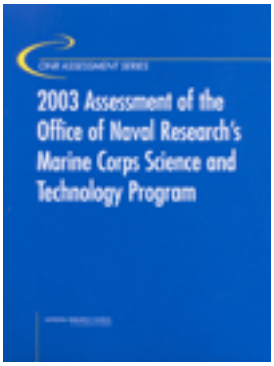

2003 Assessment of the Office of Naval Research's Marine Corps Science and Technology Program

Committee for the Review of ONR's Marine Corps Science and Technology Program, National Research Council

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Naval Studies Board
Division on Engineering and Physical Sciences

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Preface

The mission of the Office of Naval Research (ONR) is to maintain a close relationship with the research and development community and the operational community to support long-range research, foster discovery, nurture future generations of researchers, produce new technologies that meet known naval requirements, and provide innovations in fields relevant to the future Navy and Marine Corps. Accordingly, ONR supports research activities across a broad range of scientific and engineering disciplines. As one means of ensuring that its investments appropriately address naval priorities and requirements and that its programs are of high scientific and technical quality, ONR requires each of its departments to undergo an annual review, with a detailed focus on about one-third of the reviewed department's programs. Since 1999, the Naval Expeditionary Warfare Department (Code 35) of ONR has requested that the Naval Studies Board (NSB) of the National Research Council (NRC) conduct these reviews for its constituent divisions. The first review of ONR's Marine Corps Science and Technology (MCS&T) program was conducted in 2000.[1]

The MCS&T program reviewed in this report is administered through the Expeditionary Warfare Operations Technology Division (Code 353) of Code 35. At the request of ONR, the NRC established the Committee for the Review of ONR's Marine Corps Science and Technology Program (see Appendix A for biographies of the committee members) to review and evaluate Code 353 efforts in (1) basic research (6.1); (2) applied research (6.2) and advanced technology development (6.3); and (3) the Littoral Combat (LC) component of the Littoral Combat and Power Projection Future Naval Capability (FNC). Note that because the LC-FNC was initiated after the NSB's 2000 review of the MCS&T

[1]Naval Studies Board, National Research Council. 2000. *2000 Assessment of the Office of Naval Research's Marine Corps Science and Technology Program*, National Academy Press, Washington, D.C.

program, the current review represents a first look at this part of the program. The committee-selected review criteria were as follows:

- Impact on and relevance to Marine Corps needs;
- Appropriateness of the investment strategy within the context of Marine Corps priorities and requirements;
- Navy/Marine Corps program integration effectiveness;
- Balance of size, time horizon, and risk of funded programs;
- Scientific and technical quality; and
- Progress by the MCS&T program subsequent to the 2000 NSB review.

The committee was also asked to identify promising new research areas that should be considered for inclusion in future MCS&T program activities.

The committee met once, May 13-15, 2003, in Washington, D.C., both to hear presentations on more than 80 funded Code 353 projects and to prepare an initial draft report (see Appendix B for the meeting's agenda). In addition, committee members received background material from Code 353 before and after the meeting. Owing to variations in the content of individual presentations, it proved difficult to evaluate each Code 353 project uniformly against the criteria listed above. However, all criteria were considered by the committee in developing its recommendations. The months between the committee meeting and the publication of this report were spent preparing and revising the draft manuscript, gathering additional information, submitting the report to external review and responding to the review comments, editing the report, and subjecting it to a security review. The committee's report reflects its consensus views on the issues addressed.

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:

David E. Borth, Motorola Corporation,
Milton Finger, Livermore, California,
Ernest N. Petrick, Ann Arbor, Michigan,
David E. Richwine, National Air and Space Museum,
Charles H. Sinex, Applied Physics Laboratory, Johns Hopkins University,
Merrill I. Skolnik, Baltimore, Maryland, and
Christopher D. Wickens, University of Illinois at Urbana-Champaign.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions and recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Lee M. Hunt, Alexandria, Virginia. 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

Executive Summary

Administered through the Expeditionary Warfare Operations Technology Division (Code 353) of the Office of Naval Research's (ONR's) Naval Expeditionary Warfare Department (Code 35), the Marine Corps Science and Technology (MCS&T) program has three parts:

- The Littoral Combat (LC) component of the Littoral Combat and Power Projection Future Naval Capability (FNC),[1] funded for FY03 at $21.8 million for applied research (6.2) and at $13.3 million for advanced technology development (6.3);
- Core Thrusts, funded at $11.9 million for 6.2 work and at $11.2 million for 6.3 work; and
- Basic Research, funded at $3.4 million for 6.1 work.

These budget figures are summarized in Table ES.1. As a whole, the MCS&T program, whose mission is to exploit the technology opportunities that will produce enhanced expeditionary warfighting capabilities for the Naval Services, represents approximately 17 percent of Code 35's FY03 budget.[2]

As a result of its assessment, the Committee for the Review of ONR's Marine Corps Science and Technology Program developed three sets of findings and recommendations. Its general findings and recommendations for the MCS&T program as a whole and for each of the program's three parts—the LC-FNC, Core Thrusts, and Basic Research (reviewed in order of program size)—are presented below as well as in Chapters 1 through 4. The committee's recommendations for the more than 80 individual projects it reviewed are presented in Chapters 2, 3, and 4.

[1]The other component of the Littoral Combat and Power Projection FNC is focused on expeditionary logistics and is administered by ONR's Industrial and Corporate Programs Department (Code 36).

[2]The committee noted that the ONR (and the MCS&T program) budget relies heavily (~15 percent for MCS&T) on annual congressional plus-ups. The lack of certainty regarding the availability of these additional funds concerned the committee because of the difficulties this situation presents in establishing long-range planning within the MCS&T program.

TABLE ES.1 ONR Code 353 Marine Corps Science and Technology Program Budget for FY03 (millions of dollars)

Portion of Program	6.1	6.2	6.3	Total
Littoral Combat Future Naval Capability		21.8	13.3	35.1
Core Thrusts		11.9	11.2	23.1
Basic Research	3.4			3.4
Total funding	3.4	33.7	24.5	61.6

NOTE: Beginning in FY99, ONR initiated a reorganization of its initiatives to create two primary elements: (1) Future Naval Capabilities (FNCs), which was to receive all of ONR's 6.3 budget and roughly half of its 6.2 budget (currently, not all 6.3 funds are committed to the FNCs), and (2) Discovery and Invention (D&I), to which is allocated the remainder of ONR's 6.2 budget and all of its 6.1 budget. For the purposes of this review the D&I effort of the MCS&T program comprises Basic Research and the 6.2-funded projects of the Core Thrusts.

MARINE CORPS SCIENCE AND TECHNOLOGY PROGRAM AS A WHOLE

General Observations

Code 353 has changed in positive and productive ways since the Naval Studies Board's initial review of the MCS&T program in 2000.[3] At that time, a significant portion of the program had just been assigned to Code 353 and needed focus. In the current review, the committee was favorably impressed by the quality of many of the MCS&T program's components and by the strength of the interaction that has developed between Code 353 and the Marine Corps Warfighting Laboratory,[4] as well as by the capabilities and evident motivation of the presenters.

