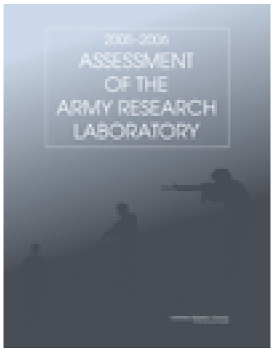

2005-2006 Assessment of the Army Research Laboratory

National Research Council

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2005–2006

ASSESSMENT OF THE ARMY RESEARCH LABORATORY

Army Research Laboratory Technical Assessment Board

Division on Engineering and Physical Sciences

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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 W. Dally, University of Maryland, College Park (Emeritus),
David R. Ferguson, Boeing Technical Fellow (retired),
James L. Flanagan, Rutgers, The State University of New Jersey (Emeritus),
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William S. Marras, Ohio State University, and
Charles V. Shank, E.O. Lawrence Berkeley National Laboratory.

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 Alton Slay of Slay Enterprises, Inc. Appointed by the National Research Council, 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.

Contents

Summary

The charge of the Army Research Laboratory Technical Assessment Board is to provide biennial assessments of the scientific and technical quality of the Army Research Laboratory (ARL). These assessments include the development of findings and recommendations related to the quality of ARL's research, development, and analysis programs. The Board is charged to review the work only of ARL's six directorates—and this excludes review of two key elements of the ARL organization that manage and support basic research: the Army Research Office and the Collaborative Technology Alliances. The advice provided focuses on technical rather than programmatic considerations. The Board is assisted by six standing National Research Council (NRC) panels, each of which focuses on a portion of the ARL program conducted by one of ARL's six directorates. When requested to do so by ARL, the Board also examines work that cuts across the directorates. The Board has been performing assessments of ARL since 1996; the current report summarizes the Board's findings for the 2005-2006 period, during which 83 volunteer experts in fields of science and engineering visited ARL annually, receiving formal presentations of technical work, examining facilities, engaging in technical discussions with ARL staff, and reviewing ARL technical materials.

The Board continues to be impressed by the overall quality of ARL's technical staff and their work, as well as the consistent relevance of their work to Army needs. The Board applauds ARL for its clear, passionate concern for the end user of its technology—the soldier in the field. While two directorates (the Human Research and Engineering Directorate and the Survivability and Lethality Analysis Directorate) have large program support missions, there is considerable customer-supported work across the directorates, which universally demonstrate mindfulness of the importance of transitioning technology to support immediate and near-term Army needs. ARL staff also continue to expand their involvement with the wider scientific and engineering community, including monitoring relevant developments elsewhere, engaging in significant collaborative work (including the Collaborative Technology Alliances), and sharing work through peer reviews (although the sensitive nature of ARL work increasingly presents challenges to such sharing).

ARL is generally working very well within an appropriate research and development (R&D) niche and has been demonstrating significant accomplishments. Examples among many include development of technology for electromagnetic armor, machine translation of foreign languages, autonomous sensing, portable fuel cells, hyperspectral imaging anomaly detection, flexible displays, and portable biotoxin analysis; research in atmospheric acoustics and radio-frequency (RF) propagation in battlefield environments, auditory awareness and speech communication in battlefield environments, and active stall control and active wake modeling for rotorcraft; development and application of sophisticated models of soldier performance and of software to support assessment of survivability and lethality of systems; and studies to assess and improve the designs of helmets and body armor for soldiers.

ARL is increasingly addressing challenges that require cross-directorate collaboration by performing crosscutting work. The Board encourages ARL to continue to address several specific areas that require collaboration across ARL directorates. It is clear that ARL views high-performance computing as a critical technology driven by requirements from a variety of applications across multiple directorates, including armor and armaments, atmospheric modeling, aerodynamics, and computational biology. There is an opportunity to improve the understanding of what is common across these many applications so that an ARL-wide support strategy can be enhanced. In particular, the extensive use of the high-performance computing resources for modeling and simulation provides an opportunity in these areas to develop an ARL methodology that will ensure that the best possible scientific practices are being employed and that redundant infrastructural effort is minimized. Additionally, carefully exploring opportunities to exploit the modeling resources would help to significantly reduce the costs of system hardware and software development and testing for applications such as hardware prototyping, system predictive performance modeling, and verification and validation of multiscale analysis and forecast models.

ARL is also conducting important programs in autonomous robotics and in human-robot interactions, demonstrating significant challenges with respect to control of multiple robotic elements. A worthwhile endeavor would be to consider an enterprisewide development effort dealing with the autonomous coordination of multiple robotic systems and addressing the supervisory control of groups of unmanned aerial vehicles (UAVs) by smaller groups of human operators.

A unified effort in the area of information security, especially in the establishment of test and "bake-off" facilities and organizations, would help to clarify the problems faced by the Army and to identify when the best of commercially viable technologies are likely to provide some at least interim solutions.

Ad hoc wireless networks are beginning to permeate many of ARL's projects, from sensor networks distributed over the battlefield, to dynamic intelligence networks aboard UAVs, to intra- and intersoldier networks. Efforts that bring together these disparate groups would facilitate shared approaches, code, and subsystems to spur progress across the board. One of the most important technologies for addressing the dramatic increase in data made available by these networks is information fusion. To attack this multidisciplinary problem, there could be great advantages in combining relevant ARL resources in new ways and then focusing this effort on a manageable set of important problems. This could spur development of robust solutions that will help define the overall information fusion landscape and thereby more general architectures.

ARL has been responding admirably to severe pressures to transition new technologies quickly to the field and to simultaneously address the challenging requirements of the Future Combat Systems (FCS), while also maintaining its role with respect to longer-term basic research. The Board recognizes the importance of each of these types of endeavor for ARL but notes here the importance of basic research as a foundation for future R&D accomplishments since basic research activities may be at greater risk currently. ARL has been successfully addressing these significant challenges by careful management of technical resources; this effort has been strengthened and stabilized over the past 2 years by appointment of permanent management in several key positions. Through its extensive interactions with the external academic, industrial, and government research and development community, ARL develops opportunities to hire talented scientists, engineers, technicians, and managers. Contacts are developed through the Collaborative Technology Alliances, the Army Research Office, regular stakeholder meetings, collaborative work at the directorates, planned interaction with academic organizations, and regular recruiting activities. ARL's ability to secure needed talent would be enhanced by any administrative adjustments that improve speed and flexibility with respect to new appointments.

1

Introduction

THE BIENNIAL ASSESSMENT PROCESS

This introductory chapter describes the biennial assessment process, identifies important research areas that involve crosscutting collaboration across the Army Research Laboratory (ARL) directorates, summarizes the results of the Board's review of ARL's crosscutting work in quantum computing and communications, and notes the linkage between the Army Research Office (ARO) and the ARL directorates.

The charge of the Army Research Laboratory Technical Assessment Board (ARLTAB) is to provide biennial assessments of the scientific and technical quality of ARL. These assessments include the development of findings and recommendations related to the quality of ARL's research, development, and analysis programs. The Board is charged to review the work only of ARL's six directorates—and this excludes the review of two key elements of the ARL organization that manage and support basic research: the Army Research Office and the Collaborative Technology Alliances. While the primary role of the Board is to provide peer assessment, it may also offer advice on related matters when requested to do so by the ARL Director; the advice provided focuses on technical rather than programmatic considerations. The Board is assisted by standing National Research Council (NRC) panels that focus on particular portions of the ARL program. The Board's assessments are commissioned by ARL rather than by one of ARL's parent organizations.

The Army Research Laboratory Technical Assessment Board currently consists of 11 leading scientists and engineers whose experience collectively spans the major topics within the scope of ARL. Six panels, one for each of ARL's in-house directorates,[1] report to the Board. Each Board member sits on a

[1]The six ARL directorates are the Computational and Information Sciences Directorate (CISD), Human Research and Engineering Directorate (HRED), Sensors and Electron Devices Directorate (SEDD), Survivability and Lethality Analysis Directorate (SLAD), Vehicle Technology Directorate (VTD), and Weapons and Materials Research Directorate (WMRD) (see

panel, six of them as panel chairs. The panels range in size from 9 to 17 members, whose expertise is tailored to the technical fields covered by the directorate(s) that they review. In total, 83 experts participated, without compensation, in the process that led to this report.

The Board and panels are appointed by the National Research Council with an eye to assembling balanced slates of experts without conflicts of interest and with balanced perspectives. The 83 experts include current and former executives and research staff from industrial research and development (R&D) laboratories, leading academic researchers, and staff from Department of Energy (DOE) national laboratories and federally funded R&D centers. Nineteen of them are members of the National Academy of Engineering, three are members of the National Academy of Sciences, a number have been leaders in relevant professional societies, and several are current or past members of organizations such as the Army Science Board, the Air Force Scientific Advisory Board, the Air Force Weapons Laboratory, Defense Science Board panels, and the Defense Advanced Research Projects Agency (DARPA).

The Board and its panels are supported by National Research Council staff, who interact with ARL on a continuing basis to ensure that the Board and panels receive the information they need to carry out their assessments. Board and panel members serve for finite terms, generally 4 years, staggered so that there is regular turnover and a refreshing of viewpoints.

Biographical information on the Board members appears in Appendix B, along with a chart listing the Board membership and the name of each panel, its membership, and the name of the ARL directorate that it reviews.

Preparation and Organization of This Report

The current report is the fifth biennial report of the Board. Its first biennial report was issued in 2000, and annual reviews by the Board were issued in 1996, 1997, and 1998. As with the earlier reviews, this report contains the Board's judgments about the quality of ARL's work (Chapters 2 through 7 focus on the individual directorates). The rest of this chapter explains the rich set of interactions that support those judgments.

The amount of information that is funneled to the Board, including the consensus evaluations of the recognized experts who make up the Board's panels, provides a solid foundation for a thorough peer review. This review is based on a large amount of information received from ARL and on panel interactions with ARL staff. Most of the information exchange occurs during the annual meetings convened by each panel at the appropriate ARL sites. In both scheduled meetings and less formal interactions, ARL evinces a very healthy level of exchange and acceptance of external comments. The assessment panels engaged in many constructive interactions during their annual site visits in 2005 and 2006. In addition, useful collegial exchanges took place between panel members and individual ARL investigators outside meetings as ARL staff members sought additional clarification about panel comments or questions and drew on panel members' contacts and sources of information.

Panel meetings lasted for 2 or 2½ days, during which time the panel members received a combination of overview briefings by ARL management and technical briefings by ARL staff. Prior to the meetings, some panels received extensive materials for review, including staff publications.

The overview briefings brought the panels up to date on the Army's long-range planning. This context-building step is needed because the panels are purposely composed mostly of people who—while

Appendix A, which contains an ARL organizational chart as well as a tabulation of ARL funding by technical unit). The Board does not have a panel specifically devoted to the Army Research Office (ARO), which is another unit of ARL, but all Board panels examine how well ARO and ARL's in-house research and development are coordinated.

experts in the technical fields covered by the directorates(s) they review—are not engaged in work focused on Army matters. Technical briefings for the panels focused on the research and development goals, strategies, methodologies, and results of selected projects at the laboratory. Briefings were targeted toward coverage of a representative sample of each directorate's work over the 2-year assessment cycle. A growing trend is to include poster sessions that allow direct panelist interaction with other projects that either were not covered in the briefings or were covered in prior years.

Ample time during both overview and technical briefings was devoted to discussion, both to clarify each panel's understanding and to convey the observations and understandings of individual panel members to ARL's scientists and engineers (S&Es). The panels also devoted sufficient time to closed-session deliberations, during which they developed consensus findings and identified important issues or gaps in a panel's understanding. Those issues or gaps were discussed during follow-up sessions with ARL staff so that the panel was confident of the accuracy and completeness of its assessments. Panel members continued to refine their findings, conclusions, and recommendations during written exchanges and teleconferences after the meetings. When necessary, the panels received presentations that were classified at the Department of Defense (DoD) "Secret" level. This report, however, does not contain classified information.

In addition to the insights gained from the panel meetings, Board members received exposure to ARL and its staff at Board meetings each winter. Also, some Board members attended the annual ARL Program Formulation Workshop, at which the ARL directorates discussed their programs with the directorates' customers. In addition, several Board members attended the 2005 and 2006 symposia that highlighted progress among ARL's Collaborative Technology Alliances (CTAs).

Assessment Criteria

The Board and panels applied assessment criteria organized by six categories (Appendix C presents the complete set of assessment criteria):

1. *Effectiveness of interaction with the scientific and technical community*—criteria that indicate cognizance of and contribution to the scientific and technical community whose activities are relevant to the work performed at ARL.
2. *Impact on customers*—criteria that indicate cognizance of and contribution in response to the needs of the Army customers who fund and benefit from ARL R&D.
3. *Formulation of projects' goals and plans*—criteria that indicate the extent to which projects address ARL strategic goals and are planned effectively to achieve stated objectives.
4. *R&D methodology*—criteria that indicate the appropriateness of the hypotheses that drive the research, of the tools and methods applied to the collection and analysis of data, and of the judgments about future directions of the research.
5. *Capabilities and resources*—criteria that indicate whether current and projected equipment, facilities, and human resources are appropriate to achieve success of the projects.
6. *Responsiveness to the Board's recommendations*—The Board does not consider itself to be an oversight committee. The Board has consistently found ARL to be extremely responsive to its advice, and so the criterion of responsiveness encourages discussion of the variables and contextual factors that affect ARL's implementation of responses to recommendations, rather than an accounting of responses to the Board's recommendations.

During the assessment, the Board emphasized the following considerations:

1. How does the work of the ARL compare with similar work being performed elsewhere?
2. Is the work sufficiently unique and appropriate to the ARL niche?
3. Are there especially promising projects that, with application of adequate resources, could produce outstanding results that could be transitioned ultimately to the field?

Completion of the Report

In July 2006, the Board met for 2 days to share members' summaries of their panels' observations and concerns. This report represents the Board's consensus findings and recommendations. The Board's aim with this report is to provide guidance to the ARL Director that will help ARL sustain its process of continuous improvement. To that end, the Board examined its extensive and detailed notes from the many Board, panel, and individual interactions with ARL over the 2005-2006 period. From those notes it distilled a short list of the main trends, opportunities, and challenges that merit attention at the level of the ARL Director. The Board used that list as the basis for this report. Specific ARL projects are used to illustrate these points in the following chapters when it is helpful to do so, but the Board did not aim to present the Director with a detailed account of 2 years' worth of interactions with bench scientists. The draft of this report was subsequently honed and reviewed according to NRC procedures before being released.

CROSSCUTTING ISSUES

The needs and opportunities for developing new approaches to selected areas of crosscutting research (i.e., research involving collaboration across two or more ARL directorates) were identified in the Board's 2003-2004 assessment report.[2] At that time, modeling and simulation, information assurance and security, and interdirectorate activities were singled out as notable topics worthy of special attention. Although it is clear to the Board that significant progress has been made by ARL in encouraging and facilitating research in each of these areas, the need for additional crosscutting work has also accelerated during the past 2 years. The Board strongly encourages ARL to continue to support new interdisciplinary initiatives. The following areas of particular opportunity are discussed below: high-performance computing, autonomous system common technologies, information fusion, information security, ad hoc wireless networks, and system prototyping and model verification and validation.

High-Performance Computing

It is clear that ARL views high-performance computing as a critical technology driven by requirements from a variety of applications across multiple directorates, including armor and armaments, atmospheric modeling, aerodynamics, and computational biology. The response to these requirements varies across scientific disciplines and across the directorates, including the use of third-party codes, the development of in-house code capabilities, and small R&D efforts of generally short duration. In addition, the strategic plans of the Computational and Information Sciences Directorate (CISD) include petascale computing as an important strategic direction.

[2]National Research Council. 2005. *2003-2004 Assessment of the Army Research Laboratory.* Washington, D.C.: The National Academies Press, pp. 6-7, 12-13, 19, 25, 30, 37-38, 50, 54.

The Board is concerned that the worthy ambitions of ARL may outstrip the resources, especially human, available to the laboratory. Even the application of existing simulation tools requires significant investments to understand the applicability and limitations of the algorithms and software, as well as for the extension of such tools to meet specialized ARL needs. Algorithm and code development originating within ARL must be carefully planned, particularly in an era of limited resources: the development of new simulation capabilities involves substantial expenditures over long periods of time. Finally, petascale computing is an enterprise with large uncertainties and risks: the hardware is an order of magnitude more expensive than current hardware and will require a much larger space and power infrastructure, and the vendors will be supplying much less of the software stack needed to use the machines productively. Moreover, it is important to address the question of readiness of any relevant software for a petascale architecture before such acquisitions are made.

Given these risks, and the importance of simulation to the ARL mission, the Board recommends that ARL sponsor a crosscutting study on modeling, simulation, and high-performance computing. Issues that could be examined in such a study include:

1. ARL applications drivers, both current and emerging;
2. Current ARL capabilities in simulation and modeling;
3. Opportunities for new algorithmic and software technologies to have an impact on ARL work;
4. Implications for high-performance computing requirements at ARL, including hardware, software stack, middleware libraries, and applications codes;
5. A method for verification and validation; and
6. Strategic planning issues, including building core competences, developing team structures, and opportunities for leveraging across applications, domains, and directorates.

Autonomous System Common Technologies

Current military operations are employing robotic systems in unprecedented numbers and roles. Many types of unmanned aerial vehicles (UAVs) are used for intelligence, surveillance, and reconnaissance (ISR); targeting and tactical intelligence; and even tactical engagement in certain circumstances. Unmanned ground vehicles (UGVs) are being employed to deal with the improvised explosive device (IED) threat. Unfortunately, most of the systems in use require the attention of at least one operator for each vehicle. The potential combat leverage available via unmanned and robotic systems will never be realized until the ratio of operators to unmanned systems is reduced. Although the use of robotic “swarms” in military operations has been advocated widely, they are unrealistic under current operating protocols. The Army’s Future Combat Systems include, conceptually at least, multiple types of robotic components; their leverage could be increased significantly via one-to-many control. Achieving the one-to-many control paradigm through technological superiority is one key approach to countering the higher leverage obtained by potential enemies employing an asymmetric approach to engaging U.S. forces.

During the last biennial assessment cycle, the Board reviewed, at the request of the ARL Director, robotics work being performed by multiple ARL directorates and their partners in the Robotics Collaborative Technology Alliance. The Board found that the ARL robotics work was of high quality. The issues of unmanned vehicle supervisory control and multiplatform coordination were discussed briefly, but most of the review (and indeed most of the work) focused on robotic perception, mission packages, and supervisory control of single platforms.

Although these areas are extremely important for future Army utilization of autonomous systems, the time is ripe to consider an ARL enterprise development effort dealing with the autonomous coordination of multiple robotic systems (i.e., exchange of information and autonomous actions taken by the robotic systems without human intervention to further the mission of the federation), and addressing the supervisory control of groups of UAVs by smaller groups of human operators. Building on a strong foundation of research on individual robots, ARL can also bring to bear significant talent from the Human Research and Engineering Directorate (HRED) to address human-system integration, and from the Sensors and Electron Devices Directorate (SEDD) and CISD to address platform-to-platform communications and mutual awareness, and can potentially leverage ad hoc networking based on Blue Radio to address a flexible platform-to-platform and platform-to-base communications architecture.

A key advantage of this approach is that it will position ARL to serve Army needs in a large variety of contexts and concepts of operations, regardless of the specific properties of the individual unmanned systems that are ultimately developed or acquired by the Army. Commercial developers are outpacing Army in-house efforts in individual robotic systems, whereas multiplatform coordination and supervisory control of large numbers of robotic systems represent new frontiers that for now are relevant mostly to military rather than commercial users. Strategic application of resources to these problems can position ARL to enable the Army to excel in the operational use of unmanned and robotic systems.

