many international efforts. The presenter emphasized that quantum solutions currently work on few problems and that much research is still needed.

Nanophotonics

This videotaped presentation focused first on the worldwide drivers of research on nanotechnology, including research on photonic crystals, plasmonics, metamaterials, negative index materials, and nanostructures. The discussion further explored this worldwide industry driven by commercial interests, emphasizing its strong coupling to nanoelectronics and biotechnology. Nanophotonics is an enabler for many systems improvements, not a fieldable system in its own right.

HUMAN 2.0

Virtual Reality

This presentation discussed virtual worlds, which can mimic reality and also transcend reality, even though the distinction is often unclear. Augmented reality includes the fusion of cyber datasets and real-world environments. Cyber data come from many sources, including sensors, models, multiple online sources, and/or a parallel virtual world. Virtual reality is increasingly part of the civilian consumer experience, as exemplified by the many applications now running on cell phones.

Cognitive Neuroscience

Pathways to enhanced cognition were the main topic. Research might involve gene manipulation, man-machine interfaces, and artificial intelligence. Gene manipulation can be used to enhance memory as well as degrade it, to minimize fear or to create more fear. The man-machine interface could enhance training and might also be used as a tool to hack into the mind. Artificial intelligence could provide a means for cognitive (neuromorphic) command and control and could also create intelligent agents.

Modeling, Simulation, Gaming

The presentation started with the premise that the average teenager spends more time playing computer wargames than baseball. Thus, high-performance computing is changing the world, and games and simulations are ubiquitous. Also, the United States no longer has dominance in any of these fields (high-performance computing, computer games, and simulations). Many of the advances that drive these developments not only are available commercially but also are found in open-source libraries that provide access to nonstate entities; at the same time, they are also responsible for massive speedups in algorithm performance and provide virtual reality training simulators with which an enemy can develop skills for asymmetric conflicts.

ENERGY

Lightweight Electronic Systems

The evolution of lightweight power technology was the main theme in this presentation, which discussed the status of portable electronic power technologies such as batteries, solar cells, and fuel cells. Increased energy power density will lead to increased functionality for portable military applications. A soldier's portable battery weight will be reduced severalfold in the next few years. The presenter also made the point that mission durations for battery-powered robotic systems would increase over the next 10 years. Solar cell technology is also being advanced to satisfy commercial demand. This type of supplemental power backup will also facilitate the logistics support necessary for carrying out this class of missions. Fuel cells, too, are portable and can simplify logistics, and their technologies are also commercially driven.

High-Energy-Density Materials

The presentation started by reminding the audience that high-energy-density materials are fundamental components of many major weapons systems. Research and development for high-energy-density materials and their applications to major weapons systems is being pursued both internationally and within the United States. The presenter mentioned research areas and agendas, as well as areas where there was concern.

Hypersonic Systems

General considerations surrounding hypersonic systems development efforts were the main theme of this presentation. Hypersonic flight is generally defined as flight above Mach 5.³ Cruise altitudes typically range from 80,000 to 110,000 feet for air-breathing hypersonic systems. Practical hydrocarbon-fueled military systems will probably remain below Mach 8, which is where the thermal limit of the fuel heat sink is reached.⁴ One of the highlighted trends was that while transient hypersonic systems have been flying for years, sustained air-breathing hypersonic systems are just emerging. This presentation also included the tactical advantages of hypersonic systems and made the point that air-breathing hypersonic cruise missiles will significantly challenge air defense systems.

³NRC. 1998. *Review and Evaluation of the Air Force Hypersonic Technology Program*. Washington, D.C.: National Academy Press. Available at http://books.nap.edu/catalog.php?record_id=6195. Accessed August 30, 2010.

⁴NRC. 2006. *A Review of United States Air Force and Department of Defense Aerospace Propulsion Needs*. Washington, D.C.: The National Academies Press. Available at http://www.nap.edu/catalog.php?record_id=11780. Accessed August 30, 2010.

Affordable Space Launch

There are many active space programs in the world, including both government-sponsored and commercial ventures. “Affordable space launch” is associated with technologies that provide access to space along with a fairly low barrier to entry in terms of both resources and control strategies. The feat of putting an object into space under control is a nontrivial accomplishment that might pose a threat or adversely impact U.S. interests.

Admiral James R. Hogg's Comments

Box 2-1 gives a full transcript of Admiral Hogg's address.