Many of the individual projects in the MCS&T program pursue worthwhile objectives; however, their relationship to key Marine Corps warfighting concepts—Expeditionary Maneuver Warfare (EMW)[5] and its components, Operational Maneuver From the Sea (OMFTS)[6] and Ship-to-Objective Maneuver (STOM)[7]—was often unclear in the presentations made to the committee. Yet, the Marine Corps demonstrates a good understanding of the importance of communicating its vision to and cooperating with the Chief of Naval Research and the personnel in ONR and, as a result, Code 353 is positioned to focus the MCS&T program on supporting the fast-changing missions and operational needs of the future Marine Corps. In general Code 353 is heading in the right direction and is attempting to pursue Marine Corps objectives, although better coordination is always desirable.

[3]Naval Studies Board, National Research Council. 2000. *2000 Assessment of the Office of Naval Research's Marine Corps Science and Technology Program*, National Academy Press, Washington, D.C.

[4]The Marine Corps Warfighting Laboratory retains 6.3-funded programs related to demonstration, experimentation, and integration of S&T products in support of concepts and future capabilities development.

[5]Gen James L. Jones, USMC, Commandant of the Marine Corps. 2001. *Expeditionary Maneuver Warfare,* Department of the Navy, November 10.

[6]Headquarters, U.S. Marine Corps. 1996. *Operational Maneuver From the Sea*, U.S. Government Printing Office, Washington D.C., January 4.

[7]LtGen Paul K. Van Riper, USMC (Ret.). 1997. "A Concept for Ship-to-Objective Maneuver," *Marine Corps Gazette*, Marine Corps Association, Quantico, Va., November.

LC-FNC Planning and S&T Investment Strategy

The LC-FNC's dual-track planning—near- and long-term oriented—began with an emphasis on STOM.[8] The near-term projects (18 to 36 months), intended to produce rapid results in response to critical needs identified by the Marine Corps and Code 353 prior to the creation of the LC-FNC, were designed to get the LC-FNC off to a quick start. Most of the projects presented to the committee were in this category. Longer-term projects (36 to 60 months) are scheduled to receive funding beginning in FY04.[9] Presentations on a number of FY04 new starts did not, however, show any direct linkage of these new starts to specific findings of the long-term planning activities.

Near-term planning also led to the establishment of four LC-FNC enabling capabilities (ECs) under which the various product lines and projects are grouped: EC 1—Intelligence, Surveillance, and Reconnaissance (ISR) for the Amphibious Force; EC 2—Expeditionary Fire Support for the Marine Air-Ground Task Force (MAGTF); EC 3—MAGTF Maneuver in the Littorals; and EC 4—Command and Control (C2). These four ECs appear to the committee to provide a reasonable set of topic areas to coordinate and categorize the STOM shortfalls identified by Code 353 in planning activities.

The committee believes that the longer-term top-down planning process established by Code 353 to help convert LC-FNC goals into a science and technology (S&T) investment strategy is conceptually excellent—particularly in its heavy up-front involvement with the Marine Corps user community. Nevertheless, improvements in its implementation are needed.

To identify and prioritize shortfalls in STOM capability, Code 353 used panels of experts (users, technologists, and so on) engaged in war gaming and other similar concept-generation exercises. These exercises resulted in a series of Broad Agency Announcement (BAA) solicitations seeking innovative technologies to address critical shortfalls. Several teams of potential users then took part in a STOM-based technology insertion game to assess and prioritize the technology improvements proposed in the BAA responses.

Although this approach represents an excellent start, the committee expressed two concerns about it:

1. Relying exclusively on BAA responses as the source of candidate technologies for an S&T investment strategy is a fundamental flaw in the process. A collection of BAA responses does not guarantee that all critical issues are being addressed, and simply rearranging the responses does not in itself constitute a strategy.
2. The proposed S&T investment strategy should not be definitively evaluated by a group of users such as the technology insertion group. Users and technologists often have dramatically differing visions of the role of S&T and how best to leverage S&T to support military operations.

The gap between users and the S&T community can be bridged by "bilingual" people who have the ability to understand and to listen to users, comprehend what they are seeking, and then communicate those requirements to the S&T community. By understanding the state of the art of the relevant technologies, such people are able to help identify a series of specific projects that support the needs expressed by users.

[8]Thomas O'Leary, Director, Expeditionary Warfare Operations Technology Division, Office of Naval Research, "ONR's Marine Corps Science and Technology Program: The Context," slide 11, presentation to the committee on May 13, 2003.

[9]See in Chapter 1 the section titled "LC-FNC Planning and Investment Strategy."

Recommendation. Code 353 should take the following steps to strengthen the LC-FNC strategy for investing in S&T.

- Avoid relying solely on Broad Agency Announcement solicitations and reorganization of the responses; instead, use a "translation" team of bilingual people skilled in understanding and interpreting the users' concerns and needs as the basis for identifying a series of specific projects representing a final S&T investment strategy.
- Ensure that the final review of the resulting S&T investment strategy is done by another independent group of appropriately bilingual (user/technologist) experts.

Although the committee thought that most of the projects presented during the current review were of interest to the Marine Corps, it also believed that greater cohesion was necessary to develop the balance of effort necessary to support the overall Marine Corps mission. The entire MCS&T program (including the Core Thrusts and Basic Research) would benefit from consistent use of the approach recommended above for developing an S&T investment strategy. Such a planning process should better enable Code 353 to identify critical Marine Corps capability gaps and to systematically plan technology efforts to fill these gaps.

Recommendation. Code 353 should develop a robust process for formulating an S&T investment strategy based on planning of the kind recommended for the LC-FNC and focused on supporting Marine Corps capabilities needed for Expeditionary Maneuver Warfare. Code 353 should then apply that strategy to all aspects of the MCS&T program.

Effect of the LC-FNC on the Core Thrusts

The LC-FNC appears to have greatly benefited Code 353—through its sustained funding, its attention from the Navy, its strong focus on Marine Corps problems, and its creation of a promising S&T investment planning process. However, establishment of the LC-FNC also appears to have had an adverse impact on the content of the MCS&T program's Core Thrusts.

While valuable in themselves, the FNCs are also intended to complement the Discovery and Invention (D&I) portion of ONR's portfolio. However, the committee observed that the necessary separation of time horizons (near- versus long-term) and mission focus (transition versus discovery) between the FNC and D&I elements appears to have been weakened in many of the Core Thrust projects reviewed.

In particular, Code 353 seems to have initiated a strong Core Thrust focus on Marine Corps technology needs, but several of the resulting projects have transition plans and short-term expectations similar to those for FNC projects.[10] In addition, many of the short-term Core Thrust projects appear to the committee to offer minor improvements to existing hardware or are focused on integration of existing systems, and thus are not developing base-level technologies necessary for significant improvements in capabilities. To complicate matters further, Code 353 has planned to allocate approximately $15 million annually through FY07 to non-FNC 6.3 projects;[11] this effort was a source of concern to the committee since it seems to be FNC-like in character and thus confounds the division of mission between the LC-FNC and the Core Thrusts elements of the MCS&T program.

[10]One example is the tactical unmanned ground vehicle project, which was briefed to the committee as part of Code 353's Core Thrusts yet is also listed on other ONR documents as a project supported through ONR's Autonomous Operations FNC.

[11]Thomas O'Leary, Director, Expeditionary Warfare Operations Technology Division, Office of Naval Research, "ONR's Marine Corps Science and Technology Program: The Context," slide 14, presentation to the committee on May 13, 2003.