Information Fusion

One of the most important new technology processes to emerge over the past few years is "information fusion," or "knowledge discovery," whereby disparate pieces of data are combined to yield higher-level knowledge, or information, that becomes "actionable intelligence" when presented in a sufficiently concise form and at the right time. In the commercial arena such technologies have been the drivers behind Web searching and data mining, for example. It also has been recognized in a variety of recent forums to be of increasing military importance, from a 2005 report of the National Research Council (*Getting Up to Speed: The Future of Supercomputing*[3]) to the 2006 Joint U.S. Defense Science Board and U.K. Defense Scientific Advisory Council Task Force on Defense-Critical Technologies.

Within the Army in recent years there have been a variety of efforts to kick-start information fusion efforts in support of the soldier, such as Horizontal Fusion and Warrior's Edge. In many cases, such efforts have focused too soon on general overall architectures before development of a deep understanding of the problems for which such "information" can make a difference, what sensors are available to provide the raw data out of which knowledge can be fused, and how and where this fusion process can most efficiently take place. To make real progress in the near term, the Board encourages ARL to explore multidivision and multidirectorate efforts to select some manageable set of problems and to develop reasonably robust solutions for those problems that will help define the overall information fusion landscape and thus more general architectures.

Information Security

The National Information Systems Security Glossary defines *information systems security* as "the protection of information systems against unauthorized access to or modification of information, whether in storage, processing or transit, and against the denial of service to authorized users or the provision of service to unauthorized users, including those measures necessary to detect, document, and counter such threats." This is clearly of real concern today in the wired computer network arena, both military

[3]National Research Council. 2005. *Getting Up to Speed: The Future of Supercomputing*. Washington, D.C.: The National Academies Press.

and private, and of growing concern to the military as it moves to ad hoc networks formed from groups of warfighters. Therefore, the Board encourages ARL to consider developing crosscutting efforts in this area, especially in the establishment of test and "bake-off" facilities and organizations that help identify what the real problems faced by the Army are (both common and unique), and recognize when the best of commercially viable technologies provide some at least interim solutions. A similar approach has been taken in the machine translation arena, with extraordinary results for the warfighter.

Ad Hoc Wireless Networks

Ad hoc networks are electronic networks in which the individual nodes attempting to communicate come in and out of contact with one another, can move dynamically (and thus affect which other nodes they may be in contact with), and may encounter environmental constraints (e.g., power, bandwidth, real time, security) not present in traditional networks. Such networks, particularly wireless ones, are beginning to permeate many of ARL's projects, from sensor networks distributed over the battlefield, to dynamic intelligence networks aboard UAVs, to intra- and intersoldier networks. The Board encourages ARL to consider efforts to bring together these disparate groups so that fertilization of approaches, code, and subsystems can engender progress across the board.

System Prototyping and Model Verification and Validation

Virtually all hardware systems for environmental measurements, communications, signal processing and analysis, and data display and application have become completely dependent on system-integrated computers during the past 20 or so years, essentially in conjunction with the development of advanced microprocessor technology. One of many fringe benefits of this approach is that it is now possible to predict computationally the performance of most parts of most advanced technology systems (e.g., remote sensors in which advanced inverse mathematical methods are required to extract the critical measurement data or adaptive communications systems that alter their mode of operation as environmental conditions change).

Coincident progress in the development and understanding of small-scale structures and phenomena in Earth, the atmosphere, and the oceans, including even many turbulent processes, is such that the output of a variety of computational fluid dynamics and atmospheric and oceanic models is quite adequate for defining the space-time behavior of signal propagation media, both for electromagnetic and acoustic signals. A continuing challenge for ARL is to ensure that appropriate verification and validation activities are applied to projects whose results rely heavily on models. The Board encourages ARL to carefully explore opportunities to exploit its high-performance computer and model resources for applications such as hardware prototyping, system predictive performance modeling, and verification and validation of multiscale analysis and forecast models. Progress in this area should reduce significantly the costs of system hardware and software development and testing. The Board also encourages ARL to consider ways of capturing the results of many of the field tests it performs every year relative to such phenomena so that the results can be searched at future times for answers to questions not yet asked today. When coupled with next-generation computing systems and with advances in information fusion and data mining as discussed earlier, such test sets may allow the creation of "virtual laboratories" in the future, and the quick response to unforeseen Army needs that may prove vital.

QUANTUM COMPUTING AND COMMUNICATIONS

As previously noted, each panel normally reviews the work of a single ARL directorate. In 2005, at the request of the ARL Director, the Board undertook an additional review, forming a team that assessed the quantum computing and communications activities within ARL. The entirety of ARL's activities in these areas falls within two programs: one in CISD and one in SEDD. Both programs had theoretical and experimental components.

The SEDD program in the security of optical quantum key distribution (QKD) systems is world-class. On the theoretical side, its principal investigator has an established track record in this area, publishes in respected peer-reviewed journals, and is widely esteemed in the quantum information community. This experimental program is rather new, but the support of DARPA, the Advanced Research and Development Activity (ARDA), and other agencies external to ARL is a clear indication of the importance of this work. In addition, given ARL's extremely large extramural program in quantum information through ARO, it is very important that ARL have in-house researchers in the field who can act as advisers to this program.

QKD technology holds the potential for yielding important operational applications in the intelligence arena, once fundamental research problems are successfully addressed. ARL's principal investigator in this area is in a position to be a leader in the field in this important research. The continued successes of this ARL program would help maintain Army input into QKD developments, and this would make it much more likely that the Army would benefit from the additional security provided if this promising technology reaches its potential.

The CISD program consisted of a set of theoretical examinations of computational algorithms and a laboratory that is well equipped for experimental work. The theoretical work, which lacked focus and integration, consisted of a set of dated work of unclear relevance addressing algorithm development, numerical solutions to nonlinear equations, and "quantum-inspired" algorithms. There were few peer-reviewed publications representing the program, there were no examples provided to indicate that the work has been implemented in application software, and it was not clear that the patent submissions applied for were timely or well received by the U.S. Patent and Trademark Office. The lack of outside investment and the dearth of peer-reviewed publications suggest that the work in this area may not be aligned with mainstream activity in quantum cryptography. However, the experimental facilities have considerable value, which could be exploited if there were tighter links to other researchers in the quantum computing and communications community. The Board encourages ARL to examine possible joint research with, for example, Multidisciplinary University Research Initiatives (MURIs) sponsored by ARO in such areas as quantum imaging, single proton sources, and detectors.

LINKAGE BETWEEN THE ARMY RESEARCH LABORATORY AND ARMY RESEARCH OFFICE

The Board is not charged to review the work funded by the Army Research Office, which is an organizational entity within ARL. ARO is a significant basic research asset with a significant fraction of the total ARL 6.1 budget. Considering the important role that basic research has played in the development of Army-relevant technologies and the similar high-payoff role that it could play in the future, the Board is interested in learning the ways in which the work portfolio of ARO is integrated into the activities normally reviewed by the Board. To understand more fully the ARL basic research enterprise and context, the Board suggests that in all future reviews by the Board, ARO be asked to summarize and present results of those 6.1 programs that it sponsors which are relevant to the ARL work being presented at the review.

2

Computational and Information Sciences Directorate

INTRODUCTION

The Computational and Information Sciences Directorate (CISD) was reviewed by the Panel on Digitization and Communications Science during May 3-5, 2005, and May 23-25, 2006. CISD consists of three research divisions: Computer and Communication Sciences, Battlefield Environment, and High-Performance Computing. It also includes the Corporate Information Office and the Enterprise Management Center, which serve the entire Army Research Laboratory (ARL) through a combination of computing hardware, software, and staff.

CISD performs research for the following purposes: to help design a robust, highly mobile battlefield communications network while ensuring that the information provided to commanders is current, authentic, accurate, and protected; to develop high-fidelity "micro" weather forecasts in near-real time (i.e., to predict weather in 10 minutes or less for the next 0 to 2 hours) in order to support combat intelligence operations and troop engagement decisions; to enhance the decision-making prowess of commanders in the battlefield; and to develop robust physics-based, high-performance computing models and software for concept evaluation, design, and analysis (usually in support of computational science efforts in other ARL directorates).

Tables A.1 and A.2 in Appendix A show the funding profile and the staffing profile for CISD.

CHANGES SINCE THE LAST REVIEW

Since the last documented review (for the 2003-2004 period), there have been a variety of changes that have affected CISD's research activities. First is a solidification of management within the directorate, with two of the three divisions receiving permanent, high-quality managers. Second, a new International Technology Alliance (ITA) has been initiated, focused on networking and information sciences. Finally, the major Horizontal Fusion and Warrior's Edge programs have come and gone, and the Command and Control in Complex and Urban Terrains (C2CUT) Army Technology Objective (ATO) was incorporated into the Networked Enabled Command and Control ATO led by the Communications-Electronics Research, Development, and Engineering Center as directed by the Assistant Secretary of the Army for Acquisition, Logistics, and Technology. All three have had a distinct impact on CISD's research portfolio.

ACCOMPLISHMENTS AND OPPORTUNITIES

Most Significant Advances

The Digitization and Communications Science Panel that reviews CISD yearly has continued to see improvements in the quality of the research being performed by CISD researchers and in the demonstration of the relevance of their work to Army needs. A concern from 2003-2004 about the number of acting management has been solved, with the appointment of a permanent director and permanent division chiefs.

CISD continues to demonstrate technology leadership in several areas. The machine translation of foreign languages, in particular, is such an area. Embedded machine translation systems (computer systems with one or more machine translation engines embedded in them) are developed at ARL to provide the Army with multilingual technologies for text and speech translation, document exploitation, and electronic message exchange. Technologies are adopted and adapted from the outside whenever possible and developed internally when necessary.

Over time, machine translation systems have grown from a laptop with a page-feed scanner, a battery pack, and embedded Forward Area Language Converter (FALCon) software to a range of systems, including a soldier-based system composed of a personal digital assistant (PDA) with a camera and tailored software, to more capable vehicle-based and collateral-space-based systems, each with its own tailored suite of hardware and software. Accomplishments in this area include the following: development of a PDA-based document triage system enabling soldiers in the field to determine the relevance of seized documents; development of a Web-enabled version of Document Exploitation Suite software; development of a Web-accessible testbed, which has been used to create task-based translation accuracy metrics and to determine "best of breed" Arabic components for upgraded software; and CISD's technical lead of a team that went to Iraq for the initial assessment of a Defense Advanced Research Projects Agency (DARPA) two-way Iraqi-English speech translation prototype.

This language technology group has focused on developing evaluation criteria and test conditions under which commercial technology offerings can be and are being evaluated in an environment that allows identification of the best candidates for Army deployment. Machine translation evaluation is critical to identifying which machine translation engines are good enough for which foreign languages to go on which systems and platforms to support which users performing which tasks. Rather than focusing solely on technology development in an area with a much larger commercial base, the CISD approach ensures that CISD not only knows where the current problems are in the state of the art, but also when progress has been made in solving them and what holes are not being plugged with commercial developments. Prior reviews of CISD by the Army Research Laboratory Technical Assessment Board (ARLTAB) have discussed the potential usefulness of a more focused approach to validation and verification of new technologies—the approach used with machine translation may be worth emulating in other project areas.

Selected areas of research in atmospheric acoustics and radio-frequency (RF) propagation in battlefield environments continue to demonstrate a leadership position. Much of the work in acoustical propagation in the Battlefield Environment Division (BED) is firstrate, of world-class quality. This acoustical work is of great value to the Army because transmission loss resulting from propagation through the atmosphere is a key component in predicting acoustic detectability and acoustic signatures and therefore in determining operational acoustic sensor performance. Currently, BED is conducting research to develop and evaluate acoustic propagation models that incorporate the environmental effects of the atmosphere, turbulence, terrain, forests, urban structures, and land-water interfaces on acoustic signatures, and to develop remote sensing techniques using acoustic and seismic waves to provide information on conditions in the battlefield environment, including urban structures.

The combination of in-depth theoretical and wide-ranging experimental work in atmospheric optical propagation performed by researchers at the ARL Intelligent Optics Laboratory may well be the finest in the world in this area. The assembled laboratory facilities for this work are extremely impressive and are all being used for outstanding, Army-relevant research, both basic (e.g., propagation fundamentals) and highly applied (e.g., applications to new communications and imaging systems). Past efforts of this group in adaptive optics for applications in high-energy laser weapons and free-space optical communications have led to significant improvements in the quality of optical transmission through the atmosphere. Its ongoing work continues to push the envelope by focusing on the development of handheld high-bit-rate (gigabit-rate), active, adaptive laser communications systems capable of operating in atmospheric turbulence, and in developing conformal phase-locked fiber-based optical systems for optical communications, imaging, and laser weapon applications. This group's recognition of the speckle effects in laser illumination applications is insightful, and the proposed solutions under investigation are novel and quite possibly effective.

It is clear that ARL continues to view high-performance computing (HPC) as a critical technology driven by requirements from a variety of applications across multiple directorates; these applications are in areas including armor and armaments, atmospheric modeling, aerodynamics, and computational biology. CISD has a unique role in that it is both a user and developer of codes for HPC facilities. Some projects, such as the Simple Parallel Object-Oriented Computing Environment for the Finite Element Method (SPOOCEFEM) code, represent solid examples of software engineering. SPOOCEFEM was an infrastructure development project, its primary goal being the creation of a scalable framework for unstructured mesh, finite-element simulations. The code was written in C++, and significant effort was employed to ensure that the overheads associated with object-oriented programming were minimized while retaining strong features such as reusability and maintainability. This prize-winning code was intended to be used primarily in composite manufacturing processes, and its performance was good. It had all of the attributes needed for a successful supercomputer-level code, object-oriented modular construction, concerns for scalability, validation, and verification among them. Although this effort has ended, aspects of it may be used in future projects and it demonstrates that CISD can perform effective software engineering work.

Developing leading-edge research expertise can involve both external hires and internal support for the advanced graduate education of CISD personnel. Over the past 2 years the panel has seen multiple examples of high-quality Ph.D. graduate work, for the most part with a solid relationship to Army needs, being done by current CISD employees.

Finally, a new International Technology Alliance has been established to focus on network theory, security across systems of systems, sensor information processing and delivery, and distributed coalition planning and decision making. These are all topics of emerging importance to future Army systems, and they mesh well with many of the other CISD undertakings, such as information fusion.

Opportunities and Challenges

A newly emerging area of far-reaching importance to the Army is information fusion, the extraction of actionable intelligence from disparate data sources. In recent years, the Office of the Secretary of Defense's Horizontal Fusion and Army's Warrior's Edge programs have focused, with little real progress, on developing large-scale architectures for such applications. Recent refocusing of the research direction by CISD on "small fusion" problems, such as letting a soldier know what is around the corner of a building in real time, is far more realistic and liable to lead to deployable tools earlier. The challenge will be to know when it is time to integrate different fusion applications (both from ARL and from the broader community) into more generic capabilities, especially those including learning, and in verifying and validating against metrics that are not yet defined. The bake-off methodology employed by ARL in the machine translation area is a model worth considering here. This essentially means determining good evaluation metrics and constructing very stressful scenarios and test cells in which candidate applications can be demonstrated in a common environment, with the best ones and remaining issues identified.

Another area with tremendous implications for Army missions is ad hoc networks, especially wireless and sensors at the network nodes. Ad hoc networks are electronic networks in which the individual nodes attempting to communicate come in and out of contact with one another, can move dynamically (and thus affect which other nodes they may be in contact with), and may encounter environmental constraints (power, bandwidth, real time, security) not present in traditional networks. Examples include ground-dispersed sensor networks distributed around a battlefield for movement detection, air-dispersed networks for local weather prediction, networks of individual soldiers as they interact on the battlefield, and even on an individual soldier as he loads or unloads different gear with Bluetooth connectivity. The problems here are significant, ranging from power management for maximizing the lifetime of an overall sensing capability, to guarantees of real-time delivery, to security for ensuring that misleading data cannot be entered into a network or that adversaries cannot surreptitiously extract vital information from a network. The potential correlation with information fusion is obvious. ARL has developed an automated service discovery capability that, by maintaining network awareness (connection state, bandwidth, and topology), protects domain application from network disruptions due to mobility and terrain so that established connections between producers and consumers can be preserved.

ARL currently has multiple projects underway in this area, ranging from purely practical demonstrations of some capabilities using off-the-shelf networking equipment and protocols, to algorithms for specific network applications. Once again there is also a large external commercial, university, and government-run suite of projects underway in similar areas, and the challenge to ARL will be to move expeditiously toward deployable technologies while avoiding duplication of other work and yet still ensuring that the Army's unique requirements are being solved.

Of related and increasing importance are network security issues, especially ones that rely on wireless networks. While CISD maintains a significant Network Intrusion project, much of it is focused on active day-to-day defense of current wired networks, using for the most part tools derived from industry and academia. Current resources do not permit much real targeted research into Army and battlefield issues, especially for wireless networks. However, ARL has the capability and facilities to construct very stressful scenarios and test cells in which security issues can be demonstrated in a common environment, the best ones identified, and remaining issues brought to the surface. Thus, some variation of the bake-off model demonstrated by the machine translation group may again be appropriate as additional resources are identified.

High-performance computing is becoming an essential part of a broad swath of ARL projects. Despite the relatively large budget allocated to HPC, however, the bulk is spent on hardware and hardware-related infrastructure, with only a few million dollars spent on applications and tools. Even here, such in-house tools as SPOOCEFEM are developed and then apparently left mostly unused. A principal concern regarding this area is the possibility that the worthy ambitions of ARL may outstrip the resources available. Even the application of existing simulation tools requires significant investments to understand the applicability and limitations of the algorithms and software, as well as for the extension of such tools to meet specialized ARL needs. Algorithm and code development originating within ARL must be carefully planned, particularly in an era of limited resources: the development of new simulation capabilities involves substantial expenditures over long periods of time.

Petascale computing is an enterprise with large uncertainties and risks: the hardware is an order of magnitude more expensive than current systems and will require a much larger space and power infrastructure; and the vendors will be supplying much less of the software stack needed to use the machines productively. Efforts by ARL to develop in-house system architectural evaluation tools may thus be of limited use; a more productive approach for the long term may be to focus on what ARL mission-critical applications need to scale to the peta range, understand the real requirements of such applications, and work toward those unique algorithms or software that will be needed to implement the applications when such systems become available.

A challenge for the atmospheric signal propagation work, for which ARL has world-class facilities, is to ensure that appropriate experimental design techniques are used in this process. In cases where there is high potential for revisiting prior experiments, it is important to look for anomalies found in the field, and formal methods for saving, querying, and retrieving such experimental data should be put in place. The potential of a quick-response "virtual laboratory" for answering unforeseen questions quickly is significant and may be worth significant consideration, especially as petascale computing systems are considered.

Polarimetric imaging is an area in which BED has the resources necessary to perform cutting-edge experimental work. The addition of one or two scientists whose primary interests are in the fundamentals of atmospheric turbulence would help to provide the theoretical horsepower necessary to move the science forward. This would facilitate further progress in understanding the fundamentals of atmospheric signal propagation, particularly in battlefield environments when conditions are such that observations cannot be uniquely interpreted, and it could also facilitate collaborative studies with staff who work with computational fluid dynamics and high-resolution, mesoscale atmospheric models.

RESEARCH ASSESSMENT

Methodology

The issue of validation and verification is one of continuing concern to the Board. Validation refers to the methodology used to ensure that a mathematical model of a phenomenon does in fact mirror the real world correctly, especially in those areas of interest to a particular program; verification is the process of examining whether the implementation of these models, both in terms of computer codes and initializing conditions, is done in a manner that does in fact deliver results consistent with the models. The continuing challenge to ARL is to ensure that projects whose results rely heavily on such models really do have the appropriate amount of attention given them.