The above concerns were first brought to the attention of Code 353 in the 2000 review of the MCS&T program. Among other things, that review recommended that Code 353 "eliminate . . . [from the Core Thrusts] activities that do not conform to the usual ONR S&T standards of innovation and technical aggressiveness . . . [and] embark on a discovery program to identify and refine technologies that can have a substantial payoff in achieving OMFTS."[12] Although the Core Thrusts need not exclude all demonstration and transition initiatives, those supported should meet ONR's standards for quality and should remain more flexible in terms of program requirements and timelines than is typical for FNCs.

Recommendation. Code 353 should ensure that the MCS&T program's Core Thrusts and Basic Research components support the mission of discovery and invention, that is, exploration aimed at the long-term development of base-level technologies that could support future FNC and Marine Corps Warfighting Laboratory program initiatives. Thus, Code 353 should remove from the Core Thrusts and Basic Research portfolios short-term, transition-oriented initiatives.

Aspects of Transitioning Products to Use

Transitioning products to use in the field involves a few potential problems that must be avoided. Users who agree to accept a product in transition from the S&T community generally expect to receive something that can be fielded rapidly, that is, a product that is well on its way to providing a full suite of "-ilities," which include such product issues as reliability, availability, manufacturability, maintainability, and so on (e.g., a product that provides corrosion and shock resistance and comes with detailed drawings, user guides, repair manuals, and the like). It was clear that the need for these capabilities was not being considered in any of the current projects for which presenters described having (or generating) technology transition plans. Evidently it was assumed that such capabilities could be supplied later during acquisition. However, it is the experience of the committee that inclusion of the "-ilities" often has a significant impact on the S&T design goals for a product and must be planned for early on.

Another critical aspect of transitioning products within the Navy/Marine Corps development and acquisition communities is that almost all fielded naval equipment is supplied by contractors and not by the Navy or the Marine Corps itself. Thus it is critical that ONR-developed technology and products find their way as quickly as possible into the contractor community. Many of Code 353's projects aim to connect with and transition into this community, as much of the S&T work is performed out-of-house through various, often competing contractors. The committee encourages this effort.

Recommendation. For S&T development products intended for transition, Code 353 should develop technology transition plans that include up-front considerations of the "-ilities," such as product reliability, manufacturability, maintainability, and other capabilities necessary in the overall fielding of products to the user community.

Responses to Issues from the 2000 NSB Assessment

Some of this committee's comments and recommendations correspond substantively to those made in 2000.[13] At the same time, the committee was pleased to see that Code 353 responded explicitly to

[12]Naval Studies Board, National Research Council. 2000. *2000 Assessment of the Office of Naval Research's Marine Corps Science and Technology Program*, National Academy Press, Washington, D.C., p. 20.

[13]Naval Studies Board, National Research Council. 2000. *2000 Assessment of the Office of Naval Research's Marine Corps Science and Technology Program*, National Academy Press, Washington, D.C.

many of the 2000 assessment's recommendations. Listing and discussing issues raised in 2000, the presentations indicated which recommendations had been implemented, and to what degree.

The 2000 review identified a number of high-level technical deficiencies in the overall MCS&T program. By and large the current program is in the process of addressing these issues—some vigorously and effectively, others less so, but all are being addressed.

MARINE CORPS SCIENCE AND TECHNOLOGY PROGRAM—THE THREE PARTS

LC-FNC

The LC-FNC planning process described above explicitly emphasized the STOM concept as a focus point for identifying shortfalls in Marine Corps capabilities. Recently, the Marine Corps and the Navy co-authored the overarching *Naval Operating Concept for Joint Operations*,[14] which contains EMW as a critical naval concept. The committee was concerned that the LC-FNC seems not to be responding strongly enough to implications of EMW beyond those contained within STOM; sea basing, in particular, is emphasized in EMW as well as in the Navy's capstone concept, Sea Power 21,[15] and has recently been called out by the Commandant of the Marine Corps as one of his top priorities.[16] However, sea basing receives no direct or leveraged support through the MCS&T program.

Following the establishment of the LC-FNC, the Department of the Navy's Science and Technology Corporate Board,[17] which approves and prioritizes all FNCs, also established Expeditionary Logistics (ExLog) as a separate component of the Littoral Combat and Power Projection FNC to address critical logistical capability gaps, including deployment from and reconstitution of a sea base, for naval forces engaged in expeditionary operations.[18] Both the LC-FNC and the ExLog-FNC are intended to support S&T that will enable future expeditionary military operations, but the two have separate integrated product teams, separate performing organizations (the ExLog-FNC S&T lead is ONR Code 36—Industrial and Corporate Programs), and separate funding. The committee saw little or no interaction occurring between these two FNC efforts. Considering the critical role logistics plays in enabling OMFTS and STOM, this separation seems unwise.

Recommendation. The Department of the Navy's Science and Technology Corporate Board should (1) expand the LC-FNC's mission to include Marine Corps capability needs for all of Expeditionary Maneuver Warfare and (2) provide a means for strongly coupling the integrated product teams for the

[14]ADM Vern Clark, USN, Chief of Naval Operations, and Gen Michael W. Hagee, USMC, Commandant of the Marine Corps, 2003, *Naval Operating Concept for Joint Operations,* Department of the Navy, March; Gordon England, Secretary of the Navy; ADM Vern Clark, USN, Chief of Naval Operations; and Gen James L. Jones, USMC, Commandant of the Marine Corps, 2002, *Naval Power 21…A Naval Vision,* Department of the Navy, October.

[15]ADM Vern Clark, USN, Chief of Naval Operations. 2002. "Sea Power 21," *Proceedings*, Vol. 128/10, U.S. Naval Institute, Annapolis, Md., October, pp. 32-41.

[16]Special Projects Directorate, U.S. Marine Corps Headquarters. 2003. "The Marine Corps General," Vol. 15, April 14.

[17]The Department of the Navy Science and Technology Corporate Board is composed of the Vice Chief of Naval Operations, the Assistant Commandant of the Marine Corps, and the Assistant Secretary of the Navy for Research, Development, and Acquisition.

[18]Expeditionary Logistics (ExLog) component of the Littoral Combat and Power Projection Future Naval Capability (FNC). 2002. *Expeditionary Logistics,* Office of Naval Research, Arlington, Va., June 3. Available online at <http://www.onr.navy.mil/explog/explog/overview.asp>. Accessed on August 20, 2003.

Littoral Combat and the Expeditionary Logistics components of the Littoral Combat and Power Projection FNC. At a minimum, it should assign Code 353 the co-S&T lead of the ExLog-FNC (with full voting rights) while retaining Code 353 as the S&T lead of the LC-FNC.

The committee's general recommendations for each of the program areas in the LC-FNC portion of the MCS&T program—Intelligence, Surveillance, and Reconnaissance for the Amphibious Force (EC 1), Expeditionary Fire Support for the MAGTF (EC 2), MAGTF Maneuver in the Littorals (EC 3), and Command and Control (EC 4)—are listed in Table ES.2 and discussed in Chapter 2.

Core Thrusts

The Core Thrust projects—6.2 and 6.3 activities not contained in the LC-FNC—were generally of high quality and seemed to address valid topics of interest to the Marine Corps. In many cases, however, it was difficult to see a rationale for the organization, prioritization, and support of these individual projects, which struck the committee as little more than a collection of "targets of opportunity" rather than topics related to significant shortfalls in EMW or STOM capabilities. In addition, presenters rarely mentioned Marine Corps needs or capability shortfalls, and when they did, the links appeared ad hoc rather than the result of a planned process. The apparent lack of an overall S&T investment strategy for the Core Thrusts concerns the committee. A planning process similar to that recommended for the LC-FNC, but focused on the long-term development of technology areas, would strengthen the Core Thrusts part of the MCS&T program.

A number of Core Thrust projects presented were leveraged against much larger U.S. Army or Defense Advanced Research Projects Agency (DARPA) programs, but the extent of the Code 353 contributions was in many cases unclear. In addition, in most Core Thrust areas committee members were aware of directly relevant activities in the Navy, other Services, and/or DARPA, of which the presenters, when asked, seemed to have little or no knowledge. The apparent lack of coordination concerned the committee, particularly in regard to potential duplication of efforts.

Recommendation. To better structure its support for the underpinnings of Expeditionary Maneuver Warfare as well as Ship-to-Objective Maneuver, Code 353 should establish an S&T planning process for the MCS&T program's Core Thrusts, similar to that recommended above for the LC-FNC, that is suitably focused on the long-term capability needs of the Marine Corps.

Recommendation. In its Core Thrust projects, Code 353 should enable broad coordination of efforts beyond Code 35 (and beyond ONR), where possible and practical, with relevant S&T activities in the other Services and in government agencies.

The committee's general recommendations for each of the Core Thrusts areas—Maneuver; Firepower; Mine Countermeasures; Logistics; Human Performance, Training, and Education; and Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance—are listed in Table ES.2 and discussed in Chapter 3.

Basic Research

Established in FY00 to support the discovery of new technology for enabling future capabilities in support of the individual Marine Corps warfighter, the Basic Research portion of the MCS&T program appears to be a useful addition to the larger Navy 6.1 program. However, some of the work presented to the committee as basic research, although potentially useful, was not "basic." Much the same observa-

TABLE ES.2 Summary Listing of Recommendations for Program Areas Within the Marine Corps Science and Technology Program's Three Parts

Program Area	Recommendation
Littoral Combat Future Naval Capability	• The Department of the Navy's Science and Technology Corporate Board should (1) expand the LC-FNC's mission to include Marine Corps capability needs for all of Expeditionary Maneuver Warfare and (2) provide a means for strongly coupling the integrated product teams for the Littoral Combat and the Expeditionary Logistics components of the Littoral Combat and Power Projection FNC. At a minimum, it should assign Code 353 the co-S&T lead of the ExLog-FNC (with full voting rights) while retaining Code 353 as the S&T lead of the LC-FNC.
Enabling Capability 1, Intelligence, Surveillance, and Reconnaissance (ISR) for the Amphibious Force	• Code 353 should reexamine EC 1, ISR for the Amphibious Force, and seek to expand its funding options beyond sensors and platforms tied to Tier II UAV [unmanned aerial vehicle] development. • Code 353 should establish better coordination between EC 1, ISR for the Amphibious Force, and EC 4, Command and Control, as well as better coordination with related intelligence community, joint, and other Service research and development programs.
Enabling Capability 2, Expeditionary Fire Support for the Marine Air-Ground Task Force (MAGTF)	• Before FY04, Code 353 should assess the feasibility of integrating the expeditionary fire support projects with those of other Service components and should review relevant prior Army and DARPA studies.
Enabling Capability 3, MAGTF Maneuver in the Littorals	• Code 353 should continue to pursue situational awareness efforts with vigor. • Code 353 should accelerate efforts to support the needs of mine countermeasures and military operations in urban terrain by systematically addressing the many identified shortfalls.
Enabling Capability 4, Command and Control (C2)	• Code 353 should review all C2 enabling capability projects to ensure coordination with ISR enabling capability projects and alignment of the outputs of both enabling capabilities to Expeditionary Maneuver Warfare.
Core Thrusts	• To better structure its support for the underpinnings of Expeditionary Maneuver Warfare as well as Ship-to-Objective Maneuver, Code 353 should establish an S&T planning process for the MCS&T program's Core Thrusts, similar to that recommended above for the LC-FNC, that is suitably focused on the long-term capability needs of the Marine Corps. • In its Core Thrust projects, Code 353 should enable broad coordination of efforts beyond Code 35 (and beyond ONR), where possible and practical, with relevant S&T activities in the other Services and in government agencies.

TABLE ES.2 Continued

Program Area	Recommendation
Maneuver	• Code 353 should transition the reconnaissance, surveillance, and targeting vehicle project and the tactical unmanned ground vehicle project out of the Maneuver thrust as planned, but should continue support of initiatives in hybrid-electric and unmanned vehicles.
Firepower	• Code 353 should immediately transition near-term projects in the Firepower thrust to an appropriate FNC. • Code 353 should establish leveraging opportunities to support broad ONR and/or DARPA initiatives in the area of naval surface firepower support.
Mine Countermeasures	• Code 353 should seek to leverage research on development of wide-area surveillance detection systems for use in mine countermeasures. • Code 353 should collaborate with DARPA; the Army; Naval Sea Systems Command, PMS-210; Coastal Systems Station (CSS) Panama City; Naval Air Systems Command, PMA-263; and the Marine Corps Warfighting Laboratory, the Organic Mine Countermeasures FNC, and the other ONR codes to address mine countermeasures at the Naval Enterprise level with a view beyond the 3-year horizon that seems to pervade current MCM efforts. The S&T planning process described in Marine Corps Order 3900.15A contains the structure to allow such collaboration. • Code 353 should develop an overall mine countermeasure strategy involving all research and development programming levels.
Logistics	• Code 353 should coordinate with the Expeditionary Logistics component of the Littoral Combat and Power Projection FNC regarding implications of Expeditionary Maneuver Warfare for Marine Corps logistics. • Code 353 should support new Logistics thrust projects in expeditionary on-shore fuel logistics and on-shore materials transportation. • Code 353 should, in a timely manner, transition relevant MCS&T Basic Research projects on lightweight power sources into 6.2- and 6.3-supported programs.
Human Performance, Training, and Education	• Code 353 should keep abreast of ONR and other Service investments in training and education in order to be able to influence them. In addition, programs in intelligent tutoring systems by ONR and the Army (especially the FY04 Science and Technology Objective in this area managed by the Army Research Institute) could offer significant benefits to the Marine Corps if appropriate personnel from Code 353 were placed on the relevant integrated product teams.