In response to prior criticism and recommendations, the Board was pleased to see the emphasis being placed on the validation and verification of a number of BED analysis and forecast models (e.g., battlefield environment, meteorological, and acoustical and other signal propagation). The Board does suggest that more thought now be given to experimental design rather than to ad hoc case studies.

The issue of making systems engineering expertise part of many research problems is becoming of increasing importance to ARL, especially as more and more work is done "for customers," and as more commercial off-the-shelf technology is used in prototyping and demonstration efforts.

Contributions to Army Needs

The work at CISD is generally very well targeted to Army needs. For example, several very successful deployments to Iraq of selected technologies have resulted from the Computer and Communication Sciences Division's approach to automated language translation technology. The Battlefield Environment Division has established its Army and national science niche in defining and predicting the characteristics of meteorological phenomena that are critically important to fixing the properties of the atmosphere and Earth on time and space scales relevant to rural and urban battlefield situations. The emerging focus on "small fusion" holds the potential for a significant advance in soldier survivability and effectiveness in an urban battlefield. The continued use of HPC assets to simulate complex phenomena in advance can continue to accelerate the transition of new technologies to battlefield-deployable status.

Contributions to the Broader Community

Because the BED is uniquely sited and qualified to serve as a national micrometeorological research facility, the Board was pleased to see that Division scientists are significantly expanding their involvement and growing leadership in national and international, multiagency, and multinational experiments. Better understanding of the stable, usually nocturnal, atmospheric boundary layer is a specific area of critical importance to the Army and to the sciences generally. Therefore, focusing BED expertise on this problem and aerosol characterization with respect to soldier health is well advised and offers the potential for national leadership and recognition.

Likewise, work such as the natural language translation that involves a neutral and well-defined mechanism for comparing competitive developments from commercial firms provides all such entrants a clear picture of the state of the art in the basic technology, metrics for evaluating that state, and technologies that offer clear-cut advantages. The emerging International Technology Alliance on Networking offers the potential for a similar broad industrial involvement.

CROSSCUTTING ISSUES OF RELEVANCE TO THE DIRECTORATE

All of the crosscutting issues discussed earlier in this document are of direct relevance to CISD. Just-in-time information fusion is essential to tomorrow's connected battlefield, but general architectures are not currently available, and focused efforts are needed in smaller steps. Autonomous control of vehicles is not possible without both such information fusion and advanced algorithms designed for real-time environments. HPC is a key pillar of ARL research, and the limited CISD resources available for real research need to be targeted for maximum long-term impact. Network security, especially wireless and ad hoc networks, will impact all directorates, but CISD has the expertise to understand the underlying issues and limitations of current protocols. Validation and verification continue to be of concern across virtually all CISD projects.

3

Human Research and Engineering Directorate

INTRODUCTION

The Panel on Soldier Systems reviewed a sample of programs of the Human Research and Engineering Directorate (HRED) of the Army Research Laboratory (ARL) during April 27-29, 2005, and May 1-3, 2006. HRED is organized as two divisions to conduct research and development efforts to enhance soldier performance. The Soldier Performance Division conducts a broad program of soldier-centered basic and applied scientific research and technology development, directed toward maximizing battlefield effectiveness. The Human Factors Integration Division conducts analyses and applied studies to ensure that soldier performance requirements are adequately considered in technology development and system design. Tables A.1 and A.2 in Appendix A show the funding profile and the staffing profile for HRED.

The framework for the assessment, as presented by the acting director, was HRED's dual objectives of providing science and technology to enable transitional capabilities for the smaller, smarter, lighter, and faster future force, while also seeking opportunities to accelerate the insertion of technologies directly into the current force. Within this framework of dual objectives, the reviewed projects demonstrated a high level of scientific merit and relevance to the Army's needs. The professionalism and enthusiasm of the HRED staff in presenting information and answering questions about individual programs and projects were also at very high levels. Although critical in the past about insufficient outreach, the Board is very impressed with the growing participation of HRED in the scientific and technical community and with the open dissemination of research results.

CHANGES SINCE THE LAST REVIEW

HRED has continued to adjust its programs to meet changing requirements for the Army's transformation to a smaller, smarter, lighter, and faster future force. For example, as the Army moves toward increasing levels of automation to meet its mission requirements, HRED has initiated efforts to address the enhancement of soldier performance in automation-related functions. A series of projects has been initiated in response to an Army Technology Objective in human-robotic interaction to address critical operator performance issues in the development and deployment of semiautonomous robots, such as unmanned air and ground vehicles. Studies have now been conducted to assess factors affecting control performance and situation awareness, operator performance and workload relative to the number and types of assets controlled, and the effects of team size on robot controller performance.

Continuing improvements were observed in the quality of, and the rationale for, experimental designs employed by the HRED researchers. One notable advance was the more extensive use of soldier-centered modeling tools during the initial phase of the research to analyze the work domain, operationalize hypotheses, and/or systematically select parameter values. This is evidence that the model>test>model approach that has been advocated by the Board is finding its way into the planning and conduct of experimental studies—that is, the development and use of soldier-centered models to assess the work domain and plan studies, to clarify and extrapolate the experimental results, and then to integrate the empirical results to further enhance the models. The use of this approach can become more widespread at HRED if those who conduct experimental studies develop a better understanding of the value and operation of available models.

The latest review revisited HRED efforts in the development, application, and refinement of soldier-centered design tools and analysis. The goal of these modeling efforts has been to develop and apply computer simulation methods of the type that can enable the analysis of human-hardware interactions in a variety of anticipated scenarios. These simulations can ensure the early insertion of human systems integration considerations, constraints, and measures into the acquisition cycle. The tools and their enhancements resulting from these efforts have also been useful in supporting HRED research efforts by mapping work domains to ensure that the most relevant tasks are addressed in research efforts and by integrating research results to enhance and further their application to operational systems. The core (and workhorse) of the soldier-centered design and analysis efforts has been the task-based Improved Performance Research Integration Tool (IMPRINT). Recent usability and redesign efforts have resulted in the development of two enhanced versions of the tool: IMPRINT Standard for the typical model user, and IMPRINT Pro for the sophisticated model user. The earlier gap analysis and the current stressors analysis have guided efforts to develop more effective approaches to adding IMPRINT functionality. Moreover, input from outside contractors and the modeling community has been employed effectively in the process of upgrading the model. These efforts have also been very responsive to Board suggestions, such as the need for improving visualization during model applications and increasing the extent of formal collaboration with academic, tri-service, and other government groups and laboratories.

ACCOMPLISHMENTS AND OPPORTUNITIES

Most Significant Advances

The Board applauds recent HRED efforts to extend the utility and applicability of soldier-centered design tools by integrating them into a powerful, easy-to-use modeling platform for exploring systems concepts and designs. The effort consists of integrating two models with IMPRINT and developing the needed middleware and a unified interface, the Human Behavior Architecture (HBA), to facilitate both cognitive and manual task modeling. One model, Command, Control and Communications Techniques for Reliable Assessment of Concept Execution (C3TRACE), depicts human tasks with an information flow and net-centric focus. It is designed to evaluate the effects of organizational structure and information technology effects on human-system performance. The other model, Adaptive Control of Thought-Rational (ACT-R), represents human cognitive functioning in simulations and assessments. The IMPRINT and ACT-R interaction and control are particularly critical to this effort, as is the need to model a proactive information-gathering capability. However, caution should be exercised with the ACT-R integration so as not to assume that this model is now a complete, unified theory of cognition.

In support of the Vice Chief of Staff, Army, Holistic Helmet Study Group, HRED conducted a set of quick-turnaround studies to assess survivability issues relative to helmet design, fit, wear, and compatibility factors. This study was notable, inasmuch as HRED completed four high-quality, definitive studies within a month that provided an extensive amount of revealing and useful data to the Army. Evaluation of the two helmets now in Army use showed a significant impact of design on the capability of sound localization, an important capability for threat identification and targeting and for maintaining situation awareness in the field. In addition, the two helmets differed greatly, relative to the amount of pain experienced from extended wear. Added to these results were findings that relatively few soldiers have helmets that fit and also that few soldiers wear their helmets properly, whether they fit or not. How the helmets fitted and how they were worn were also shown to affect the ability to sight weapons and use goggles. The extensive, detailed data collected in these studies supported in-depth analyses to answer the many questions raised by the principal results. The proposed utility analysis presented for review should provide a transparent approach to needs analyses and the future evaluation of helmet design alternatives, particularly when coupled with sensitivity analysis and within a holistic, systems engineering framework.

Research on auditory awareness and speech communication continues to be an exemplary program at HRED. The program demonstrates an insightful anticipation of future Army needs and the development of applied research that is cast in terms of basic research requirements in which research questions are effectively formulated and research designs are appropriate to well-articulated needs and objectives. Moreover, the program is being conducted within the context and understanding of related work that is being conducted in other laboratories of the Department of Defense (DoD). In addition, there is an impressive list of university partnerships, industry cooperative relationships, and links to related government and international research programs. The assessment covered a selection of projects from a much broader program of research.

The research on spatial audio with a bone-conduction interface provided very encouraging results for sound localization via bone conduction—bone conduction audio, combined with head-related transfer functions, produced absolute localization errors no greater than audio from standard headphones. While the results so far are limited, the direction for future research is clear and critical—to examine sound localization performance with transducers placed on locations of the skull other than the mandibular condyle. Another promising line of research in sound localization involves determining the effect of sound duration on localization accuracy. While this preliminary study was also considerably limited in scope (the listener's head movements were restricted, the sound durations were very short, and the experimenters had not yet had an opportunity to replicate results with a paradigm that requires subjects to perform meaningful additional activities other than listening alone), it provided clear direction for further research. The Board recommends experimental designs in which head movements are measured during signal localization, and analyses that address the extent to which degree and type of head movements predict variations in responses. The Board believes that the measurement of head movements would be relatively easy and inexpensive to implement.

The Human Factors Integration Division is providing a growing amount of support to Army customers (more than 150 projects each year), influencing the design and fielding of systems to enhance soldier performance. These efforts are typically conducted under the structure of the manpower integration (MANPRINT) program that addresses the integration of manpower, training, personnel, human engineering, safety, health, and survivability. An outstanding example of this type of effort was the field evaluations recently completed by the HRED Communications and Electronics Command (CECOM) Field Element at Fort Monmouth, New Jersey, of the hand-held Global Positioning System (GPS) receiver. The poor human factors design of this system had led to, among numerous other incidents, an incident in Afghanistan in which three Special Forces soldiers were killed and 20 injured when they mistakenly called fire on their own position. The study resulted in the identification of 1 critical, 5 major, and 13 minor design problems in the operation of this device, together with associated redesign recommendations.

Opportunities and Challenges

As the lead for the Human Centric-Network Enabled Battle Command (HC-NEBC) project, HRED is undertaking a very ambitious and challenging effort. The project utilizes the Modeling Architecture for Technology, Research and Experimentation (MATREX) environment to launch the development of an integrated collection of models, simulations, and tools that can be employed for analysis, experimentation, and technology trade-off studies. HRED heads a team consisting of the contractor, DCS, the MATREX infrastructure team, the Training and Doctrine Command (TRADOC) Analysis Center, the Simulation and Training Technology Center (STTC), and the Army's Aviation and Missile Research, Development and Engineering Center (AMRDEC). The Board identifies the following as some of the major challenges: designing and implementing the middleware required for integrating the various components; addressing the complex conceptual framework as suggested by the behavioral terminology being employed (e.g., role, task, service, behavior, activity); addressing active as well as passive processing of information; implementing the needed feedback structures; and developing, implementing, and validating the behavioral models. Program success may require focusing, initially, on incremental system development—starting, for example, with a simple command structure and behavioral model and building on the workload scheduling algorithms being developed for IMPRINT.

A recently initiated modeling effort addresses the intelligence, surveillance, and reconnaissance (ISR) functions that support the military decision-making process. The objective is to adapt IMPRINT to answer critical organizational and human performance questions imposed by new force structures and technologies. The Board believes that the effort must go beyond IMPRINT to consider the incorporation of appropriate cognitive models. While ACT-R has an empirical base, the model is not suitable for decision-making tasks involving these types of inputs; consequently, adapting or developing an appropriate cognitive model is likely to be a major challenge. The Board suggests that it may be advisable to mitigate the challenge at the start by limiting the source of intelligence being modeled to the most tractable, such as sensor data. Since this research is forward looking, the current emphasis on the non-urban battlefield environment may not adequately reflect the future needs of the military.

HRED is engaged in a joint effort with the Night Vision and Electronic Sensors Directorate (NVESD) of the Communications and Electronics Command to provide 24-hour mobility vision for dismounted soldiers. The goal is to provide adequate situation awareness, target detection, and obstacle avoidance when traversing field and urban terrain on foot. The principal focus of the research is on performance with a sensor that is capable of providing both thermal and intensified images in various selected combinations on a single display. The program has made effective use of static experimental tasks to answer some of the preliminary questions concerning the effects of sensor offsets and image fusion algorithms. However, definitive results to support the fundamental research objectives must necessarily employ dynamic, real-world tasks in the future. In real-world situations, for example, the two sensor modes may not reliably produce the same setoff contours, leading to situations in which the two images are not readily reconciled or fused. Consequently, one needs to address the possibility of sensory rivalry or sensor veto, where one source is given dominance over the other.

The many customer-driven reactive research projects conducted each year (more than 150), such as the GPS study noted above, provide a long-term opportunity for HRED to become more proactive in providing customer support. Such an approach would entail the development of standardized approaches (e.g., common measures, systematic variation of parameters) to the design and conduct of studies, leading to the compilation of the data from multiple studies in a form that would permit meta analyses (such as multiple regression) across studies at a later time. Such an approach would also actively seek opportunities to incorporate additional, low-cost, potentially useful measures in these studies, even though not required to meet the original objectives of a study. The goal would be to develop resources such as additional, more specific models, rules, and guidelines that can be applied immediately in response to customer needs, reducing the need for lengthy field studies and analyses. It may also be worthwhile to increase designer access to certain human factors modeling tools as another means of supporting Army customers. A user-friendly Web-based interface that allows designers to use rudimentary human factors modeling tools during the operational concept exploration phase could result in human factors considerations being included earlier in the system design cycle. This proactive approach to customer-driven research would be facilitated by concerted activities that integrate the plans, approaches, and results of various HRED projects.

An axiomatic principle of human factors research and design is that the development of equipment and systems is most efficient when human factors principles and guidelines are considered early during the determination of system requirements and the specification of system functions and performance parameters. The Board realizes that the ARL mission does not normally include the actual design of equipments and systems. HRED research projects do produce data that readily can be transformed into a relevant set of human factors needs and design recommendations and, in turn, into recommended designs or design modifications. It is the view of the Board that the ultimate impact of human factors research may be considerably greater if HRED actually took the next step, when appropriate, and generated model design specifications and design exemplars as products of its efforts. For example, both the GPS and helmet studies referenced earlier produced sufficient design-relevant data to support such efforts; the research results plus application of the proposed utility analysis could be the basis for a model ARL helmet. This is not an approach that would be totally new to HRED. In a project reviewed earlier on Army fixed-bridge construction, HRED developed short-term solutions to problems identified during its innovative use of ergonomics analysis tools to document the biomechanical stress and physical hazards imposed when lifting bridge components using existing manual methods. HRED developed prototype hand tools and portable hoist and cart systems from the results of its studies for further testing and refinement in the field.

A battlefield testbed at Fort Dix, New Jersey, was the setting for a field study to determine the impact of a digitized command interface on situation awareness and workload at the platoon level. This study demonstrated the challenges of fielding computer support systems and conducting research to assess their impact: there were frequent problems with communications networks; equipment usability problems led to distractions and frustrations; soldiers had not developed proficiency with tasks because they had received only classroom training; and there was an inability to freeze action in the field to enable the completion of data collection instruments required by the experimental design. As a consequence, the research results were not definitive and were difficult to interpret. While the Board appreciates the challenges of conducting field studies that rely on coordination with and support of others, it believes that in planning complex field studies such as this, adopting its previous suggestions for the use of more intensive peer reviews during the planning of projects would serve to anticipate and help avoid problems of the types encountered.

RESEARCH ASSESSMENT

Methodology

In general, HRED programs demonstrated excellent anticipation of future needs, research properly cast in terms of fundamental requirements, and well-constructed experimental designs with appropriate data analyses. On the other hand, some programs would benefit from more formalized research plans with better-articulated goals and objectives. As the Board has suggested previously, research planning probably would benefit from more intensive internal (and possibly external) peer reviews of research objectives and of the methods proposed for the conduct and analysis of research projects. Such a practice would leverage the considerable expertise of senior scientists and, hopefully, lead to the development of better theoretical constructs, the formulation of more appropriate research hypotheses, and the construction of more powerful experimental designs and statistical analyses to better support the resulting assertions and conclusions. This in-house review program would complement the desirable practice of peer review through journal publications and presentations, where feasible.

As modeling development efforts move forward, there will be an increasing need to develop and apply effective processes for validating model output and archiving validation results, particularly with tasks that have a less structured workflow, such as intelligence, communications, and maintenance. The Board envisions a verification and validation process designed to assess the underlying assumptions of the model and to identify the potential advantages and limitations of a particular model. The process would encompass the collection and use of "ground-truth" data where appropriate. In this regard, the Board recognizes that, for many model applications, there is no ground truth; moreover, there may be no funds to collect and archive ground-truth data when they are available. Unlike a statistical modeling situation in which there are training and testing data sets, the modeling conducted by HRED often requires going beyond any observed reality. Consequently, an analytic validation approach may be employed, rather than empirically-based ground-truth comparisons.

Even so, HRED should recognize the value of and be alert to opportunities for establishing some type of ground-truth database (consisting of previously collected data for which correct outcomes are known and previously published data that have been incorporated into the model) to assess the value of model improvements and enhancements. Such a database would need to be both comprehensive, in terms of sampling key system dynamics, and ecologically sound in order to help prevent spurious model validation. In this context, a formal process for assessing how the models have been used to guide further developments could be helpful. Such a tracking system could document successes as well as help prevent model improvements in one dimension of the system at the expense of predictive capability in other important dimensions. The bottom line is that the user will then know the extent to which the model produces the true result when that result is known, thus providing an appropriate level of confidence in its application when truth is not known. One approach to using a ground-truth database consists of a train-the-model phase and a test-the-model phase. In the training phase, one set of data is employed to adjust the parameters of the model so as to obtain the correct outcomes. In the testing phase, another comparable set of data is employed to cross-validate the results to see if the correct outcomes are obtained on data other than those on which the model was trained. Positive results provide confidence that the model is both valid and robust.

The Board would like to see the coherence of the sensors and perception research program enhanced by a formalized research plan with specific goals and objectives, relating basic and applied research efforts, and showing a more active connection with the broader vision of the research community. For example, the military is fond of the idea that auditory and tactile channels are underutilized. While it is plausible that these modalities could be used for alerts, the Board worries about plans that suggest that information can be handed off to another sense when vision is overloaded. There are "central executive" limitations that create bottlenecks between the senses as well as bottlenecks within a sensory modality. For example, one cannot read this report and listen to speech at the same time without sacrificing speed or comprehension or both. The Board recommends, in addition, that those working in the area of sensor fusion review papers on binocular vision and cue combination that have been presented at meetings of the Vision Sciences Society.[1] These papers are not specifically about sensor fusion, but much in them is relevant to this research. They also identify a number of researchers worthy of being contacted on these issues.

Feedforward control (or a forward model) is a concept derived from control theory to define a process in which a system takes action in advance of error caused by a disturbance or demand on that system. This proactive manner of control is superior to compensatory forms of control that wait until an error state exists before corrective action is taken. Feedforward control requires that some aspects of the input disturbance be measurable, the effect of the disturbance on system output be known, and the feedforward control mechanism have the capability to counteract the effects of the disturbance. Taking this concept from simple, tightly controlled systems (like advanced temperature control) and applying it to the complex world of command and control is a sizeable challenge, but one that HRED is undertaking. Specifically, feedforward control was studied to understand its importance in command predictions, learning, and performance in a game-based exercise. While the Board applauds HRED for undertaking this line of research with this limited first step, further efforts will require a more clearly defined and operationalized construct for feedforward control in the command and control environment. For example, feedforward control in command operations must be clearly distinguished from what may otherwise be considered simply a problem of information presentation or training.

As stated earlier, the design and conduct of experimental studies at HRED are showing continuing improvement, leading to projects that are producing definitive, relevant, and useful research results. The next step in enhancing the utility of experimental research will be to employ deeper analyses of behavioral measures. For example, many of the studies presented during this assessment employed factorial designs that were analyzed by means of analysis of variance. While these analyses are very useful in determining the main effects and interactions among variables, they have limitations when attempting to apply the results to designs or decisions. Designing the studies so that regression analysis is also possible may provide results in a more usable form that would reveal graded effects of varying design parameters. Other avenues to deeper analysis include process tracing techniques to better understand underlying strategies, defining key aspects of situation awareness necessary for mission success, analyzing and displaying variance to better understand measurement reliability and causes of performance outliers, and further assessing experimental results by comparing them with other studies completed under comparable conditions. Deeper analyses, for example, could have been applied to the well-executed study of the effects of latency and levels of autonomy on the control effectiveness and situation awareness in human-robot interaction. With four latency conditions applied in two different modes, four levels of autonomy, two measures of situation awareness, and two dependent measures of performance, there are limitations to analyzing and presenting the results solely in a series of bar

[1]See, e.g., *Journal of Vision*, Volume 6, Number 6, 2006, *Abstracts of the 2006 Meeting of the Vision Sciences Society*.

charts. It would be helpful to present these results in a more integrated and meaningful way, and this also would help clarify the limitations of experimental findings and conclusions. Using the experimental data to estimate parameters of a process model, such as one developed with IMPRINT, could effectively integrate and extend the experimental results.

More effective and complete analyses of work domains during the preparation and design of experiments will enhance the future interpretation and generalizability of study results. For example, in a study that attempted to determine the effects of number and type of robotic assets employed on the target detection and acquisition performance of human controllers, findings indicated that performance was best with one unmanned aerial vehicle (UAV). However, the results could be explained simply by the nature of the task—the target detection and acquisition task selected for this experiment could have been most effectively performed by the UAV alone, without the need for any other assets. That is, resource allocation by the controller may have been task dependent. An effective approach to defining the work domain, structuring the experimental approach, and selecting appropriate tasks for experiments is to employ a soldier-centered tool such as IMPRINT during the planning of the study. The Board is pleased to see this approach being utilized with some of the studies that are currently in the planning stage, particularly in the research being initiated to address adaptive automation in human-robotic interaction. This is another example of the potential utility of the model>test>model approach discussed earlier. A more complete analysis of the work domain also would benefit the study of the manning requirements for UAV systems.

Contributions to Army Needs

HRED maintains an understanding and appreciation of Army needs through extensive contacts with soldiers through its various field elements, through feedback from soldier participants in its studies, and through analyses of databases and exploratory studies related to soldier issues and performance. As a consequence, the projects reviewed were determined to have direct relevance and the potential for significant contributions to Army needs.

The Board is concerned, however, that HRED is not looking ahead far enough during the formulation of its research strategies, objectives, and plans. Many of the research efforts continue to be conducted within the "battlefield" context, even while prominent military strategists and analysts are projecting very different scenarios for the future—scenarios for urban and asymmetric warfare, for example. A broader range of scenarios would enhance the generalizability of findings to current and projected missions and would enable HRED to better integrate the findings from its varied studies. One member of the Soldier Systems Panel recently discussed this issue with the Deputy Director of National Intelligence for Analysis. The Deputy Director made the point that the extension of current trends (for example, increased globalization, communications flow, opportunities for terrorism) will continue to blur the line between personal security and national security, which in turn will further blur the line between law enforcement and military operations, and between activities involving people and those involving territory. As a consequence, research that focuses on "blue forces" against "red forces" arrayed in the countryside may not be particularly useful in addressing problems of the future.

Among other efforts, HRED has supported the Army transition to Future Combat Systems (FCS) for several years now by conducting critical soldier workload analyses. Currently, these efforts are directed toward using modeling tools to identify potential high-workload and multimodal interface task combinations for soldiers operating military ground vehicles (e.g., to identify crew-size requirements) and robotic assets, and they are being conducted in collaboration with the program of research on robotics. The combination of Unified Modeling Language (UML) to define system function allocations and IMPRINT to define crew function allocations is very promising, as is the application of modeling to assess the value of auditory and haptic interface alternatives. Some of the potential limitations of this approach are the ability to recognize when tasks are synergistic or share a common mode so that they each demand fewer resources than when performed alone; the ability to handle ill-defined tasks; the capability of considering the consequences of future tasks in scheduling; and the accommodation of the full range of factors influencing workload—such as vehicle motion and robotic monitoring and control.

Future Combat Systems and associated future networked systems-of-systems will intensify the need to make critical design decisions relative to the roles of automation and supervisory control. Thus, HRED should be at the forefront of anticipating and conducting research in this area. The case study of fratricide involving the Patriot missile system, along with statistical data on incidents of fratricide, provided an excellent historical perspective on these problems and their importance to the Army. Researchable issues that should be aggressively addressed by HRED include those involving appropriate organizational structures, configuration management and placement, training requirements and system understanding (including the degree of knowledge of operational systems functions and error recovery), calibration of trust, issues involving situation awareness, and support requirements for decision making. The Board does understand that HRED is addressing some of these issues in its ongoing programs of research on adaptive automation and robotics.

Because of the importance to the Army of having trained personnel available in its critical specialties, the macro-ergonomic approach taken by HRED to reducing attrition during highly demanding military training is a significant contribution to the Army's needs. The study demonstrated HRED recognition of a significant military problem and also demonstrated the challenge of addressing complex problems to accommodate immediate demands while also working toward a systemic solution. The development of a proactive computer-based assessment and decision tool, employable across a range of specialties, to analyze trainee characteristics and prescribe programmatic interventions and changes, is likely to be a valuable contribution to the solution of attrition problems in the Army. The complexity of the interactions between the many psychological and social factors, however, may require a team with a broader range of expertise than is currently being utilized.

The HRED program Cognitive Foundations of Performance in Military Environments is addressing issues that are important and central to soldier performance. For example, one line of research in this program addresses the effects of combat stress on the processing of information presented visually on digital displays. Typically this information is presented on small displays in very close or overlapping spatial proximity; the ability to filter out distracting information and attend to important information is critical to effective performance in many common operational tasks. Researchers have taken a first step in understanding the effects of stress in this work domain, but have much work yet to do to obtain definitive results that can be applied to Army operations. Some important factors to consider in designing further experiments include incorporating control conditions to resolve potentially ambiguous results; obtaining continuous psychophysiological measures during task performance; obtaining multiple dependent measures, including physical responses; and employing tasks that incorporate elements that relate to actual operations, such as more representative test periods (e.g., length of task, time of day). The program is also addressing multitasking, an increasingly important aspect of Army operations, and has completed the first in a series of studies—factors affecting multitasking performance. Additional studies will address predictors, strategies, limitations, and teamwork in multitasking. There is an opportunity in this research to employ some of the deeper behavioral measures, particularly process tracing, control issues, variability and reliability analyses, discussed earlier.

As the Army moves to the more extensive use of semiautonomous vehicles and considers various platforms from which human operators control them, the effects of interactions with these environments on soldier performance become critical. HRED has developed and is employing a Crew Integration and Automation Test Bed Advanced Technology Demonstrator (CAT-ATD) to study the factors that are likely to degrade performance, as well as possible measures to mitigate degradation effects. When a moving vehicle is being controlled from another moving vehicle, for example, factors other than controller performance come into play, such as the likelihood that soldier controllers become incapacitated from a combination of motion sickness and control or display disparities. Research reported during this review determined that in such an environment, incapacitation is a significant problem and that future tactics should consider ensuring that the operator be able to disassociate the motion cues on the robotic display from those of the operator's platform. Future simulator studies will examine the specific factors that are likely to mitigate the influence of the motion environment.

Contributions to the Broader Community

In previous reviews, the Board has emphasized the need for greater HRED interaction with the external research community and has encouraged researchers to share the results of HRED projects and programs through increased publication in the scientific literature and presentations at important professional meetings. HRED has continued to move in this direction, with contributions to the broader community now at a new high and likely to increase. Some examples of contributions, collaborations, and outreach efforts are provided in this section of the report.

A study of audio cues to assist soldier visual search of robotic system displays was launched from a review of previous research conducted elsewhere that suggested the potential utility of audio spatial cues in guiding the search of map displays. The study was conducted with the collaboration of researchers at Rensselaer Polytechnic Institute, who will perform a follow-up study as part of a cooperative research and development agreement. A journal article based on the research is being prepared. The HRED research program on multitasking performance extends from fiscal year 2003 through fiscal year 2007. In addition to the dissemination of results to the U.S. Army by means of ARL technical reports, results will be disseminated to the DoD Human Factors Engineering Technical Advisory Group, Harford County Emergency Operations Center (a study participant), Air Force Research Laboratory, NASA-Johnson Space Center, and the National Space Biomedical Research Institute.

The research program on the modeling of visual search tasks has involved the participation of researchers beyond HRED and is designed to make contributions to the broader modeling community, particularly those involved with modeling efforts that have come to be known as ACT-R. In the conduct of a project on memory for unattended information during visual search, data were obtained for the research from Harvard Medical School, researchers at Rice University contributed to the design of the search task, and a postdoctoral student (now a permanent employee at HRED) participated in the conduct of the research. While the Army is the primary recipient and beneficiary of the results of this research, the findings will help to inform the further development of ACT-R. An article is in preparation for publication in the *Journal of Experimental Psychology*.

Undertaken to better understand and enhance the interactions of multiple soldiers controlling multiple semiautonomous unmanned ground vehicles (UGVs) during military operations in urban terrain, the HRED research program is being conducted in conjunction with the University of Central Florida. At this time, one book chapter, five conference proceedings papers, and two conference presentations have been published, are in publication, or have been accepted.

CROSSCUTTING ISSUES OF RELEVANCE TO THE DIRECTORATE

Crosscutting issues on modeling and robotics should be relevant to this directorate. As discussed previously, the development and application of soldier-centered design tools continue to be vital to many programs at HRED. The HRED researchers are cognizant of the need for verification and validation, the need to relate their programs to those of others, and the extent of collaboration required to meet their objectives. The recently initiated Army Technology Objective at HRED on human-robotic interaction and the amount of research now underway in this area suggest the potential importance of pursuing crosscutting issues with other researchers addressing the application of robotics in the Army.

4

Sensors and Electron Devices Directorate

INTRODUCTION

The Sensors and Electron Devices Directorate (SEDD) was reviewed by the Panel on Sensors and Electron Devices during July 13-15, 2005, and May 3-5, 2006. SEDD contains four divisions that are reviewed by this panel: Electro-Optics and Photonics; RF (Radio Frequency) and Electronics; Signal and Image Processing; and Directed Energy and Power Generation.

SEDD also has responsibility for the Advanced Sensors Collaborative Technology Alliance (CTA) and the Power and Energy CTA, and contributes to the Robotics CTA, headed by the Army Research Laboratory's (ARL's) Weapons and Materials Research Directorate. Each CTA began in 2001 and has a 5-year term, with an option for 3 more years. The Advanced Sensors and the Power and Energy CTAs are ending, as well as the Microelectronics Center (a collaboration with the University of Maryland and Johns Hopkins University). A new 5- to 10-year Network and Information Sciences International Technology Alliance (ITA) with the United Kingdom began in 2006, and a new 5-year Micro Autonomous Systems and Technology CTA is expected to be awarded in 2007.

Tables A.1 and A.2 in Appendix A show the funding profile and the staffing profile for SEDD.

CHANGES SINCE THE LAST REVIEW

SEDD continues to do outstanding work that is highly relevant to the needs of the U.S. Army. SEDD has adapted and fine-tuned its research areas to focus on those areas with the highest potential payback, both near term and long term. In addition, SEDD has had a good deal of success in hiring extremely capable scientists and engineers into the directorate. As a result, the high-quality work performed in SEDD reflects both the wisdom of the course corrections made in research direction and the quality of people involved in the research.

The level of interaction among the different groups within SEDD is notable and highly productive. The enthusiasm and excellent morale of the SEDD researchers are evident, which in turn provides an environment conducive to accomplishment.

ACCOMPLISHMENTS AND OPPORTUNITIES

Most Significant Advances

SEDD has made significant advances in a number of research and development (R&D) areas over the past 2 years. Areas with particularly notable results include autonomous sensing, hyperspectral imaging anomaly detection, portable handheld biotoxin analysis, methanol fuel cells for portable power applications, pulse power shaping, microelectromechanical systems (MEMS) phase shifters, flexible displays, prognostics and diagnostics, laser eye protection, perovskite materials, mercury cadmium telluride on silicon for infrared (IR) detectors, and a system that has been deployed for current battlefield operations.

SEDD's autonomous sensing group continues to be a leader in the field, and this area should be considered as a candidate for inclusion as a top-quality area in ARL. This group has achieved considerable success in formulating new and innovative approaches to pressing autonomous sensing problems. Acoustic and magnetic sensor fusion and integration represent an important step forward.

The work on hyperspectral imaging anomaly detection is first rate, with significant progress to report. A novel method for clutter suppression, called the principle of indirect comparison, was developed. An impressive demonstration of camouflaged sniper detection was seen in a video prepared in response to a challenging problem presented to ARL by a Research, Development and Engineering Center (RDEC) partner.

The development of a handheld DNA biosensor would be revolutionary, and considerable progress has been made in this area. The prototype, developed in conjunction with the University of California at Santa Barbara, may be at the forefront of this technology. The work merges microfluidics with MEMS and is relatively immature, but it holds great promise.

Methanol fuel cells for portable power applications have now achieved a 20 watt output, a significant advancement. The collaboration with DuPont is a good step in the right direction. The reliability, performance, and operating characteristics of these cells are under investigation by SEDD for Army applications.

SEDD has done an impressive job of developing high-power pulse shaping for electromagnetic armor and guns. Existing silicon switch modules are used to achieve fast rise times, and newer silicon carbide (SiC) switches are being explored for peak currents of up to 250 kiloamperes.

The work on MEMS phase shifters (MEMS-enabled electronically scanned antennas) has made great progress over the past 2 years. Both the electrostatic and the lead zirconium titanate (PZT)-actuated MEMS show good promise. ARL's production capability has been dramatically enhanced by the acquisition of new process tools. The PZT MEMS are unique to ARL, and could have a significant impact on phased-array performance.

Significant advances also have been made in flexible displays, with considerable progress in both hardware development and image plane resolution. The collaboration with the Flexible Display Center at Arizona State University is an excellent model for collaborative development on an international scale.

Prognostics and diagnostics may seem mundane at first glance, but ARL's work in this area, using commercial off-the-shelf wireless and controller hardware for temperature, humidity, vibration, and shock monitoring, is first-rate in all regards. The approach is reasonable, and all relevant issues have been taken into consideration during the development process. This work uses the results from ARL's MEMS sensors development in a very productive and efficient fashion. There are many applications for this work in both military and commercial applications.

Eye protection from damage due to lasers is an important problem, and SEDD is doing state-of-the-art work on two different fronts: equipment protection and human eye protection. The group is developing new materials designed to ARL specifications, has excellent collaborations with outside researchers, and is actively exploring new electro-optic and magneto-optic materials originally developed for telecommunication applications.

Perovskite material development for voltage-controlled true-time delay for phased-array antennas has made excellent progress, and SEDD is to be applauded for applying fundamental materials science to an important practical problem. The work is at the state of the art, especially the integration of thin, tunable dielectrics with low-loss, low-κ (low dielectric constant) dielectrics for electrically controlled, variable-length transmission lines.

Mercury cadmium telluride on silicon for IR detectors has shown amazing progress, and should be considered for inclusion as a top-quality area within ARL. The IR detector results are impressive, the group has an excellent relationship with outside contractors, and the technology has been transitioned to the Night Vision Laboratory and Rockwell Science Center. This group is at the forefront of research into lattice-mismatched materials.

No specific comments can be given with regard to a system that has been successfully developed for battlefield operations except that the progress has been remarkable in a short period of time for a very pressing Army problem.

Opportunities and Challenges

SEDD has exceptional strength in a number of important areas, including acoustic and autonomous sensing, radar and communications, advanced sensors, and image processing. SEDD has increasing strength in fuel cells, power shaping, biosensors, IR and perovskite materials, and flexible displays. Short-term requirements continue to be an issue when they detract from ARL's mission of longer-term technology research and development.

The Electro-Optics and Photonics Division is doing excellent work in the areas of infrared materials on silicon and laser eye protection, as noted above. The atomic-clock and Bose-Einstein devices in SEDD were interesting, but it is not clear what the motivation is for this work. The ultraviolet (UV) opto-electronics group is to be commended for testing devices from the Defense Advanced Research Projects Agency (DARPA) and is encouraged to broaden outside collaboration, as considerable work is ongoing in this area. It was not clear that the reviewed "nanoscale compositionally inhomogeneous" work was unique in anything except nomenclature.

The RF and Electronics Division is exceptionally strong and is widely recognized in the microwave community for its strength. The PZT MEMS work should be compared directly with the more conventional MEMS approach, with a demonstration of a small electronically scanned antenna using both approaches. The Agile RF effort is at the cutting edge, with excellent research to support its development, and the technology is being transitioned to Raytheon. The nanoelectronics work is good, but it is not clear that the goals are well defined, nor is it clear that the work is at the cutting edge. SEDD should consider more of a first-principles approach to nanoelectronics, understanding that the entire community is facing the same problem of insertion relevance. The reported ultrawideband (UWB) radar work is on the right track. UWB radar is a relatively unexplored field; ARL is at the forefront and is to be commended for working with a leading expert at the State University of New York at Buffalo.

Signal and image processing with autonomous sensing is one of the most successful areas of SEDD, but there is concern that the push for immediate results and applications in this area has reduced the resources available for longer-term research and development for future applications. ARL's image processing work is well respected and highly visible in the community and has a good publication record. However, it is important to appreciate that kernel methods are not the only approach to image processing; it is advisable to continue to do comparisons with other, perhaps simpler methods as well.

The Directed Energy and Power Generation Division is achieving excellent results in a number of areas, including SiC switches, methanol fuel cells, lithium-ion (Li-ion) batteries, and power pulse shaping. The electric field cage is state of the art, but there are some areas that continue to face challenges. Fuel reforming does not show much progress. It is not clear that power MEMS has clear direction relative to the goals for this work. The batteries area continues to face challenges, as Li-air batteries do not generate enough power for Army applications, and sodium electrolytes are not an appropriate approach. However, the munitions-batteries area holds opportunities for making progress. The high-energy laser work is focused on fundamental components using scalable technologies; it is important that the work should also be intended to make ARL a smart buyer.

RESEARCH ASSESSMENT

Methodology

SEDD is fortunate to have some of the leading scientists and engineers in the field working in its labs. The research methodology employed by these employees is, in general, consistent with that at leading research universities and other government laboratories. In most cases, the program goals and objectives are well understood before the start of the project, and progress is mapped on a regular basis. It is not clear that every program has a well-defined roadmap; this may be useful, regardless of the size or type of program.