Continues

TABLE ES.2 Continued

Program Area	Recommendation
Human Performance, Training, and Education (continued)	• On a very basic level, the Marine Corps should monitor the reorganization of all Navy education and training and the deployment of asynchronous distributed learning capabilities by both the Army and the Navy. The Marine Corps will probably have to develop some content that is specific to its doctrine and training needs, but the payoff from appropriate leveraging could be very large. • Code 353 is strongly urged to leverage and influence research on human performance assessment, both within Code 353's current portfolio and in relation to all Marine Corps training and education. Research on human performance assessment should be an integral part of all human performance, training, and education research sponsored by Code 353, could be accomplished with relatively small investments, and would certainly yield large dividends in terms of the feedback provided to current and future programs. • Code 353 is encouraged to become familiar with the Commandant of the Marine Corps's Special Projects Directorate programs in training and education. Code 353 should also solicit the active participation of senior Marine Corps leadership in the S&T development process for training and education to ensure that innovative ideas and systems can be rapidly readied for testing by operational forces.
Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR)	• Code 353 should continue to invest its research resources in C4ISR areas that are tightly coupled to the Marine Corps operational concepts of Ship-to-Objective Maneuver and Operational Maneuver From the Sea. Especially in the domain of C4ISR, a small investment in a critical area, coupled with other Service and Department of Defense investments, could produce significant results for the Marine Corps.
Basic Research	• Code 353 should broaden its Basic Research focus areas to create a more robust and sustainable series of efforts. The new focus areas should result from a careful assessment of Marine Corps needs. A suggested reorganization of focus areas and sample topics is provided in Table ES.3. — Code 353 should strive to set aside a small amount of uncommitted 6.1 funds (perhaps a few hundred thousand dollars) to foster additional flexibility in program support and to enable quick looks (e.g., a few months to a year) at new, unforeseen, novel concepts that arise from time to time. — Code 353 should establish a formal mechanism to allow continuing feedback of 6.2 and 6.3 findings to the 6.1 office to help identify fruitful new areas of 6.1 research. — Code 353 should work aggressively to expand the funding base for Basic Research so that a coherent set of significant Marine Corps-related projects can be supported.

TABLE ES.2 Continued

Program Area	Recommendation
	— The Marine Corps should be involved in all aspects of the Code 353 research and development process, including the strategic development of the Basic Research part of the MCS&T program. In support of this goal, Code 353 should participate in (or encourage the Marine Corps leadership to participate in) meetings of the Defense Committee on Research, which currently has representatives from all the Services except the Marine Corps. — As a means of fostering leveraging with basic research efforts outside ONR, Code 353 should regularly review the biennial Department of Defense Basic Research Plan.

tion was made in the 2000 review. Intended to explore fundamental questions for potential future developments that are not yet fully formulated, basic research might also be used to assist development work that is handicapped for want of some fundamental knowledge. In both cases feedback from 6.2 and 6.3 activities to 6.1 is essential to highlight critical technical areas. Also needed in the Basic Research component is better coordination for transitioning 6.1 results into 6.2 and 6.3 applications.

Marine Corps personnel could assist in strategic planning for 6.1 work by helping to steer it not into projects, but rather into technology areas likely to support long-term combat needs. The current Basic Research focus areas—communications, lightweight power sources, information efficiency, landmine detection, human sensory enhancement, enhanced lethality, laser eye protection, sensing, and corrosion prevention—could be strengthened by reorganizing along the lines suggested by the committee in Table ES.3.

In addition, to be effective, the small Marine Corps-oriented 6.1 part of the MCS&T program must be leveraged as much as possible. Code 353 is well aware of the need for leveraging, but the current Basic Research effort is handicapped by the low funding levels.

Recommendation. Code 353 should broaden its Basic Research focus areas to create a more robust and sustainable series of efforts. The new focus areas should result from a careful assessment of Marine Corps needs. A suggested reorganization of focus areas and sample topics is provided in Table ES.3. In addition,

- Code 353 should strive to set aside a small amount of uncommitted 6.1 funds (perhaps a few hundred thousand dollars) to foster additional flexibility in program support and to enable quick looks (e.g., a few months to a year) at new, unforeseen, novel concepts that arise from time to time.
- Code 353 should establish a formal mechanism to allow continuing feedback of 6.2 and 6.3 findings to the 6.1 office to help identify fruitful new areas of 6.1 research.
- Code 353 should work aggressively to expand the funding base for Basic Research so that a coherent set of significant Marine Corps-related projects can be supported.
- The Marine Corps should be involved in all aspects of the Code 353 research and development process, including the strategic development of the Basic Research part of the MCS&T program. In

TABLE ES.3 Suggested Reorganization of Basic Research Focus Areas and Sample Topics

Focus Area	Sample Topics
Command, Control, Communications, Computers, and Intelligence (C4I)	Ad hoc wireless networking Beyond-line-of-sight communications Short-range, high-density, low-power communications Antijam protection Information assurance
Energy	Lightweight power sources and rechargeable electric storage devices Energy-efficient devices and techniques High-energy-density storage
Sensing	Sensors for situation awareness (pre-attack) Sensors for damage assessment (post-attack) Sensors that work in an urban environment Mine detection: fundamental physical mechanisms and phenomenology in surf and on land Unmanned surveillance/reconnaissance vehicles Non-communications use of ultrawideband radar
Materials	Materials and structures Sensing materials Corrosion prevention
Human Factors	Non-lethal weapons Psychological profiling to identify potential terrorists Human sensory enhancement
Oceanography and Environment	Shallow-water oceanography: bottom structure in the surf zone, bottom interactions, and surf and current characteristics Effects on warfare of hostile or unusual climates (weather)
Weapons	Enhanced lethality Aim-point accuracy

support of this goal, Code 353 should participate in (or encourage the Marine Corps leadership to participate in) meetings of the Defense Committee on Research, which currently has representatives from all the Services except the Marine Corps.

- As a means of fostering leveraging with basic research efforts outside ONR, Code 353 should regularly review the biennial Department of Defense Basic Research Plan.[19]

These recommendations for the Basic Research portion of the MCS&T program are also listed in Table ES.2.

[19]Office of the Deputy Under Secretary of Defense (Science and Technology). 2002. *Basic Research Plan (BRP),* Department of Defense, Washington, D.C.

Summary Listing of General Recommendations and Suggestions

In addition to the general recommendations presented above for each of the MCS&T program's three parts—the LC-FNC, Core Thrusts, and Basic Research—the committee developed for each part's primary areas additional general recommendations that are presented in Chapters 2 through 4. Table ES.2 is a summary list of all these general recommendations. Table ES.3 presents the committee's suggestions for reorganizing the focus areas in the Basic Research part of the MCS&T program and lists sample topics in each area.

The committee's recommendations for the more than 80 individual projects it reviewed are presented in Chapters 2 through 4.

1

Marine Corps S&T Program as a Whole

PROGRAM STRUCTURE

The Marine Corps Science and Technology (MCS&T) program, administered and directed by the Expeditionary Warfare Operations Technology Division (Code 353) of the Office of Naval Research (ONR), has three primary parts: (1) the Littoral Combat (LC) component of the Littoral Combat and Power Projection Future Naval Capability (FNC), (2) Core Thrusts, and (3) Basic Research. In this chapter the committee provides general observations on the overall MCS&T program and high-level recommendations for improvement. The next three chapters discuss each of the three parts of ONR Code 353's MCS&T program—the LC-FNC, Core Thrusts, and Basic Research—in order of program size beginning with the largest. Each chapter begins with a discussion of research areas followed by a detailed discussion of the projects assessed.

Beginning in FY99, ONR initiated a reorganization of its funding classifications and initiatives to create two primary organizational elements: (1) Future Naval Capabilities, to which was to be allocated all of ONR's advanced technology development (6.3) budget and roughly half of its applied research (6.2) budget;[1] and (2) Discovery and Invention (D&I), to which was to be allocated the remainder of ONR's 6.2 budget and all of its basic research (6.1) budget. Since FY99, the first category has been expanded into what is now known as Exploitation and Deployment, which contains the FNCs as a subcategory, along with a new group of large non-FNC programs known as Naval Innovations, which includes such efforts as the UCAV-N, X-Craft, Electric Ship, and Electromagnetic Gun.