In general, the overall research and development goals are well aligned with ARL and the U.S. Army's long-term needs. On some occasions when the Army's needs are more immediate, long-term R&D is sacrificed for short-term results. It is appropriate for ARL and SEDD to have this flexibility, with the understanding that the immediate needs are short term in nature. In fact, ARL is to be highly commended for its ability to deliver short-term results when necessary, as it is a validation of the capability of the labs.

Contributions to Army Needs

SEDD continues to make important and lasting contributions to ARL, the Army, and the United States. The four divisions within SEDD contribute to the success of the U.S. Army in electro-optics and photonics, RF and electronics, signal and image processing, and directed energy and power generation. The research and development effort within SEDD is well defined to be aligned with the needs of the Army, and as a result the contributions are relevant to the Army's needs.

For example, the work on laser eye protection is important for every soldier in the field. The acoustic sniper detection system developed within SEDD and already deployed continues to make valuable contributions. Radar, communications, biohazard detection, and power generation—all developed within SEDD—also are all relevant to the Army's immediate and long-term needs.

Contributions to the Broader Community

Many of the technologies developed within SEDD make both direct and indirect contributions to the broader community. Much of the research ongoing within SEDD is state of the art, publishable, and valuable to the broader scientific community. For instance, SEDD is a leader in microwave radar and communications and is well recognized as such in the microwave community.

CROSSCUTTING ISSUES OF RELEVANCE TO THE DIRECTORATE

Many crosscutting issues are of direct relevance to SEDD. Computation and modeling continue to be relevant to SEDD, as does nanotechnology in general. Information security is relevant to RF communications and quantum cryptography.

5

Survivability and Lethality Analysis Directorate

INTRODUCTION

The Survivability and Lethality Analysis Directorate (SLAD) was reviewed by the Panel on Survivability and Lethality Analysis during June 14-16, 2005, and May 15-17, 2006. SLAD is the U.S. Army's primary source of survivability, lethality, and vulnerability (SLV) analysis and evaluation support with regard to major Army systems. SLAD's general objective is to ensure that soldiers and systems can survive and function on the battlefield and to assess the degree to which Army systems are reliably lethal to enemy forces. Its mission includes SLV analysis and assessment through the entire life cycle of major Army systems, from development through acquisition to deployment and operation, in the context of a full spectrum of battle space environments and threat forces, tactics, and systems. SLAD further provides advice to Army Headquarters, Program Executive Officers, and subordinate Program Managers, as well as an array of other evaluators, system developers, and Army contractors, and other defense-oriented laboratories. Finally, SLAD is tasked with supporting special studies and inquiries motivated by and affecting current operations.

In contrast to most other directorates at ARL, SLAD's portfolio includes relatively little applied research funding, and no basic research funding. The overwhelming majority of SLAD funding is later in the Department of Defense (DoD) Research, Development, Test and Evaluation (RDT&E) chain, either provided by acquisition programs for SLV support or by RDT&E management support funding organic to the Army Research Laboratory (ARL). The small fraction of applied research funding supporting SLAD is devoted to the development of tools, techniques, and methodologies required to undertake SLV analysis and assessment. This portfolio of funding reflects a relatively long period of stable SLV techniques, emphasizing ballistic survivability of armored systems and lethality of U.S. weapons systems against armored systems.

SLAD is now supporting SLV analysis in a much broader and more rapidly evolving context, in which communications and networking, rather than weapons systems per se, are felt to be the essential and sustaining advantage of U.S. military forces. A central concern of the Board has been whether the directorate's funding portfolio will result in tools, techniques, and methodologies capable of providing the Army with the assessment capability needed under the emerging paradigm of net-centric warfare in an irregular battle space.

Tables A.1 and A.2 in Appendix A show the funding profile and the staffing profile for SLAD.

CHANGES SINCE THE LAST REVIEW

SLAD has experienced very significant changes, both organic and environmental, since the previous biennial assessment report. First, SLAD's management has changed significantly, with a new Director, a new Division Head, and multiple middle management changes over the preceding 2 years. Second, SLAD has experienced an unprecedented level of program turnover (reaching 20 percent of its portfolio in fiscal year 2006) as SLAD support to current operations has displaced more routine SLV work, especially on legacy Army systems. SLAD funding also has grown during this assessment period, primarily to enable acquisition and deployment of SLAD-developed, urgently needed quick-reaction technology in support of current operations. ARL and SLAD management expect SLAD funding to decrease in coming fiscal years.

Third, SLAD has continued to advance the development of methodologies aimed at assessing the effectiveness of systems of systems (SoS), which has been a continuing recommendation of the Board; the Board notes that the pace of that development has slowed, almost certainly as a direct result of the two changes noted earlier in this section. Although the slowdown is understandable, future SLAD contributions to critical Army needs are contingent on continued development of SoS assessment techniques. In 2006, ARL management indicated that it was willing to consider a Strategic Technology Initiative (STI) in the area of SoS methodology under SLAD leadership. As discussed later in this section, the Board strongly recommends that SLAD avail itself of this opportunity.

Finally, SLAD is undertaking significant modernization of its SLV analysis infrastructure; this modernization is a critical task for SLAD, since the current effort will significantly affect its future capability to conduct, and especially to integrate the results of, SLV analysis.

More broadly, the Board notes that SLAD has a more fully integrated perspective, broader intra-directorate communications and understanding, and a more global (if still implicit) vision for its future than in previous review periods. Even under the pressures of supporting current operations, SLAD is conducting many of its development tasks as components of an integrated set of capabilities, as opposed to a set of isolated tasks. This change, if exploited aggressively by SLAD and ARL management (and coupled with an increasingly strategic view on issues such as collaboration, workforce development, and the ability to do more with fewer resources), offers significant potential for the directorate, not only to consolidate its advances of the past few years but also to move to the next level of contribution to Army needs.

ACCOMPLISHMENTS AND OPPORTUNITIES

Most Significant Advances

SLAD's continued development of the Modular UNIX-based Vulnerability Estimation Suite (MUVES)-3 software infrastructure reflects both modern management and technology for a substantial software program; as noted above, successful completion of MUVES-3 (with validated transition of component tools from the current production environment) is a critical enabling task for SLAD. Progress on this effort has been excellent, and both program and SLAD management have correctly identified the most important issues to be addressed in the near term. SLAD took a relatively bold step in implementing MUVES-3 in Java; the Board believes that the platform independence deriving from this decision will pay significant dividends in the future. Although the Program Manager has demonstrated concern over the performance impact of Java, the Board encourages SLAD to continue on this path, and to avoid compromising platform independence through the use of custom hardware, such as application-specific integrated circuits or field-programmable gate arrays.

The Target Interaction Lethality Vulnerability (TILV) program can be considered as the primary vehicle to populate MUVES-3 with methodology for kinetic vulnerability/lethality assessment as both Army and threat systems evolve. This program is well managed and technically rigorous, and reflects excellent collaboration within ARL; TILV serves to bridge basic research efforts of the Weapons and Materials Research Directorate into the SLV methodology developed by SLAD. The Board notes that TILV has been addressing the rapidly evolving threat experienced in current operations and expected in the future. While this forward-looking perspective is very positive, SLAD must be especially careful to apply critical mass to each of the concepts it addresses.

SLAD recognized the importance of the Army's Future Combat Systems (FCS) very early in that program's evolution. That early recognition is now paying off (for both SLAD and the Army), with SLAD being strongly linked to the FCS program, supporting optimization of FCS survivability and lethality at both the SoS and platform levels, and SLAD having key roles in design, modeling, and damage assessment in the context of live-fire testing. Over 60 staff years of SLAD support are being devoted to this effort, using a combination of SLAD mission funding and FCS program funding.

A key example of SLAD effectiveness in support of FCS has been in the area of network vulnerability assessment. SLAD had the FCS network software running before at least one of the Lead System Integrator groups, and has been doing innovative work and exploit development work that the Board considers worthy of SLAD's approaching the Defense Advanced Research Projects Agency (DARPA) to seek additional support.

Opportunities and Challenges

As noted previously, the Board has continually urged SLAD to focus development effort on the ability to assess SoS effectiveness, especially as it applies to FCS. SLAD has made key strides forward along these lines over the past few years.

The development of the Mission and Means Framework (MMF), a collaboration between the current SLAD Director and the preceding Interim Director, represents a key step in developing a holistic process allowing subsystem and platform performance to be reflected in an assessment of overall mission effectiveness for both current systems and those under consideration for the future. SLAD has used this framework in several example pieces of analysis for Army customers. Further, other elements of the SLAD tool set are now oriented toward providing input to MMF, reflecting an integrated perspective on SLAD tasks, as noted previously. However, with the promotion of the current Director and the transfer of the previous Interim Director to another directorate at ARL, progress on MMF has slowed, while much remains to be done. The mathematics supporting MMF should be extended to support probabilistic scenarios and to quantify uncertainties resulting from MMF analysis. Other, more junior SLAD staff will need to carry out this work, both to remove senior managers from being in series with development work and to provide support to a broader set of customers. It is also critical that SLAD work on a more concise approach to presenting the MMF (both its substance and its potential significance) to potential customers and decision makers. SLAD should also ensure that it is aware of kindred work in other fields, such as the Survivable Network Analysis work done by the Software Engineering Institute at Carnegie Mellon University.

The System of Systems Survivability Simulation (S4), conducted in collaboration with scientists at the Physical Sciences Laboratory of New Mexico State University (NMSU), is a much more concrete approach to SoS SLV analysis. Essentially a large multiple-entity simulation, it is aimed at assessing SoS effectiveness by simulating combat between friendly and hostile forces, modeled in detail at the platform level. This approach has the advantage that it is constructive and the results transparent (at least in terms of gross observables such as force attrition). The fidelity with which various components are modeled varies considerably; the data networks are modeled at a very high level of fidelity, whereas sensor systems and weapons are modeled in a more generic fashion. To complicate the interpretation of results, a large number of decision-making processes (DMPs), representing the human decision makers on the battlefield, generate a significant fraction of the simulation dynamics. A simulation run generates a significant quantity of data, and the collaborators have developed a number of fairly abstract tools to organize that data. While the comparison of simulation runs differing in carefully controlled ways reflecting force elements or attributes to be assessed may well provide insight, it is also likely that results can be interpreted in terms of the limitations in the sophistication or fidelity of the DMPs, the lack of a consistent architecture and component fidelity, or other factors beyond the scope of this report. The Board is skeptical that S4 represents a robust methodology that would support SoS SLV analysis for FCS; it is more valuable as a tool for development of insight motivating other tool development than as an assessment methodology per se. The Board has strongly recommended that SLAD propose to ARL management an approach to an SoS Strategic Technology Initiative not based exclusively on S4. The S4 effort contains SLAD's most significant academic collaboration; an alternative approach in pursuit of the STI would also permit SLAD to broaden its stable of outside collaborators.

In the area of SoS information assurance vulnerability assessment, SLAD is supporting an area of high potential vulnerability for the Army, but it relies too heavily on open-literature vulnerabilities and checking for installation of current patches as released by commercial software vendors. SLAD is not collaborating with other information assurance (IA) centers of excellence, such as CERT (a center of Internet security expertise at the Software Engineering Institute operated by Carnegie Mellon University) or the SANS (System Administration, Networking, and Security) Institute in this effort. The Board has recommended a different, potentially unique alternative to this approach: developing the capability to rapidly test the effects of applying system patches to an array of information operation assaults, in an automated fashion. In many respects, such an architecture would bring to the information domain something akin to the ballistic analysis for which SLAD is so widely renowned in the kinetic domain.

More generally, the area of IA seems to represent one of the keys to the effectiveness of network-centric warfare. SLAD must innovate to develop and adapt the assessment approaches that will be needed to understand this increasingly critical dimension of SoS effectiveness.

Geometry is often a problem for organizations (e.g., in the automotive and aerospace industries) that rely on geometric models to drive analyses, and the problem may surface in vendor-provided geometry software. Geometry represents a recurring problem area for SLAD in its kinetic SLV analysis. Representation of platform and subsystem geometry in SLAD analysis infrastructure frequently requires work-arounds and remedial action by SLAD staff, because the information is not provided by the commercial vendors of the platforms (at least not in a readily assimilated form). This recurring issue cries out for a holistic and systematic solution (which may require the involvement of the Army acquisition executives) to free SLAD resources for reassignment to the many novel problems SLAD is addressing for the Army. Further, SLAD should undertake a critical review of the geometric skills that it needs as core competency. Cost effectiveness and risk-value analysis should be used to parsimoniously establish the skills and tools required. If lower-shaded geometry will suffice, ray tracing may not be necessary. If time-stepped static geometry will suffice, it may obviate the huge investment required to support dynamic geometry.

Finally, the Board notes that SLAD currently supports SLV analysis relative to chemical, biological, and radiological threats at a level of about 4 staff-years per year, down over an order of magnitude relative to the activity level of 5 to 10 years past. This represents a subcritical effort, incapable of contributing significantly to the Army's understanding of this wide range of threats.

RESEARCH ASSESSMENT

Methodology

SLAD has continued to advance the development of methodologies aimed at assessing the effectiveness of systems of systems, which has been a continuing recommendation of the Board; the Board notes that the pace of that development has slowed, almost certainly as a direct result of the two changes noted earlier in this chapter. While understandable, future SLAD critical contributions to Army needs are contingent upon continued development of SoS assessment techniques. In 2006, ARL management indicated that it was willing to consider a Strategic Technology Initiative in the area of SoS methodology under SLAD leadership. The Board strongly recommends that SLAD avail itself of this opportunity.

SLAD is now supporting SLV analysis in a much broader and more rapidly evolving context, one where communications and networking, rather than weapons systems per se, are felt to be the essential and sustaining advantage of U.S. military forces. A concern of the Board has been whether the directorate's funding portfolio will result in tools, techniques, and methodologies capable of providing the Army with the assessment capability needed under the emerging paradigm of network-centric warfare in an irregular battle space.

Contributions to Army Needs

As noted previously, SLAD research (in the development of tools for SLV assessment) and analysis underpin Army understanding of the survivability and lethality of its systems. This is particularly true with respect to kinetic threats, which dominate current operations. However, the significance of information threats is expected to grow, and represents a potentially critical vulnerability for FCS. SLAD is making excellent progress in establishing infrastructure that will support network vulnerability assessment. Methodologically, SLAD's successes largely lie in the future (as is the case with regard to IA methodology rather broadly in the DoD context), and are likely to be significantly enhanced by broader involvement with and collaboration within the IA community.

Current operations in Iraq and Afghanistan are receiving very significant technical support from SLAD. That significance is reflected in both the scope of the efforts and their current and likely future effectiveness. Although the details of these contributions are inappropriate for this report, their scope, technical sophistication, rapid development, and dissemination reflect very favorably on SLAD staff as skilled applied scientists and engineers working cohesively and with a high degree of alignment with their mission.

Finally, the development of adequate SoS SLV methodology represents the most significant contribution to U.S. Army needs that SLAD is empowered by charter and mission to make. SLAD is making progress toward this goal, but more progress is needed and will require persistence, innovation, and strategic commitment from SLAD and ARL management.

Contributions to the Broader Community

The SLAD portfolio does not lend itself as readily as those of the other directorates within ARL to external collaboration, publication, and conference participation. SLAD insularity significantly compromises its ability to leverage academic and commercial developments, especially in the areas of computer and network security, where investment outside the Army dwarfs organic resources and capabilities. Academic collaboration is also a key to strategic workforce development, since exposure of graduate and undergraduate students to highly relevant applied research and development may enhance SLAD's recruiting pool. As noted earlier, pursuit of an SoS STI separate from S4 (and the team of NMSU collaborators) would enable SLAD, with high probability, to double its collaboration outside the Army. The ability to satisfy a critical need for the Army and simultaneously to substantially enhance SLAD's interaction outside ARL makes the prospective STI an opportunity on which SLAD must capitalize.

SLAD staff has shown increasing conference and professional society involvement in recent years. Funding constraints and demands for support of current military operations appear to have recently blunted this improving trend. SLAD and ARL management should resist the temptation to allow current short-term pressures to cause a relaxation into a more insular posture. Strategic workforce development demands that SLAD staff seek professional enrichment and involvement in the broader technical community.

CROSSCUTTING ISSUES OF RELEVANCE TO THE DIRECTORATE

Army Research Laboratory Technical Assessment Board discussion of validation, verification, and accreditation (VV&A) is highly relevant to SLAD. Ground-truth data generated through live-fire testing is an extremely expensive and hence limited commodity. SLAD has a Configuration Management Board that gates inclusion of assessment tools into MUVES. This is a natural framework in which to accomplish VV&A. The Board requests that the processes within this framework be examined during the coming assessment cycle.

6

Vehicle Technology Directorate

INTRODUCTION

The Vehicle Technology Directorate (VTD) was reviewed by the Panel on Air and Ground Vehicle Technology. The directorate has four divisions that are reviewed by the Panel: Loads and Dynamics, Structural Mechanics, Engine Components, and Engine and Transmission Systems. The first two of these divisions are located at the National Aeronautics and Space Administration (NASA) Langley Research Center in Virginia, and the other two are located at the NASA Glenn Research Center in Ohio.

Tables A.1 and A.2 in Appendix A show the funding profile and the staffing profile for the VTD.

The assessment detailed below reflects visits by the Panel on Air and Ground Vehicle Technology to the VTD sites at NASA-Glenn (September 12-14, 2005) and NASA-Langley (May 23-25, 2006), as well as the December 2005 meeting of the ARL Technical Assessment Board.

CHANGES SINCE THE LAST REVIEW

There were three significant events that represented significant changes and potential impact on the VTD mission. The first of these was the selection of the directorate to be relocated to Aberdeen Proving Ground, Maryland, as part of the 2005 Base Realignment and Closure (BRAC) action. The second event was the retirement of the longtime Director of the VTD and the appointment of a replacement. The third was the announcement by NASA of its intent to restructure its aeronautics program and to focus more on space activities and on base technology in the aeronautics area. These moves indicate that the NASA aeronautics program will be operating with further budget reductions.

The BRAC announcement provided the VTD with the opportunity to conduct an introspective review of its activities and to conduct an ongoing strategic planning exercise to seek the best approach to addressing its mission and how it may best be accomplished without the four divisions being collocated in their entirety with NASA at the two NASA centers.

The retirement of the VTD Director and the appointment of a new Director appeared to the Board to have had no discernible negative functional effect on the operation of the directorate and the technical content of its activities. This level of leadership change, combined with the strategic planning, represent significant events that need to be carefully managed by ARL management to shape the VTD and maintain its valuable contribution to the Army mission. The Board's assessment is that the ARL and VTD leadership are moving forward with positive responses to these events.

The announced change in focus of the NASA aeronautics program and its effect on the VTD mission have yet to be fully assessed. The most significant effect may relate to NASA's potential actions with respect to wind tunnel operations. The VTD has been dependent on certain NASA wind tunnels for research, methods validation, and proof-of-concept testing. NASA currently has its operation of these facilities under cost-benefit review. The change from collocation with the NASA researchers should have a lesser negative impact on the important analytical methods development and applications work done by VTD, because these efforts will be reinforced by NASA's focus on base technology.

ACCOMPLISHMENTS AND OPPORTUNITIES

Most Significant Advances

Significant accomplishments during this assessment period were the demonstration in full-engine tests of the Active Stall Control Engine Demonstration (ASCED) concepts, the continued development and validation of both aerodynamic and structural analytical tools, and the application of these to Army vehicles. The Board also notes that the VTD is examining approaches to enhance the directorate's ability to recognize evolving Army needs and to facilitate the transition of technology to the user.