Avoiding these distinctions, ONR presented Code 353's program as divided into three parts: (1) the LC-FNC, (2) Core Thrusts, which included both 6.2 and 6.3 funding but which were not part of the FNC, and (3) 6.1 Basic Research. As described by ONR the objectives of the MCS&T program and its constituent parts are detailed in Table 1.1. In FY03, the MCS&T program was funded at $61.6 million.

[1]Currently, not all 6.3 funds are committed to the FNCs.

TABLE 1.1 Marine Corps Science and Technology Program Areas

Program Area	Objective
Littoral Combat Future Naval Capability	Support the development of naval Expeditionary Maneuver Warfare (EMW) via the application of technologies that enhance the ability of the Navy-Marine Corps team to achieve assured access and sustained operations in the littorals as the naval portion of a joint campaign.
Enabling Capability 1, Intelligence, Surveillance, and Reconnaissance (ISR) for the Amphibious Force	Provide enhanced autonomous and semiautonomous ISR capabilities to elements of a MAGTF. These enhanced capabilities will be locally tasked and controlled. Develop tactical systems to increase the ISR capabilities of tactical units (regiment and below).
Enabling Capability 2, Expeditionary Fire Support for the Marine Air-Ground Task Force (MAGTF)	Provide enhanced fire support to elements of a MAGTF operating ashore. Develop an expeditionary fire support system with improved ammunition and integrate all legacy and future fires systems into a Naval Fires Network. Enhance expeditionary fires at the element level of the MAGTF.
Enabling Capability 3, MAGTF Maneuver in the Littorals	Provide enhanced maneuverability of surface-landed elements of the MAGTF. Provide knowledge-based situational awareness to assault forces embarked on maneuver platforms. Allow assault forces to dynamically plan and adaptively execute the conduct of Ship-to-Objective Maneuver (STOM) operations. Improve mine and obstacle breaching capabilities from the beach exit zone to the objective to enhance maneuverability of surface-landed assault forces.
Enabling Capability 4, Command and Control (C2)	Provide the MAGTF commander with a C2 capability that can command all elements of the MAGTF. Provide increased reliability of beyond-line-of-sight communications, provide near-real-time situational awareness to all elements of the MAGTF that is scalable to the requirements of the specific MAGTF element, and optimize the flow of information over an improved data network.
Core Thrusts	
Maneuver	Conduct research and development of advanced technologies for tactical combat vehicles in the areas of mobility, survivability, electric technologies, and unmanned ground vehicles.
Firepower	Develop advanced technologies for application on current and future Marine Corps expeditionary weapons and targeting systems.
Mine Countermeasures	Develop research areas to enable technologies for detecting, localizing, identifying, and neutralizing mines in the littoral environment.

Continues

TABLE 1.1 Continued

Program Area	Objective
Logistics	Develop, demonstrate, and transition technologies that will support U.S. Marine Corps future warfighting concepts (EMW and Sea-Based Logistics).
Human Performance, Training, and Education	Enhance human decision making, increase frequency and information content of training and education, and enable warriors to win and survive.
C4ISR	Enable network-centric warfare at the tactical level in support of the warfighting concepts of EMW, STOM, and OMFTS.
Basic Research	Create new technical possibilities that permit expansion of the range of potential operational capabilities and concepts for the Marine Corps "after next" (2020-2030).

SOURCE: U.S. Marine Corps, Future Naval Capabilities Coordination Office. 2003. *Marine Corps Science and Technology Newsletter,* p. 3.

Of this amount, $26.5 million went to Code 353's Basic Research (6.1—$3.4 million) and Core Thrusts (6.2—$11.9 million, 6.3—$11.2 million), and $35.1 million went to the LC-FNC (6.2—$21.8 million, 6.3—$13.3 million) (see Table 1.2).[2] Together the three parts of the MCS&T program accounted for approximately 17 percent of ONR's Expeditionary Warfare Department (Code 35) FY03 budget.[3]

OBSERVATIONS AND RECOMMENDATIONS

The ONR MCS&T program and Code 353 have changed in positive and productive ways since the initial MCS&T review conducted by the Naval Studies Board (NSB) in 2000.[4] At that time, a significant portion of the MCS&T program had just been assigned to Code 353,[5] and the overall program needed focus. In the current review, the committee was favorably impressed by the high quality of many of the MCS&T program components presented and by the strength of the interactions that have developed between Code 353 and the Marine Corps Warfighting Laboratory (MCWL), as well as by the capabilities, optimism, and evident motivation of the presenters.

[2]These estimates are based on the FY03 budget and include business operation costs, congressionally directed projects, and mandated projects.

[3]The committee also noted that the ONR (and the MCS&T program) budget relies heavily (~15 percent for MCS&T) on annual congressional plus-ups. The committee expressed concern at this practice because it can make it more difficult to establish long-range planning within the MCS&T program.

[4]Naval Studies Board, National Research Council. 2000. *2000 Assessment of the Office of Naval Research's Marine Corps Science and Technology Program*, National Academy Press, Washington, D.C.

[5]The Marine Corps Warfighting Laboratory retains some 6.3-funded programs that are related primarily to demonstration, experimentation, and integration of S&T products in support of concepts and future capabilities development.

TABLE 1.2 Marine Corps Science and Technology Program Funding for Fiscal Year 2003 (millions of dollars)

Component	6.1	6.2		6.3		Total	Percentage of Total
		Green[a]	Blue[b]	Green[a]	Blue[b]		
Littoral Combat							
Future Naval Capability							
EC 1: ISR for the Amphibious Force		8.3	0.5	0.0	0.0	8.8	14.3
EC 2: Expeditionary Fire Support for the MAGTF		4.6	0.7	3.5	2.8	11.6	18.8
EC 3: MAGTF Maneuver in the Littorals		1.8	0.4	1.0	1.6	4.8	7.8
EC 4: Command and Control		2.9	2.6	1.6	2.8	9.9	16.1
Total FNC Funding		17.6	4.2	6.1	7.2	35.1	57.0
Core Thrusts							
Maneuver		2.3		1.6		3.9	6.3
Firepower		1.5		1.0		2.5	4.1
Mine Countermeasures		1.3		1.6		2.9	4.7
Logistics		1.6		2.4		4.0	6.5
Human Performance, Training, and Education		3.2		2.0		5.2	8.4
C4ISR		2.0		2.6		4.6	7.5
Total Core Funding		11.9		11.2		23.1	37.5
Basic Research	3.4					3.4	5.5
Total Funding (Green and Blue)	3.4	33.7		24.5		61.6	100.0

NOTE: These budget estimates are based on the FY03 budget and include business operation costs, congressionally directed projects, and mandated projects. For definitions of acronyms, see Appendix C.

[a]Denotes Marine Corps-supported research funds.

[b]Denotes Navy-supported research funds.

ONR and Code 353's Relationship with the Marine Corps

Code 353's relationship with the Marine Corps is evolving into a workable and effective partnership. The Commanding General of the MCWL (the original home of all MCS&T) is also Vice Chief of Naval Research, which allows high-level collaboration across Marine Corps development and research interests and Marine Corps influence and leveraging of broad ONR initiatives. In addition, Marine Corps officers are regularly assigned to the MCS&T program office and are consciously embedded throughout ONR. The Marine Corps demonstrates a good understanding of the importance of communicating its vision to and cooperating with the Chief of Naval Research and the personnel in ONR.

Six Marine Corps general officers co-chair various FNCs, and Marine Corps personnel are members of the integrated product teams (IPTs) for other FNCs.[6] Participation in the IPTs is extremely important because the IPT, as a group, decides on the final makeup of projects supported through a given FNC. The direct involvement of Marine Corps officers in the S&T process constitutes a valuable and long-

[6]An IPT—comprising members of the operational, acquisition, science and technology, requirements, and resources communities—is established for each FNC in order to align and partner the relevant communities and give the FNC products a better chance to transition into operational use. In addition to administering the LC-FNC, Code 353 serves as the IPT science and technology lead.

needed link between the Marine Corps and ONR, although the quality and the capabilities of the individual marines assigned are key to the success of this stratagem.

Code 353 has now had nearly 4 years of experience working with Marine Corps challenges and is becoming attuned to the S&T needs underlying Marine Corps concepts of operations (see Box 1.1). Yet, although many of the individual efforts under way in Code 353 pursue worthwhile objectives, their relationship to key Marine Corps warfighting concepts (e.g., Expeditionary Maneuver Warfare (EMW), Operational Maneuver From the Sea (OMFTS), Ship-to-Objective Maneuver (STOM), and so forth) was often unclear in presentations made to the committee. Selection of many of the topics addressed by current and planned Code 353 programs appeared to have been ad hoc and opportunistic.

At the same time, the committee found a lack of evidence that the Marine Corps has consistently laid out its vision of EMW and the subordinate concept of STOM to ONR in a manner that would permit the formulation of an imaginative and effective program of science and technology research. The committee noted that this situation is beginning to change. The Marine Corps has recently completed guidance for achieving the goals of EMW[7] and is in the process of drafting a Marine Corps S&T plan—both of which will enable Code 353 to better support development of Marine Corps capability requirements.

Review of the Marine Corps new S&T implementing document[8] shows that it provides appropriate responsibility, accountability, authority, and process definition by which to develop and manage near-, mid-, and far-term S&T strategies in a naval context. Scheduled to start during the summer of 2003, implementation of these processes will include the above-mentioned EMW guidance, in the form of a capability list, as one of the first results. The committee enthusiastically supports these organizational and process initiatives as a mechanism for managing S&T as a Marine Corps enterprise asset.

Operational synergy between the Marine Corps and the Navy appears to have grown since establishment of the Naval Operating Concept (see Box 1.1). The Naval Operating Concept includes the critical naval concepts of Sea Basing, Sea Shield, Sea Strike, and FORCEnet and their integration with the Marine Corps capstone concept EMW and its constituent operational concepts, OMFTS and STOM, thus providing a vision toward which the two Services can plan to develop a coherent program, ranging from basic research through advanced technology development, in order to support the Navy/Marine Corps team.

As a result of this increasing synergy, Code 353 should be better positioned to refocus its MCS&T program to support the fast-changing missions and operations of the Naval Services. Code 353 is heading in the right direction and is attempting to pursue Marine Corps objectives, although more coordination with the Marine Corps Combat Development Command (MCCDC) and MCWL may be necessary to ensure more effective management of the MCS&T program.

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[7]LtGen Edward Hanlon, Jr., USMC, Deputy Commandant, Combat Development. 2003. *Expeditionary Maneuver Warfare Capability List (ECL)*. Expeditionary Force Development Center, Marine Corps Combat Development Command, Quantico, Va., June 16. Available online at <https://www.mccdc.usmc.mil/ECL2003.pdf>. Accessed on December 12, 2003.

[8]Gen James L. Jones, USMC, Commandant, U.S. Marine Corps. 2002. *Marine Corps Order 3900.15A, Marine Corps Expeditionary Force Development System,* Headquarters, U.S. Marine Corps, Washington, D.C., November 26.

LC-FNC Planning and Investment Strategy

The LC-FNC began with a dual-track planning process. One track emphasized developing near-term projects (18 to 36 months long, begun in FY02) focused on rapid returns to meet critical needs (which had been identified by the Marine Corps and Code 353 prior to the creation of the LC-FNC) and designed to get the LC-FNC off to a quick start.[9] The other track initiated a more formal planning process to generate and prioritize longer-term projects (36 to 60 months long) that are to receive funding beginning in FY04. The committee noted that the LC-FNC is still in an early stage of development, and the projects that were presented seemed to come from the near-term branch of the dual-track process. A number of FY04 new starts were presented to the committee as being results of the long-term planning process; however, the presentations did not show any direct linkage of these new starts to specific findings of the planning activities.

The near-term planning also led to the establishment of four LC-FNC enabling capabilities (ECs) as organizational elements: EC 1—Intelligence, Surveillance, and Reconnaissance (ISR) for the Amphibious Force; EC 2—Expeditionary Fire Support for the MAGTF; EC 3—MAGTF Maneuver in the Littorals; and EC 4—Command and Control (C2). These four ECs appear to the committee to provide a reasonable set of topic areas for coordinating and categorizing the STOM shortfalls identified by Code 353 during the LC-FNC planning process.

LC-FNC Process for Formulating an Investment Strategy

Code 353 also established a longer-term, formal, top-down process for converting LC-FNC goals into an S&T investment strategy (Figure 1.1). In addition, the LC-FNC investment strategy formulation process has resulted in a useful means for connecting Code 353 with the Marine Corps user community.

To identify and prioritize current STOM capability shortfalls, Code 353 included a combination of expert panels (users, technologists, and so on) engaged in war gaming and other similar concept generation exercises. These exercises resulted in a series of Broad Agency Announcement (BAA) solicitations seeking innovative improvements that address critical shortfall technologies. Finally, several teams of potential users took part in a STOM-based technology insertion game (TIG) to assess and prioritize the technology improvements proposed in the BAA responses.

Attempting to identify capabilities shortfalls through a war game is an excellent idea. Code 353 engaged a group of users in STOM-based war games to identify those gaps in current Marine Corps capabilities that, if overcome, would enhance the ability of Marine Corps forces in the proposed missions. However, as presented to the committee, the war games did not involve broader issues in EMW—that is, issues other than STOM. The inclusion of members of the MCCDC Doctrine and Equipment Requirements Division, as users, was a welcome sign that the MCS&T program was becoming integrated within the broader Marine Corps community.

A panel of experienced technologists began with the resulting shortfalls list and reorganized and prioritized the related S&T areas for investigation. The committee commends use of the Technologist Panel and strongly supports its continuing to assist Code 353 in developing the LC-FNC S&T investment strategy.

This priority list resulted in a series of BAAs for innovative solutions in the shortfall areas. While

[9]Thomas O'Leary, Director, Expeditionary Warfare Operations Technology Division, Office of Naval Research, "ONR's Marine Corps Science and Technology Program: The Context," slide 11, presentation to the committee on May 13, 2003.