The ASCED addresses the issues of helicopter engine performance deterioration and loss of operating stability, caused from operation in areas in which there are high concentrations of airborne particulates. Engines operating in these conditions experience erosion of compressor blades and deposition of material on the turbine components, resulting in significant losses of aerodynamic capability and a shift of the acceleration characteristics of the engine. The ASCED program used a comprehensive approach that included modeling of the aerodynamic characteristics of the components, the engine, and its control system; component tests to establish baseline characteristics of the components and the engine; and detailed exploratory investigations into several techniques to modify and enhance the stability of the components and the overall engine system. The activities leading up to the full-engine tests with the selected enhancement features were reviewed in the meeting at NASA-Glenn in 2005. The full-engine test to demonstrate the capabilities of the selected stability enhancement devices was reviewed in the 2006 meeting at NASA-Langley.

The program was viewed as having a high degree of relevance to the Army mission and to the broader helicopter community. The results of the initial analytical modeling and component testing were assessed by the Board as good work that followed sound engineering practices and produced good results. The Board was somewhat concerned that some of the analytical modeling work on the overall engine system had been delayed owing to the relocation of one of the university researchers involved in this work, but it was reported that this effort is being reinstated successfully.

The results of the engine tests with the stability enhancing configuration were very encouraging and were considered to represent considerable success for the program. However, there were several findings relating to improvements in the stability margins of the engine when the incorporated devices were in their passive mode. While this does not detract from the improvements demonstrated and attributed to the incorporated technologies, the Board recommends that the program be expanded to fully understand the implications of all of the characteristics observed. The Board also recommends that the results be presented in an industry workshop so that the results may be quickly assimilated by the engine and operating community and these features incorporated as appropriate.

The directorate's efforts to adapt and use analytical tools, addressing aerodynamic characteristics, and the resulting dynamic interaction of helicopter structures are considered by the Board to be sound engineering work on the basis of individual programs but of more value when viewed as part of the total analytical capability of VTD. This value is further enhanced when the analytical capability is placed in the context of an integrated package of analysis, model testing, and full-scale component and vehicle testing.

The Rotorcraft Wake Modeling Using p-VTM (Particle Vorticity Transport Model) work has demonstrated significant achievements. The Board is supportive of the program but suggests that the researcher more actively investigate other research in the field to avoid duplication of effort and to accelerate the reduction to practice of this tool. The Board also supports the effort to minimize computer time through the use of multigrid approaches to providing high resolution for computational fluid dynamics (CFD) methods, and again recommends that the researcher stay abreast of other similar work in the field. The application of the analytical tools to specific applications and configurations is considered a significant part of VTD's mission, and the efforts briefed on the UH-60 helicopter, the Coaxial Rotor concept, and others are assessed to be good, sound work.

Opportunities and Challenges

VTD's eventual movement from the NASA centers will necessitate a significant movement of personnel and a change in the relationship with the NASA personnel and facilities. ARL and VTD management is taking advantage of this opportunity to conduct a focused strategic planning activity without excessive reliance on past practices and approaches and to draw closer to other components of the ARL system. The Board looks forward to the results of this ongoing planning activity.

RESEARCH ASSESSMENT

Methodology

The VTD has evolved an approach in all four divisions that has been successfully demonstrated. It is characterized by a combination of applying analytical tools, using experimental methods in controlled tests, and applying these to real full-scale vehicles and components. This approach has included a mix of Army, NASA, academic, and industrial researchers.

The Board notes that the CFD work being conducted is of significant value to understanding issues encountered in the design, operations, and system evaluation phases of a program. The same type of value is assessed as being contributed by the work on material characterization, fracture mechanics, and damage assessment. It is noted that the work on Fracture Toughness/Fatigue Resistance of Composites with Embedded Sensors has potential application to future development and operational systems.

The methodology used by the divisions at the NASA-Glenn Center also includes a mix of both analytical and experimental activities. An example of this was noted in the discussion above of the ASCED program. This division appears to be spread very thin when the staff level is compared with the number of programs currently underway, but this is partly explained by the participation of Army researchers in NASA programs of interest to the Army.

Contributions to Army Needs

The Board views VTD's programs in general as making contributions to Army needs with a wide range of near-term and far-term activities. Examples of programs that have the potential of direct contribution to near-term needs include the ASCED, which addresses engine deterioration issues currently being encountered in deployed aircraft. Also in this category are the Terahertz (THz) Nondestructive Evaluation (NDE) for Aging Aircraft Corrosion and Damage and the Application of Thermal NDE for Advanced Structures programs. These programs provide the operator with techniques for inspecting critical structures and determining the readiness of equipment. This capability also holds the potential for extending equipment deployment and decreasing the load on critical depot assets.

Programs such as the Active Twist Rotor, Tiltrotor Aeroelasticity, Multigrid Methods for High-Resolution CFD, and some of the advanced turbine material characterization programs are more long term in nature, since they are in the methods validation phase and, while a portion of these programs may find near-term applications, their full value will be realized in solving future problems and configuring new systems.

Contributions to the Broader Community

The latest review included considerable attention to the contributions that the VTD makes to industry and how this value is realized. The Board identifies three contributing factors:

1. The capable people who have experience and a balance of analytical, experimental, and applied backgrounds (i.e., dedicated personnel experienced in rotorcraft propulsion and structures with a good balance of analytical and experimental knowledge);
2. Analytical capability that is focused on Army issues (focused on the adaptation, validation, and application of codes to actual aircraft, experimental vehicles, and tests); and
3. Facility interface capability that goes beyond conducting a test in response to an external request and includes interactively designing the test and test vehicle, as well as real-time guidance of activities (i.e., access to relevant facilities to define the test configurations and procedures and to participate in a management role in the conduct of experimental work).

Examples noted by the Board that can be categorized as contributing to the broader community include the program on Nonlinear Airframe Dynamics that industry may use to address the continuing problem of preventing tail wag in rotorcraft. The Coaxial Rotor Modeling effort, while in its early stage of development, was noted as being important to the Joint Heavy Lift work currently underway. In the Engine and Transmission Systems area, selective parts of the work are considered to have direct and immediate application to existing systems, and they are making a significant contribution to the design database. Much of the high-temperature material work being done by VTD personnel at the NASA-Glenn Center is considered by the Board to be unique and important, and this important work is not being pursued in industry or academia.

CROSSCUTTING ISSUES OF RELEVANCE TO THE DIRECTORATE

The Board notes that the VTD is exploring new avenues of crosscutting work as part of its strategic planning in response to the BRAC action. There are excellent examples of information transfer and cooperation between the VTD, industry, and academia, and there are other cases in which the work may be categorized as introspective and insular. Specifically, it is noted that several researchers did not seem to be aware of work in their fields that was underway at other research institutes and in industry. The VTD is staffed with capable people, who, in some cases, would benefit from broader exposure to others working in their fields or in similar fields.

7

Weapons and Materials Research Directorate

INTRODUCTION

The Weapons and Materials Research Directorate (WMRD) was reviewed by the Panel on Armor and Armaments, which met during June 7-9, 2005, and June 5-7, 2006. The theme of the 2005 review was research and development related to lethality, and for 2006 the theme was R&D related to survivability.

WMRD contains three divisions that are reviewed by the Panel: Materials; Terminal Effects; and Ballistics and Weapons Concepts. In addition, the Army Research Laboratory's (ARL's) Robotics Program Office, acting as the principal point of contact within the Army technology base community to the Department of Defense's (DoD's) Joint Ground Robotics Enterprise (JGRE, formerly the Joint Robotics Program), is located in the Office of the WMRD Director. WMRD also provides technical support to the Army Electromagnetic Gun Program Office, which is managed under the auspices of the ARL Director. WMRD also is responsible for the Robotics Collaborative Technology Alliance (CTA), which was extended by 3 years from the original 5-year program to run through fiscal year 2009. Tables A.1 and A.2 in Appendix A show the funding profile and the staffing profile for WMRD.

CHANGES SINCE THE LAST REVIEW

During the current review period, the leadership of the WMRD and the Panel focused specifically on the area of computational science and modeling, which constitutes a significant thrust that cuts across many WMRD projects. The ongoing dialogue has resulted in greater use of effective modeling and simulation in the 2006 programs than was seen in the previous year, and more effort toward validation with experimentation was seen as well.

ACCOMPLISHMENTS AND OPPORTUNITIES

Most Significant Advances

The effort on electromagnetic armor will, without doubt, not only define the future direction of active protection systems (APS) for the Army, but should also define a paradigm for how WMRD should focus its R&D efforts. As to the future direction of APS, the emphasis on electric-power-based kinetic energy (KE) mitigation and electromagnet armor (EMA) ushers in new and novel approaches to vehicle protection, which in the future will be merged with hybrid vehicles (and perhaps electromagnetic rail guns) to form powerful electrical-energy-based fighting systems. As to an R&D paradigm, the excellent quality and promise of the work described provide a clear demonstration of how long-term investments made at WMRD in the past in fundamental work (on modeling and simulation, for example) are now having an impact on the design of new solutions to challenging Army problems.

Opportunities and Challenges

The collection of work presented at the 2005 and 2006 reviews is of very high quality, but it is in the area of armor protection (survivability) that WMRD shines most brightly. Across all the technology areas reviewed, the long-term investments made in modeling and simulation are now paying off. Of course, modeling and simulation are not activities that exist as stand-alone entities; in order to be successful, advances in modeling and simulation must go hand in hand with, and be in agreement with, experimental results, or even lead them. This, in turn, requires a multidisciplinary approach, wherein physicists, materials scientists, and computational experts all converge to address identifiable high-payoff technology areas of interest to the Army. Such a convergence has led to the excellent advances obtained in many of the areas covered in these reviews, but it is most evident perhaps in the area of KE mitigation and EMA.

The high quality of the work and the potential payoffs to the Army are the result of historical investments in basic research that have attracted good scientists and made possible the ongoing transition from heavy armor to the next generation of lighter-weight armor, which is more suitable to emerging vehicles. Such a paradigm (which includes a basic research investment, the hiring and promotion of good scientists, and a multidisciplinary approach to problem solving) is now paying off and should continue to be the R&D paradigm of the future for WMRD. The Board strongly encourages WMRD to continue and increase such investments.

RESEARCH ASSESSMENT

Methodology

Judged against efforts at universities or at national laboratories, the WMRD work appears somewhat lacking in the basic research area. If, however, WMRD is judged for its mission as an engineering and applied science facility that supplies the Army with technological solutions that would be difficult to find elsewhere, then it is succeeding. The work is focused on solving practical problems of interest and importance to the Army, and it definitely is of relevance to the soldier in the field. The morale, enthusiasm, and competence of the WMRD staff seem generally good.

The particular research problems that the WMRD team has presented are clearly ones that have benefited from theoretical modeling at an appropriate level of sophistication and will continue to do so in the future. In particular, the use of theoretical modeling for filling in important gaps in structure and mechanistic details and for validation purposes constitutes an important endeavor. However, in some cases the caliber of such modeling fell somewhat short of that needed to be a reliable tool for prediction. While commendable, the computational effort would benefit in some areas from mentoring by an experienced theoretical/computational scientist who could offer critical evaluation and guidance in key areas and high-level scope. Moreover, a distinction needs to be made between computing for engineering purposes (designing a widget) and scientific purposes (better understanding of the physics or chemistry of the problem); ARL does a fine job in the former area and falls short in the latter area. Continuing the review of the application of computational science, as applied to the complex and demanding ARL problems, would be of great benefit in advancing the overall capabilities of the directorate.

Contributions to Army Needs

A consideration in reviewing WMRD's work is that the work being reported will, if all goes well in the R&D effort, be of benefit in addressing Army needs and be technically worthwhile. In a few cases, the Board concluded that the programs had little chance of providing such benefits, and where ARL management perceives such cases, it should consider redirecting or terminating the efforts. For example, the Lightweight Cartridge Case effort has shown few positive results, and its currently planned efforts should be reexamined. The Board also had reservations about the viability of the Ceramic Gun program, which has suffered from some severe technical problems related to rifling and the inability to make long ceramic tubes with sufficient straightness to be viable.

Otherwise, the programs were well directed toward Army needs, and most of them, if successful technically, could provide important contributions. The Board is particularly impressed with the potential of the following:

- *Electromagnetic Armor and KE Threat Mitigation*—This program is a multidisciplinary effort that will define the future direction of active protection for the Army. The cooperative effort with Sandia National Laboratories is to be encouraged, and the Arbitrary-Lagrangian-Eulerian General Research Applications (ALEGRA)—large-deformation shock physics code developed at Sandia) and ARL electromagnetic studies highlight the success of using modeling in collaboration with insightful experimentation to advance a technology of great potential to the Army.
- *Dynamic Damage in Armor Ceramics*—This program highlights one of the great strengths and successes at ARL over the past few years in the theoretical understanding of armor defeat through its computational modeling and simulation as well as its experimental validation. The progress in this area has been one of the most impressive contributions from WMRD and should demonstrate the reason why basic research is necessary to make significant progress in areas of great importance to the Army.
- *Crew and Component Protection Program*—This program has a number of short-term accomplishments to its credit, including (1) mine survival kits, (2) improved crew seats, and (3) Stryker shields. The Board suggests that further emphasis is needed in the area of remote detection of explosives and constitutive modeling of blast from explosives in a nonreactive matrix (e.g., soil, street materials, concrete), all related to the improvised explosive device problem.
- *Smart Projectiles*—This is clearly an ARL success story. It is a fairly mature technology, in which various partners have played a major role. Although it has been difficult to distinguish what was done by ARL and what was done by its partners, the Board notes that effective partnering is one metric of success.

- *Terminal Effects*—With the current emphasis on defeating the enemy in urban warfare, this effort has the objective of developing multifunctional warheads with improved precision to provide the warfighter with flexibility while minimizing collateral damage.
- *Energetic Materials*—This program is focused on responding to Army needs for higher-energy and lower-sensitivity energetics that are also inexpensive and environmentally acceptable. The approaches were derived, in part, from a strategic plan formulated by the national community in energetic materials and include efforts in computational chemistry and application of a wide range of analytical diagnostic methods to characterize the properties and performance of the materials. WMRD has a long and distinguished record in the diagnostics area, and it competes favorably with rival institutions; the effort in computational modeling of energetic molecules falls short of the state of the art and needs a critical evaluation.

Contributions to the Broader Community

Basic research is critical and fundamental to the ability of ARL to address future Army needs. On behalf of maintaining an adequately robust basic research program, WMRD should undertake a thorough investigation of current and emerging programs to identify limitations of knowledge and its ability to investigate and solve current and future problems of Army interest. Once these are identified, the directorate should develop a strategy and path forward for basic and applied research efforts to address limitations, enhance fundamental knowledge, and exploit innovative findings. Many of the areas that will be identified are likely to be applicable across a large number of technology areas; therefore, there will be high payoff in the short term, and WMRD will be provided with an improved technology base to solve Army problems in the future.

CROSSCUTTING ISSUES OF RELEVANCE TO THE DIRECTORATE

Virtually every program reviewed in 2005 and 2006 uses and benefits from the computational modeling and simulation capabilities at ARL. During the 2005 review, the Panel noted that a number of programs were limited by inadequacies in their software models and simulation techniques and identified codes and software packages that could be made available to ARL. The WMRD Director took note of these comments, and significant improvements have been made in the way the crosscutting technology of computational science, modeling, and simulation is employed.

Appendixes

Appendix A

Army Research Laboratory Organization Chart, Resources, and Staffing Profile

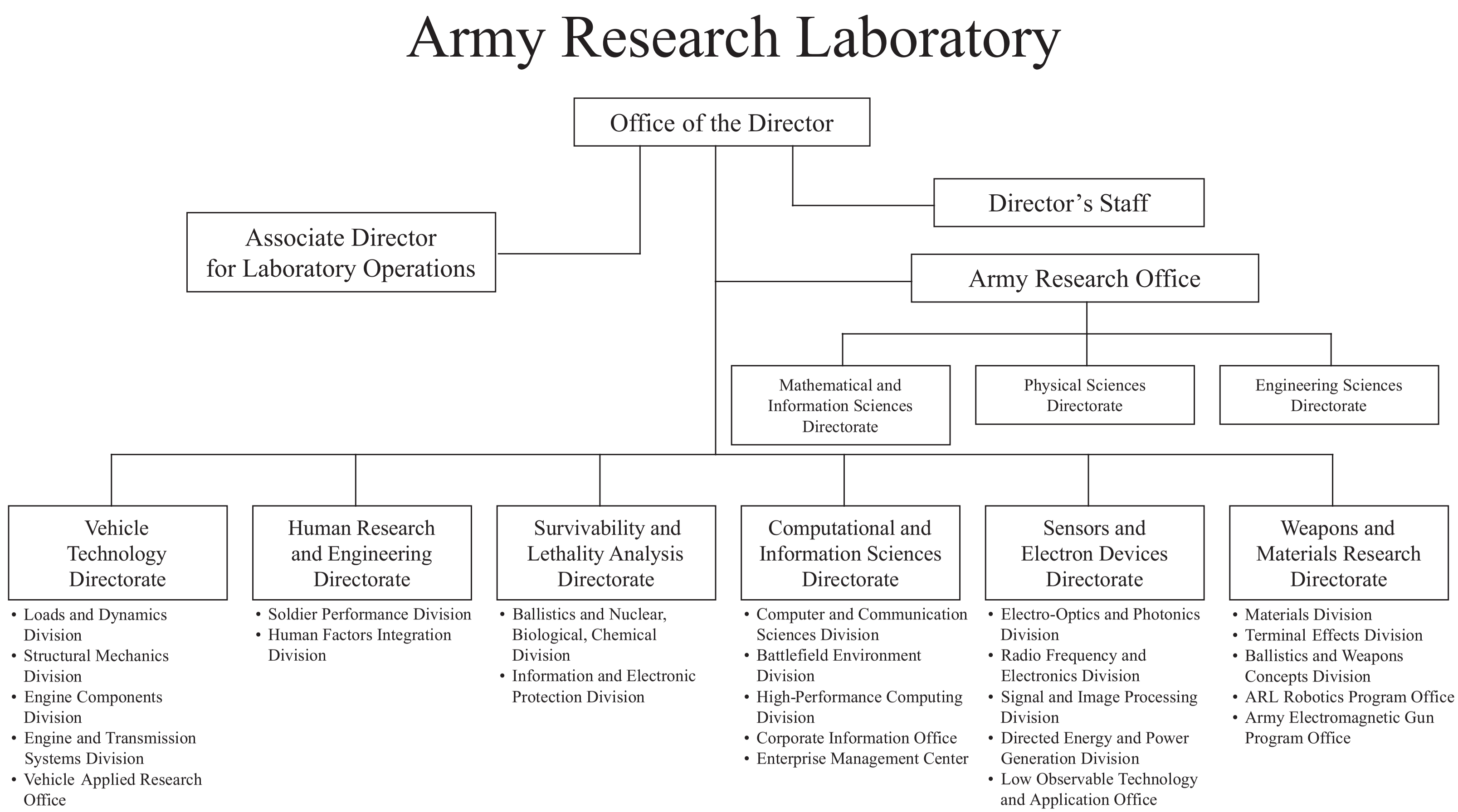

FIGURE 1.1 Army Research Laboratory organization chart.

TABLE A.1 Resources: Army Research Laboratory Funding by Directorate, Fiscal Year 2003 Through Fiscal Year 2006 (millions of dollars)

		Technical Unit					
Type of Funding		CISD	HRED	SEDD	SLAD	VTD	WMRD
6.1	FY03	15.3	2.6	9.7	0.0	4.0	22.3
	FY04	13.2	2.6	20.5	0.0	3.5	20.0
	FY05	10.3	2.8	8.5	0.0	3.7	22.2
	FY06	9.6	2.7	8.4	0.0	3.7	23.3
6.1[a]	FY03	0.0	0.0	0.0	0.0	0.0	0.0
	FY04	0.0	0.0	0.0	0.0	0.0	0.0
	FY05	7.1	0.0	0.0	0.0	0.0	0.0
	FY06	9.8	0.0	0.0	0.0	0.0	0.0
6.1[b]	FY03	7.5	5.7	11.4	0.0	0.0	0.0
	FY04	7.9	6.0	11.9	0.0	0.0	2.4
	FY05	7.7	5.8	12.5	0.0	0.0	2.4
	FY06	11.6	5.4	9.8	0.0	0.0	2.4
6.1[c]	FY03	0.0	0.0	0.0	0.0	0.0	0.0
	FY04	0.0	0.0	0.0	0.0	0.0	0.0
	FY05	0.0	0.0	19.4	0.0	0.0	0.0
	FY06	0.0	0.0	16.7	0.0	0.0	0.0
6.2	FY03	17.9	19.6	51.4	6.8	4.5	83.1
	FY04	16.8	23.7	62.3	6.5	4.5	82.7
	FY05	13.5	16.7	56.7	7.0	4.7	88.2
	FY06	13.0	16.6	57.3	6.7	4.8	71.0
6.2[d]	FY03	0.0	0.0	0.0	0.0	0.0	0.0
	FY04	0.0	0.0	0.0	0.0	0.0	0.0
	FY05	4.2	0.0	0.0	0.0	0.0	0.0
	FY06	3.7	0.0	0.0	0.0	0.0	0.0
6.2[e]	FY03	0.0	0.0	0.0	0.0	0.0	5.4
	FY04	0.0	0.0	0.0	0.0	0.0	7.5
	FY05	0.0	0.0	0.0	0.0	0.0	8.0
	FY06	0.0	0.0	0.0	0.0	0.0	8.0
6.2[f]	FY03	0.0	0.0	0.0	0.0	0.0	0.0
	FY04	0.0	0.0	0.0	0.0	0.0	0.0
	FY05	0.0	0.0	41.1	0.0	0.0	0.0
	FY06	0.0	0.0	31.9	0.0	0.0	0.0
6.3/6.4/6.7	FY03	6.9	0.2	0.0	0.1	0.0	12.8
	FY04	0.0	0.0	7.2	1.0	0.0	14.5
	FY05	3.0	0.2	4.8	0.0	0.0	12.2
	FY06	0.0	0.7	6.4	0.0	0.0	20.8

continued

TABLE A.1 Continued

Type of Funding		Technical Unit					
		CISD	HRED	SEDD	SLAD	VTD	WMRD
6.3/6.4/6.7[g]	FY03	0.0	0.0	0.0	0.0	0.0	0.0
	FY04	0.0	0.0	0.0	0.0	0.0	0.0
	FY05	2.9	0.0	0.0	0.0	0.0	0.0
	FY06	0.0	0.0	0.0	0.0	0.0	0.0
6.6[h]	FY03	0.0	0.0	0.0	34.3	0.0	0.0
	FY04	0.0	0.0	0.0	40.2	0.0	0.0
	FY05	0.0	0.0	0.0	44.1	0.0	0.0
	FY06	0.0	0.0	0.0	40.0	0.0	0.0
6.6[i]	FY03	2.7	3.1	0.0	0.0	0.0	0.2
	FY04	0.1	3.0	0.0	0.0	0.0	0.0
	FY05	0.0	2.7	0.0	0.0	0.0	0.0
	FY06	0.0	2.5	0.0	0.0	0.0	0.0
Customer Reimbursement[j]	FY03	28.6	7.9	22.7	15.4	1.0	45.5
	FY04	12.9	7.7	36.4	17.7	1.4	44.5
	FY05	17.2	8.9	78.2	71.1	1.2	63.3
	FY06	22.1	9.2	70.9	53.7	2.2	53.6
Customer Direct Citation[k]	FY03	6.8	16.7	15.9	3.5	0.0	4.8
	FY04	5.3	0.3	17.8	10.3	0.0	5.7
	FY05	7.8	1.0	27.1	74.0	0.0	22.1
	FY06	10.3	1.0	81.7	41.5	0.0	20.1
MTO[l]	FY03	0.0	0.0	0.0	0.0	0.0	0.0
	FY04	0.0	0.0	0.0	0.0	0.0	0.0
	FY05	0.0	0.0	9.5	0.0	0.0	0.0
	FY06	0.0	0.0	11.4	0.0	0.0	0.0
OMA[m]	FY03	7.4	0.0	0.0	0.0	0.0	0.5
	FY04	0.6	0.0	0.0	0.0	0.0	1.9
	FY05	0.5	0.0	0.0	0.0	0.0	0.5
	FY06	0.5	0.0	24.6	0.0	0.0	0.6
OSD[n]	FY03	1.8	0.0	2.4	0.0	0.0	0.4
	FY04	18.8	0.0	0.0	0.0	0.0	0.0
	FY05	0.0	0.0	0.0	0.0	0.0	0.0
	FY06	0.4	0.0	23.6	0.0	0.0	0.0
DARPA[o]	FY03	1.5	0.1	44.9	0.2	0.0	2.9
	FY04	1.1	0.0	44.4	0.1	0.0	2.8
	FY05	2.4	0.8	75.7	0.0	0.0	2.0
	FY06	2.7	1.1	60.0	0.0	0.0	1.3
MSRC/HPC[p]	FY03	64.3	0.0	0.0	0.0	0.0	0.0
	FY04	57.7	0.0	0.0	0.0	0.0	0.0
	FY05	55.4	0.0	0.0	0.0	0.0	0.0
	FY06	53.5	0.0	0.0	0.0	0.0	0.0

TABLE A.1 Continued

Type of Funding		Technical Unit CISD	HRED	SEDD	SLAD	VTD	WMRD
MSRC/HPC[q]	FY03	0.0	0.0	0.0	0.0	0.0	0.0
	FY04	0.0	0.0	0.0	0.0	0.0	0.0
	FY05	15.0	0.0	0.0	0.0	0.0	0.0
	FY06	12.2	0.0	0.0	0.0	0.0	0.0
Total	FY03	160.7	55.9	158.4	60.3	9.5	177.9
	FY04	134.4	43.3	200.5	75.8	9.4	182.0
	FY05	144.1	38.9	333.5	122.2	9.6	221.0
	FY06	149.4	39.2	402.7	100.4	10.7	201.1

[a]6.1 Congressional Funding.

[b]6.1 Collaborative Technology Alliances. CISD FY06 includes the Network Sciences International Technology Alliance ($4.8 million).

[c]6.1 Collaborative Technology Alliances Congressional Funding.

[d]6.2 Congressional Funding.

[e]6.2 Collaborative Technology Alliances.

[f]6.2 Collaborative Technology Alliances Congressional Funding.

[g]6.3/6.4/6.7 Congressional Funding.

[h]6.6 Technology Analysis (SLAD, Small Business Innovation Research/Small Business Technology Transfer, Field Assistance in Science and Technology, Board of Army Science and Technology, Soldier Centered Analysis, and PE 65803 [Technical Information Activities]).

[i]6.6 Management Support (Base Support).

[j]Reimbursement from customers.

[k]Direct citation of funds from customers.

[l]Microelectronics Technology Office (DARPA).

[m]Operation and Maintenance, Army.

[n]Office of the Secretary of Defense.

[o]Defense Advanced Research Projects Agency.

[p]Major Shared Resource Center and High Performance Computing (includes Mission, OSD, and Customer Reimbursable).

[q]Major Shared Resource Center and High Performance Computing Congressional Funding.

TABLE A.2 Army Research Laboratory Staffing Profile by Directorate (as of July 2006)

Staffing Information		Number [%]					
		CISD	HRED	SEDD	SLAD	VTD	WMRD
Total civilian staff	Dec-04	313	217	376	294	84	403
	Jul-06	302	208	330	305	73	419
Scientists and engineers	Dec-04	200 [64%]	162 [75%]	297 [79%]	236 [80%]	61 [73%]	282 [70%]
	Jul-06	188 [62%]	149 [72%]	272 [82%]	243 [80%]	50 [68%]	294 [70%]
Technicians	Dec-04	16 [5%]	11 [5%]	46 [12%]	32 [11%]	11 [13%]	89 [22%]
	Jul-06	14 [5%]	16 [8%]	28 [9%]	32 [10%]	12 [17%]	89 [21%]
Administrative personnel	Dec-04	97 [31%]	44 [20%]	33 [9%]	26 [9%]	12 [14%]	32 [8%]
	Jul-06	100 [33%]	43 [20%]	30 [9%]	30 [10%]	11 [15%]	36 [9%]
Other personnel							
Military personnel	Dec-04	6	3	4	15	5	5
	Jul-06	4	5	4	11	2	6
Postdoctoral researchers	Dec-04	1	1	4	0	1	0
	Jul-06	0	1	17	0	0	8
Guest researchers	Dec-04	2	3	11	0	0	0
	Jul-06	36	2	24	0	0	17
On-site contractors	Dec-04	286	1	61	80	0	133
	Jul-06	260	3	65	123	0	214
Scientists and engineers: Education							
B.S. or B.A.	Dec-04	80 [40%]	64 [40%]	85 [29%]	136 [58%]	23 [38%]	101 [36%]
	Jul-06	58 [31%]	35 [23%]	52 [19%]	121 [50%]	9 [18%]	87 [30%][a]
M.S. or M.A.	Dec-04	69 [35%]	51 [31%]	97 [32%]	78 [33%]	16 [26%]	62 [22%]
	Jul-06	81 [43%]	68 [46%]	99 [37%]	100 [41%]	21 [42%]	63 [21%][a]
Ph.D.	Dec-04	51 [25%]	47 [29%]	115 [39%]	22 [9%]	22 [36%]	119 [42%]
	Jul-06	49 [26%]	46 [31%]	120 [44%]	22 [9%]	20 [40%]	144 [49%]

TABLE A.2 Continued

Staffing Information		Number [%]					
		CISD	HRED	SEDD	SLAD	VTD	WMRD
Scientists and engineers: Ages							
Under 25	Dec-04	11 [6%]	14 [9%]	8 [3%]	19 [8%]	0	8 [3%]
	Jul-06	5 [3%]	7 [5%]	9 [3%]	12 [5%]	0	7 [2%]
25-35	Dec-04	19 [10%]	25 [15%]	33 [11%]	18 [8%]	7 [12%]	48 [17%]
	Jul-06	24 [13%]	25 [17%]	34 [13%]	39 [16%]	6 [8%]	39 [13%]
35-45	Dec-04	63 [31%]	36 [22%]	112 [38%]	82 [35%]	28 [46%]	97 [34%]
	Jul-06	48 [26%]	35 [23%]	87 [32%]	72 [30%]	22 [30%]	98 [33%]
45-55	Dec-04	65 [32%]	53 [33%]	81 [27%]	65 [27%]	14 [23%]	74 [26%]
	Jul-06	65 [35%]	46 [31%]	86 [32%]	76 [31%]	31 [43%]	78 [27%]
55-65	Dec-04	36 [18%]	28 [17%]	52 [17%]	42 [18%]	10 [16%]	50 [18%]
	Jul-06	39 [21%]	30 [20%]	44 [16%]	36 [15%]	13 [18%]	66 [22%]
Over 65	Dec-04	6 [3%]	6 [4%]	11 [4%]	10 [4%]	2 [3%]	5 [2%]
	Jul-06	7 [4%]	6 [4%]	12 [4%]	8 [3%]	1 [1%]	6 [2%]

NOTE:
CISD—Computational and Information Sciences Directorate
HRED—Human Research and Engineering Directorate
SEDD—Sensors and Electron Devices Directorate
SLAD—Survivability and Lethality Analysis Directorate
VTD—Vehicle Technology Directorate
WMRD—Weapons and Materials Research Directorate
[a]Estimate.
SOURCE: Army Research Laboratory.

Appendix B

Membership of the Army Research Laboratory Technical Assessment Board and Its Panels

ARMY RESEARCH LABORATORY TECHNICAL ASSESSMENT BOARD AND PANELS

Air and Ground Vehicle Technology Panel
(reviews VTD)

S. Michael Hudson, *Chair**
Roy Battles
Julie Chen
Alan Epstein
Charbel Farhat
Awatef Hamed
Larry Lynn
Thomas Mueller
Sia Nemat-Nasser
Kenneth Reifsnider
Christine Sloane
Michael S. Torok
Douglas Valenzuela

Armor and Armaments Panel
(reviews WMRD)

John D. Venables, *Chair**
Charles E. Anderson, Jr.
Melvin R. Baer
Kim K. Baldridge*
Thomas B. Brill
Rodney J. Clifton
Phillip Colella*
George T. Gray III
Rigoberto Hernandez
Larry G. Hill
Lynne E. Parker
Kenneth S. Vecchio
Francis W. Zok

Digitization and Communications Science Panel
(reviews CISD)

Peter M. Kogge, *Chair**
Nina M. Berry
Donald M. Chiarulli
Phillip Colella*
Lori Freitag Diachin
Jonathan P. Dowling
Joel S. Engel
Joseph Y. Halpern
Bruce B. Hicks
Frank A. Horrigan
Steven L. Mullen
Jim K. Omura
Daniel A. Reed
Alan B. Salisbury
Dennis W. Thomson*
David Waltz
Eli Yablonovitch

ARL Technical Assessment Board

Robert W. Brodersen, *Chair*
Kim K. Baldridge
Phillip Colella
Douglas H. Harris
Alfred O. Hero
S. Michael Hudson
Peter M. Kogge
John C. Sommerer
Dwight C. Streit
Dennis W. Thomson
John D. Venables

Sensors and Electron Devices Panel
(reviews SEDD)

Dwight C. Streit, *Chair**
Ilesanmi Adesida
Henry E. Bass
Robert W. Brodersen*
Elton J. Cairns
L. Richard Carley
Arthur H. Guenther
Alfred O. Hero*
Narain G. Hingorani
Linda P.B. Katehi
Leslie A. Kolodziejski
Timothy N. Krabach
David C. Munson, Jr.
Zoya Popovic
P. Paul Ruden

Soldier Systems Panel
(reviews HRED)

Douglas H. Harris, *Chair**
Donald B. Chaffin
Dennis G. Faust
Robert A. Henning
John D. Lee
Eric R. Muth
Virginia Richards
Frank E. Ritter
Jeremy Wolfe

Survivability and Lethality Analysis Panel
(reviews SLAD)

John C. Sommerer, *Chair**
Romesh C. Batra
Thomas K. Burris
John D. Christie
MarjorieAnn EricksonKirk
Alan K. Jones
Melvin F. Kanninen
John McHugh
Max D. Morris
Hilarie K. Orman
Thomas J. Peters
Stephen M. Pollock
John Reese
Fritz Steudel
Jack L. Walker
Donald C. Wunsch

* ARLTAB Member.

FIGURE B.1 Army Reaearch Laboratory Technical Assessment Board and Panels, 2006.

BIOGRAPHICAL SKETCHES OF BOARD MEMBERS

ROBERT W. BRODERSEN, *Chair*, is a member of the National Academy of Engineering, the John Whinnery Chair Professor in the Electrical Engineering and Computer Science Department at the University of California, Berkeley, and co-scientific director of the Berkeley Wireless Research Center. His expertise is in solid-state circuitry and microelectronics, and his current research is in new applications of integrated circuits focused on the areas of low-power design and wireless communications and the CAD tools necessary to support these activities. He is a fellow of the Institute of Electrical and Electronics Engineers (IEEE), and has received numerous prestigious awards throughout his career. Professor Brodersen received his Ph.D. in electrical engineering from the Massachusetts Institute of Technology.

KIM K. BALDRIDGE is director of computational applications and professor of theoretical chemistry at the University of Zurich, Switzerland. She additionally holds a distinguished scientist position at the San Diego Supercomputer Center and adjunct professorship in the Department of Chemistry at the University of California, San Diego. Her expertise covers a wide area of computational chemistry, including direct application of quantum chemical software; development of new quantum chemical algorithms; and development of visualization, middleware, database, and analysis tools for adaptation of computational chemistry and biochemistry applications to grid environments. Dr. Baldridge is a fellow of the American Physical Society and of the American Association for the Advancement of Science. She is a coauthor of a major computational chemistry software package used worldwide, and has a publication list of 120 research articles.

PHILLIP COLELLA is a senior mathematician and group leader of the applied numerical algorithms group in the Computational Research Division at the Lawrence Berkeley National Laboratory. His expertise is in numerical methods for partial differential equations and their application to science and engineering problems. He is a recipient of the IEEE Computer Society's Sidney Fernbach Award (1998) and the SIAM/ACM prize in computational science (2003), and is a member of the National Academy of Sciences (2004). Dr. Colella is also a current member of the Armor and Armaments Panel and the Digitization and Communications Science Panel.

CLIVE L. DYM (Board member in 2005) is the Fletcher Jones Professor of Engineering Design and director of the Center for Design Education at Harvey Mudd College. His primary interests are in engineering design and structural mechanics. After receiving the Ph.D. from Stanford University, Dr. Dym held appointments at the University at Buffalo; the Institute for Defense Analyses; Carnegie Mellon University; Bolt, Beranek and Newman; and the University of Massachusetts at Amherst. He was also head of his department at UMass (1977-1985) and chair of his department at Harvey Mudd (1999-2002). Dr. Dym has held visiting appointments at the TECHNION-Israel Institute of Technology, the Institute for Sound and Vibration Research at Southampton, Stanford, Xerox PARC, Carnegie Mellon, Northwestern, and the University of Southern California. He has authored or coauthored 10 books and more than 100 archival publications and technical reports. Dr. Dym was founding editor of the journal *Artificial Intelligence for Engineering Design, Analysis, and Manufacturing*, and is currently associate editor of ASME's *Journal of Mechanical Design*. Dr. Dym's awards include the Walter L. Huber Research Prize (ASCE, 1980), the Boeing Outstanding Educator Award (first runner-up, 2001), the Fred Merryfield Design Award (ASEE, 2002), the Joel and Ruth Spira Outstanding Design Educator Award (ASME, 2004), and the Archie Higdon Distinguished Educator Award (Mechanics Division, ASEE, 2006).

DOUGLAS H. HARRIS is chairman and principal scientist of Anacapa Sciences, a company that he formed in 1969 to improve human performance in complex systems and organizations. His principal contributions have been in the areas of inspection, investigation, intelligence, and maintenance performance. Dr. Harris is a past president of the Human Factors and Ergonomics Society, a past chair of the National Research Council (NRC) Committee on Human Factors, and past member of the NRC Committee on Commercial Aviation Security. He was an author of the first volume of the Wiley Series in Human Factors (*Human Factors and Quality Assurance*) and was chair of an NRC panel that produced the book *Organizational Linkages: Understanding the Productivity Paradox*. As an officer in the U.S. Navy, he completed underwater demolition training and served as the operations and training officer of an underwater demolition team.

ALFRED O. HERO is a professor in the Department of Electrical Engineering and Computer Science, the Department of Biomedical Engineering, and the Department of Statistics at the University of Michigan. His expertise includes statistical signal and image processing, detection and estimation theory, adaptive sensor networks, bioinformatics, and tomographical imaging. He has held visiting positions at the Massachusetts Institute of Technology, University of Nice, Ecole Normale Supérieure de Lyon, Ecole Nationale Supérieure des Télécommunications, Scientific Research Labs of the Ford Motor Company, Ecole Nationale des Techniques Avancées, Ecole Supérieure d'Electricité, Lucent Bell Laboratories, and MIT Lincoln Laboratory. In addition, throughout his career, Dr. Hero has served the IEEE in various leadership roles and has received a number of prestigious honors, awards, and fellowships, including an IEEE Signal Processing Society Meritorious Service Award and the IEEE Third Millennium Medal. He is a fellow of the IEEE and was named a William Clay Ford Fellow by Ford Motor Company in 1992. He was chair of USNC URSI Commission C and is president of the IEEE Signal Processing Society. He received his Ph.D. in electrical engineering from Princeton University.

S. MICHAEL HUDSON retired in 2002 from the position of vice chairman of Rolls-Royce North America. After Allison Engine Company was acquired by Rolls-Royce, Mr. Hudson served as president, chief executive officer, chief operating officer, and as a member of the board of directors of Allison Engine Company. Previously, during his tenure at Allison, he served as executive vice president for engineering, chief engineer for advanced technology engines, chief engineer for small production engines, supervisor of the design for Model 250 engines, and chief of preliminary design and chief project engineer in vehicular gas turbines. Mr. Hudson recently acquired a company involved in the development and manufacture of alternative energy and cogeneration products. He is a member of the NRC's Aeronautics and Space Engineering Board and has served as a member of several of its committees.

PETER M. KOGGE is associate dean of engineering for research and also holds the McCourtney Chair in Computer Science and Engineering (CSE) at the University of Notre Dame. Prior to his joining Notre Dame in 1994, he was with IBM Federal Systems Division, and was appointed an IEEE fellow in 1990 and an IBM fellow in 1993. In 1977, he was a visiting professor in the Electrical and Computer Engineering Department at the University of Massachusetts, Amherst. From 1977 through 1994, he was also an adjunct professor in the Computer Science Department of the State University of New York at Binghamton. Since the summer of 1997, he has been a distinguished visiting scientist at the Center for Integrated Space Microsystems at the Jet Propulsion Laboratory. He is also the Research Thrust Leader for Architecture in Notre Dame's Center for Nano Science and Technology. For the 2000-2001 academic year, he was the interim Schubmehl-Prein Chairman of the CSE Department at Notre Dame. Since the fall of 2003, he has also been a concurrent professor of electrical engineering. His research interests are in advanced computer architectures using unconventional technologies, such as "Processing-in-Memory," and nanotechnologies, such as Quantum Dot Cellular Automata (QCA).

JOHN C. SOMMERER is director of science and technology and chief technology officer of the Johns Hopkins University Applied Physics Laboratory (JHU/APL). He manages APL's overall R&D program, and oversees APL's technology transfer program, its participation in JHU education programs, and serves as primary technical liaison with the academic divisions of the university. In addition, he is an adjunct faculty member in applied physics, applied mathematics, and technical management. Dr. Sommerer has made internationally recognized theoretical and experimental contributions to the fields of non-linear dynamics and complex systems. He has served on several technical advisory bodies for the U.S. government, including his current assignment as vice chair of the Naval Research Advisory Council, the senior technical advisory body to the Secretary of the Navy, the Chief of Naval Operations, and the Commandant of the Marine Corps. He holds a Ph.D. in physics from the University of Maryland.

DWIGHT C. STREIT is a member of the National Academy of Engineering and vice president, foundation technologies at Northrop Grumman Space Technology. He has overall responsibility for development of the basic engineering, science, and technology required for space and communication systems. He has extensive experience in semiconductor devices and Monolithic Microwave Integrated Circuits for applications up to 220 gigahertz, as well as in infrared and radiometer sensors. He has led development efforts for 10-40 gigabit-per-second optical communication systems, and has experience in the development and production of opto-electronic devices and circuits. He also has previous experience in frequency-modulated continuous wave and phased-array product development for X-band to W-band radar applications. He received his Ph.D. in electrical engineering from the University of California, Los Angeles, in 1986.

DENNIS W. THOMSON is a professor and former department head in the Department of Meteorology at Pennsylvania State University. His expertise is in atmospheric physics and remote sensing, and his major research interests are atmospheric electromagnetic and acoustic propagation phenomena, remote sensing of winds and turbulence, atmospheric sounds and noise propagation, micrometeorology, and defense technology and policy. Dr. Thomson has received a number of prestigious awards; he is a fellow of the American Meteorological Society (AMS), and a former Intergovernmental Personnel Act (IPA) fellow to the Office of Naval Research. Other off-campus assignments for Dr. Thomson, on Penn State's faculty for more than 36 years, include Risoe National Laboratory, Denmark, and the Naval Postgraduate School. His national science community responsibilities have included a term as trustee of the University Corporation for Atmospheric Research, a number of DoD oversight and advisory committees, and extended service to Argonne National Laboratory and Lawrence Livermore National Laboratory. He is a multidegree graduate in physics and meteorology (Ph.D.) of the University of Wisconsin.

JOHN D. VENABLES received his Ph.D. in physics from the University of Warwick, England, and until his retirement he served as associate director and chief scientist at Martin Marietta Labs in Baltimore, Maryland. He has served on numerous study committees of the National Academies and was a member for 6 years of the Board on Army Science and Technology. He is a coauthor of an entry in the *Encyclopedia Britannica*, "Materials Science," and is currently a consultant for DARPA/DSO through Strategic Analysis Inc.

Staff

JAMES P. McGEE is the director of the Army Research Laboratory Technical Assessment Board (ARLTAB) and the Board on Assessment of National Institute of Standards and Technology Programs, within the Division on Engineering and Physical Sciences at the National Research Council. Since 1994, he has been a senior staff officer at the National Research Council, directing projects in the areas of systems engineering and applied psychology, including the Panel on Soldier Systems for the Army Research Laboratory Technical Assessment Board; the Committee on National Statistics' Panel on Operational Testing and Evaluation of the Stryker Vehicle and its Committee on Assessing the National Science Foundation's (NSF's) Scientists and Engineers Statistical Data System; the Committee on the Health and Safety Needs of Older Workers; and the Steering Committee on Differential Susceptibility of Older Persons to Environmental Hazards. He has also served as staff officer for NRC projects on Air Traffic Control Automation, Musculoskeletal Disorders and the Workplace, and The Changing Nature of Work. Prior to joining the NRC, he held technical and management positions in systems engineering and applied psychology at IBM, General Electric, RCA, General Dynamics, and United Technologies corporations. He received his B.A. from Princeton University and his Ph.D. from Fordham University, both in psychology, and for several years taught postsecondary courses in applied psychology and in organizational management.

CY L. BUTNER is a senior program officer with the ARL Technical Assessment Board. Shortly after joining the NRC in 1997, he moved from the Aeronautics and Space Engineering Board to his current appointment. Before joining the NRC, Mr. Butner served as an independent consultant to the Aeronautics and Space Engineering Board for 2 years, during which time he supported an ongoing peer review process for Air Force Office of Scientific Research proposals, and several reports on topics related to space and aeronautics programs. From 1985 until 1994, Mr. Butner worked with two aerospace consulting firms, where he supported space and aeronautics technology development programs at NASA Headquarters. Before that, he worked for RCA as a satellite solar array engineer, for NASA at the Goddard Space Flight Center as a science coop student and a materials engineer, and for the New Mexico Environmental Improvement Agency as a statistician. Mr. Butner has B.S. and M.S. degrees in physics from the American University and a B.S. degree in mathematics from the University of New Mexico.

RADHIKA S. CHARI was the administrative coordinator for the Army Research Laboratory Technical Assessment Board and the Board on Assessment of National Institute of Standards and Technology Programs of the National Research Council through July 2006. She then moved to the National Research Council's Computer Science and Telecommunications Board. Ms. Chari received her B.A. degree in philosophy from Fordham University.

PANEL ROSTERS

Air and Ground Vehicle Technology Panel

S. Michael Hudson, Rolls-Royce North America (retired), *Chair*
Roy Battles, Bell Helicopter TEXTRON Inc.
Julie Chen, University of Massachusetts, Lowell
Clive L. Dym,* Harvey Mudd College
Alan H. Epstein, Massachusetts Institute of Technology
Charbel H. Farhat, Stanford University
Awatef Hamed, University of Cincinnati
Verne L. ("Larry") Lynn, Director, Defense Advanced Research Projects Agency (retired)
Thomas J. Mueller, Professor Emeritus, University of Notre Dame
Sia Nemat-Nasser, University of California, San Diego
Kenneth Reifsnider, University of Connecticut
Christine S. Sloane, General Motors Corporation
Michael S. Torok, Sikorsky Aircraft Corporation
Douglas Valenzuela, Northrop Grumman Corporation

Armor and Armaments Panel

John D. Venables, Consultant, Towson, Maryland, *Chair*
Jan D. Achenbach,** Northwestern University
Charles E. Anderson, Jr., Southwest Research Institute
Melvin R. Baer, Sandia National Laboratories
Kim K. Baldridge, University of Zurich
Thomas B. Brill, University of Delaware
Rodney J. Clifton, Brown University
Phillip Colella, E.O. Lawrence Berkeley National Laboratory
George T. ("Rusty") Gray III, Los Alamos National Laboratory
Rigoberto Hernandez, Georgia Institute of Technology
Larry G. Hill, Los Alamos National Laboratory
James E. McGrath,** Virginia Polytechnic Institute and State University
Lynne E. Parker, University of Tennessee, Knoxville, and Oak Ridge National Laboratory
Kenneth S. Vecchio, University of California, San Diego
Francis W. Zok, University of California, Santa Barbara

Digitization and Communications Science Panel

Peter M. Kogge, University of Notre Dame, *Chair*
Nina M. Berry, Sandia National Laboratories
Donald M. Chiarulli, University of Pittsburgh
Phillip Colella, E.O. Lawrence Berkeley National Laboratory
Lori Freitag Diachin, Lawrence Livermore National Laboratory

*Panel chair in 2005.
**Panel member in 2005.

Jack Dongarra,** University of Tennessee, Knoxville, and Oak Ridge National Laboratory
Jonathan P. Dowling, Louisiana State University
Joel S. Engel, JSE Consulting
Joseph Y. Halpern, Cornell University
Bruce B. Hicks, Metcorps
Frank A. Horrigan, Raytheon Company (retired)
Richard T. McNider,** University of Alabama, Huntsville (emeritus)
Steven L. Mullen, University of Arizona
Jim K. Omura, Gordon and Betty Moore Foundation
Daniel A. Reed, Renaissance Computing Institute
Alan B. Salisbury, Independent Consultant, Oakton, Virginia
Dennis W. Thomson, Pennsylvania State University
David Waltz, Columbia University
Eli Yablonovitch, University of California, Los Angeles

Sensors and Electron Devices Panel

Dwight C. Streit, Northrop Grumman Space Technology, *Chair*
Ilesanmi Adesida, University of Illinois at Urbana-Champaign
Henry E. Bass, University of Mississippi
Robert W. Brodersen, University of California, Berkeley
Elton J. Cairns, E.O. Lawrence Berkeley National Laboratory and University of California, Berkeley
L. Richard Carley, Carnegie Mellon University
Arthur H. Guenther, University of New Mexico
Alfred O. Hero, University of Michigan
Narain G. Hingorani, Hingorani Power Electronics
Linda P.B. Katehi, University of Illinois at Urbana-Champaign
Leslie A. Kolodziejski, Massachusetts Institute of Technology
Timothy N. Krabach, Jet Propulsion Laboratory
David C. Munson, Jr., University of Michigan
Zoya Popovic, University of Colorado, Boulder
P. Paul Ruden, University of Minnesota

Soldier Systems Panel

Douglas H. Harris, Anacapa Sciences Inc., *Chair*
Donald B. Chaffin, University of Michigan
Dennis G. Faust, Lockheed Martin Corporation
Robert A. Henning, University of Connecticut
Bonnie Elizabeth John,** Carnegie Mellon University
John D. Lee, University of Iowa
Eric R. Muth, Clemson University
Virginia M. Richards, University of Pennsylvania
Frank E. Ritter, Pennsylvania State University
Jeremy M. Wolfe, Harvard Medical School, Massachusetts Institute of Technology, and Boston University

**Panel member in 2005.

Survivability and Lethality Analysis Panel

John C. Sommerer, Johns Hopkins University Applied Physics Laboratory, *Chair*
Romesh C. Batra, Virginia Polytechnic Institute and State University
Thomas K. Burris, Lockheed Martin Aeronautics Company
John D. Christie, Logistics Management Institute
MarjorieAnn EricksonKirk, Phoenix Engineering Associates, Inc.
Alan K. Jones, The Boeing Company
Melvin F. Kanninen, MFK Consulting Services
Richard Lloyd,** Raytheon Company
John McHugh, Dalhousie University
Max D. Morris, Iowa State University
Hilarie K. Orman, Purple Streak Inc.
Thomas J. Peters, University of Connecticut
Stephen M. Pollock, University of Michigan (emeritus)
John Reese, Independent Consultant, Sandy, Utah
Eugene H. Spafford,** Purdue University
Fritz Steudel, Independent Consultant, Pocasset, Massachusetts
Jack L. Walker, Independent Consultant, Ann Arbor, Michigan
Donald C. Wunsch, Independent Consultant, Albuquerque, New Mexico

Quantum Computing and Communications Group

Robert W. Brodersen, University of California, Berkeley, *Acting Chair*
Jonathan P. Dowling, Louisiana State University
Peter M. Kogge, University of Notre Dame
Dwight C. Streit, Northrop Grumman Space Technology
Eli Yablonovitch, University of California, Los Angeles

**Panel member in 2005.

Appendix C

Panel Assessment Criteria

The ARLTAB applies the following metrics or criteria to the assessment of the scientific and technical work reviewed at the Army Research Laboratory (ARL):

1. Effectiveness of Interaction with the Scientific and Technical Community
   a. Papers in quality refereed journals and conference proceedings (and their citation index)
   b. Presentations and colloquia
   c. Participation in professional activities (society officers, conference committees, journal editors)
   d. Educational outreach (serving on graduate committees, teaching or lecturing, invited talks, mentoring students)
   e. Fellowships and awards (external and internal)
   f. Review panel participation (Army Research Office, National Science Foundation, Multidisciplinary University Research Imitative)
   g. Recruiting new talent into the ARL
   h. Patents and Intellectual Property (IP) (and examples of how the patent or IP is used)
   i. Involvement in building an ARL-wide cross-directorate community
   j. Public recognition (e.g., in the press and elsewhere) for ARL research

2. Impact on Customers
   a. Documented transfer or transition of technology, concepts or program assistance from ARL to Research, Development, and Engineering Centers (RDECs) or RDEC contractors for both the long term and short term
   b. Direct funding from customers to support ARL activities
   c. Documented demand for ARL support or services (Is there competition for their support?)

   d. Customer involvement in directorate planning
   e. Participation in multidisciplinary, cross-directorate projects
   f. Surveys of customer base (direct information from customers on value of ARL research)

3. Formulation of Projects' Goals and Plans
   a. Is there a clear tie to ARL Strategic Focus Areas, Strategic Plan, or other ARL need?
   b. Are tasks well defined to achieve objectives?
   c. Does the project plan clearly identify dependencies (i.e., successes depend on success of other activities within the project or outside developments)?
   d. If the project is part of a wider activity, is role of the investigators clear, and are the project tasks and objectives clearly linked to those of other related projects?
   e. Are milestones identified if they are appropriate? Do they appear feasible?
   f. Are obstacles and challenges defined (technical, resources)?
   g. Does the project represent an area where application of ARL strengths is appropriate?

4. R&D Methodology
   a. Are the hypotheses appropriately framed within the literature and theoretical context?
   b. Is there a clearly identified and appropriate process for performing required analyses, prototypes, models, simulations, tests, etc.?
   c. Are the methods (e.g., laboratory experiment, modeling or simulation, field test, analysis) appropriate to the problems? Do these methods integrate?
   d. Is the choice of equipment or apparatus appropriate?
   e. Is the data collection and analysis methodology appropriate?
   f. Are conclusions supported by the results?
   g. Are proposed ideas for further study reasonable?
   h. Do the tradeoffs between risk and potential gain appear reasonable?
   i. If the project demands technological or technical innovation, is that occurring?
   j. What stopping rules, if any, are being or should be applied?

5. Capabilities and Resources
   a. Are the qualifications and number of the staff (scientific, technical, administrative) appropriate to achieve success of the project?
   b. Is funding adequate to achieve success of the project?
   c. Is the state of the equipment and facilities adequate?
   d. If staff, funding, or equipment are not adequate, how might the project be triaged (what thrust should be emphasized, what sacrificed?) to best move toward its stated objectives?
   e. Does the laboratory sustain the technical capability to respond quickly to critical issues as they arise?

6. Responsiveness to the Board's Recommendations
   a. Have the issues and recommendations presented in the previous report been addressed?

Appendix D

Abbreviations

ACT-R	Adaptive Control of Thought-Rational (software)
ALEGRA	Arbitrary-Lagrangian-Eulerian General Research Applications
AMRDEC	Aviation and Missile Research, Development and Engineering Center
APG	Aberdeen Proving Ground
APS	active protection systems
ARDA	Advanced Research and Development Activity
ARL	Army Research Laboratory
ARLTAB	Army Research Laboratory Technical Assessment Board
ARO	Army Research Office
ASCED	Active Stall Control Engine Demonstration
ATO	Army Technology Objective
BED	Battlefield Environment Division
BRAC	Base Realignment and Closure
C2CUT	Command and Control in Complex and Urban Terrains
C3TRACE	Command, Control and Communications Techniques for Reliable Assessment of Concept Execution (software)
CAT-ATD	Crew Integration and Automation Test Bed Advanced Technology Demonstrator
CECOM	Communications and Electronics Command
CFD	computational fluid dynamics
CISD	Computational and Information Sciences Directorate
CTA	Collaborative Technology Alliance

DARPA	Defense Advanced Research Projects Agency
DMP	decision-making process
DoD	Department of Defense
DOE	Department of Energy
EMA	electromagnetic armor
FALCon	Forward Area Language Converter (software)
FCS	Future Combat Systems
FM	frequency modulation, frequency modulated
GPS	Global Positioning System
HBA	Human Behavior Architecture
HC-NEBC	Human-Centric–Network Enabled Battle Command (software)
HPC	high-performance computing
HRED	Human Research and Engineering Directorate
IA	information assurance
IED	improvised explosive device
IMPRINT	Improved Performance Research Integration Tool (software)
IR	infrared
ISR	intelligence, surveillance, and reconnaissance
ITA	International Technology Alliance
JGRE	Joint Ground Robotics Enterprise
KE	kinetic energy
Li	lithium
MANPRINT	manpower integration
MATREX	Modeling Architecture for Technology, Research and Experimentation (software)
MEMS	microelectromechanical systems
MMF	Mission and Means Framework (software)
MURI	Multidisciplinary University Research Initiative
MUVES	Modular UNIX-based Vulnerability Estimation Suite (software)
NASA	National Aeronautics and Space Administration
NBC	Nuclear, Biological, and Chemical
NDE	nondestructive evaluation
NMSU	New Mexico State University
NRC	National Research Council
NVESD	Night Vision and Electronic Sensors Directorate

PDA	personal digital assistant
PZT	lead zirconium titanate
QKD	quantum key distribution
R&D	research and development
RDEC	Research, Development and Engineering Center
RDT&E	research, development, test and evaluation
RF	radio frequency
S4	Systems of Systems Survivability Simulation (software)
S&Es	scientists and engineers
SANS	System Administration, Networking, and Security
SEDD	Sensors and Electron Devices Directorate
SiC	silicon carbide
SLAD	Survivability and Lethality Analysis Directorate
SLV	survivability, lethality, and vulnerability
SoS	system of systems
SPOOCEFEM	Simple Parallel Object-Oriented Computing Environment for the Finite Element Method
STI	Strategic Technology Initiative
STO	science and technology objective
STTC	Simulation and Training Technology Center
SUNY	State University of New York
THz	terahertz
TILV	Target Interaction Lethality Vulnerability (software)
TRADOC	Training and Doctrine Command
UAV	unmanned aerial vehicle
UGV	unmanned ground vehicle
UML	unified modeling language
UV	ultraviolet
UWB	ultrawideband
VTD	Vehicle Technology Directorate
VV&A	validation, verification, and accreditation
WMRD	Weapons and Materials Research Directorate