Box 1.1
Naval Operating Concepts Relevant to the MCS&T Program

Efforts by the Naval Services (Navy and Marine Corps) to redefine how future engagements will unfold culminated in the joint publication in April 2003 of *Naval Operating Concept for Joint Operations*.[1] Co-signed by the Chief of Naval Operations and the Commandant of the Marine Corps, this document combines the Service visions Sea Power 21[2] and Marine Corps Strategy 21,[3] fusing the Marine Corps capstone concept of Expeditionary Maneuver Warfare (EMW)[4] and its constituent operating concepts, Operational Maneuver From the Sea (OMFTS)[5] and Ship-to-Objective Maneuver (STOM),[6] into an integrated naval picture. As the Naval Operating Concept becomes integrated throughout the Navy and Marine Corps, it is anticipated that new S&T topic areas will emerge that could be developed within the MCS&T program.

Operational Maneuver From the Sea

In the mid-1990s, the Marine Corps promulgated OMFTS as its overarching operational concept to support the naval expeditionary force concepts in "From the Sea . . ."[7] and "Forward . . . From the Sea."[8] The main premise of OMFTS was that Marine Corps forces would utilize the world's oceans as forward basing sites and maneuver space from which to launch a credible expeditionary force directly to (distant) inland objective areas without having to establish a beachhead for staging, integration, and onward movement.

Ship-to-Objective Maneuver

Under OMFTS, a Marine Air-Ground Task Force (MAGTF) would strike directly from seaborne platforms, engaging in rapid, penetrating maneuver against objectives in the littorals and beyond. The supporting concept of operations, known as STOM, involves the organization of forces at sea and their rapid conveyance by surface craft and aircraft directly to inland mission objective points, without the necessity of securing protected beachheads.[9] As such, STOM relies heavily on technologies enabling rapid and rapidly retasked maneuver capabilities.

In broad terms, OMFTS is the operating concept for using the sea as maneuver space to support at-sea staging, command and control, and firepower, whereas STOM represents the operational concept utilizing these capabilities in order to bring combat-ready forces ashore. OMFTS and STOM have been put into action as the major Marine Corps organizing principles utilized during the recent Iraq and Afghanistan conflicts. In Afghanistan, operational MAGTF elements were deployed over 400 miles inland without the assistance of large-scale shore installations.

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[1]ADM Vern Clark, USN, Chief of Naval Operations, and Gen Michael W. Hagee, USMC, Commandant of the Marine Corps. 2003. *Naval Operating Concept for Joint Operations,* Department of the Navy, March.

[2]Gordon England, Secretary of the Navy; ADM Vern Clark, USN, Chief of Naval Operations; and Gen James L. Jones, USMC, Commandant of the Marine Corps. 2002. *Naval Power 21…A Naval Vision,* Department of the Navy, October.

[3]Gen James L. Jones, USMC, Commandant of the Marine Corps. 1999. *Marine Corps Strategy 21,* Department of the Navy, July. Available online at <http://www.usmc.mil/templateml.nsf/25241abbb036b230852569c 4004eff0e/$FILE/strategy.pdf >. Accessed on August 20, 2003.

[4]Gen James L. Jones, USMC, Commandant of the Marine Corps. 2001. *Expeditionary Maneuver Warfare,* Department of the Navy, November 10.

[5]Headquarters, U.S. Marine Corps. 1996. *Operational Maneuver From the Sea*, U.S. Government Printing Office, Washington, D.C., January 4.

[6]LtGen Paul K. Van Riper, USMC (Ret.). 1997. "A Concept for Ship-to-Objective Maneuver," *Marine Corps Gazette*, Marine Corps Association, Quantico, Va., November.

[7]Department of the Navy. 1992. ". . . From the Sea," U.S. Government Printing Office, Washington, D.C., September.

[8]Department of the Navy. 1994. "Forward . . . From the Sea, Continuing the Preparation of the Naval Services for the 21st Century," U.S. Government Printing Office, Washington, D.C., September 19.

[9]LtGen Paul K. Van Riper, USMC (Ret.). 1997. "A Concept for Ship-to-Objective Maneuver," *Marine Corps Gazette*, Marine Corps Association, Quantico, Va., November.

Expeditionary Maneuver Warfare

Toward the end of the 1990s, the emergence of the Navy's Sea Power 21 concept of operations along with the growing realization that OMFTS did not sufficiently capture other critical operations native to the Marine Corps—such as sustained operations ashore and military operations other than war—gave rise to the need for a broader concept. Eventually, the new capstone concept EMW emerged and was adopted by the Marine Corps.[10]

As subordinate concepts of EMW, the Marine Corps has retained OMFTS and its supporting concept, STOM, to represent the means for the marines to support joint expeditionary warfare operations. EMW encourages the Marine Corps to continue developing the STOM capability from OMFTS, while it also encompasses those other capabilities—sustained operations ashore, military operations other than war, humanitarian assistance/disaster relief, military training, noncombatant evacuation operations, and so on—so long identified as basic capabilities or actions of the Marine Corps.

Military Operations in Urban Terrain

Military operations in urban terrain (MOUT) remains a topic of great interest to the Marine Corps, in particular in light of current peacekeeping operations in Iraq and Afghanistan. While not an explicit concept of operations within EMW, MOUT remains a significant component in Marine Corps planning for urban peacekeeping and warfare. The challenges to MOUT are many and varied, including linguistic and cultural diversity among local populations that limit the ability to conduct intelligence and psychological operations; difficulties with mobility, communicating, sensing, targeting, and navigating in the structured three-dimensional urban environment; a lack of weapons with controllable lethality that could be used to more effectively tailor military responses; and the difficulties of training for operations in large-scale urban environments.[11]

Sea Power 21

In October 2002, the Chief of Naval Operations (CNO) introduced his vision, called Sea Power 21, in response to the challenges and opportunities of the 21st century. In the CNO's words, Sea Power 21 continues "the evolution of U.S. naval power from the blue-water, war-at-sea focus of the 'Maritime Strategy' (1986), through the littoral emphasis of '. . . From the Sea' (1992) and 'Forward . . . From the Sea' (1994), to a broadened strategy in which naval forces are fully integrated into global joint operations against regional and transnational dangers."[12]

The Sea Power 21 vision contains four pillars: Sea Strike, Sea Shield, Sea Basing, and FORCEnet. Sea Strike and Sea Shield embody the offensive and defensive capabilities of the naval forces. Sea Strike, in particular, explicitly includes STOM as the key operating concept for deployment of forces ashore. Sea Basing is expanded beyond the Marine Corps sea basing concept represented within EMW to a full operating concept to free all naval forces from the limitations of, and the necessity for, local port facilities through sophisticated at-sea command and control and extensive ship-to-ship and ship-to-shore rapid, heavy-lift logistics capabilities. Finally, FORCEnet is an integrating concept that covers the networking, communications, and computer architectures and technologies needed to implement network-centric concepts, and it will tie together and enable the other three pillars of Sea Power 21.

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[10]Gen James L. Jones, USMC, Commandant of the Marine Corps. 2001. *Expeditionary Maneuver Warfare,* Department of the Navy, November 10.

[11]For additional reading on MOUT, see Marine Corps Combat Development Command, 1997, "A Concept for Future Military Operations in Urbanized Terrain," United States Marine Corps, Quantico, Va., July 25.

[12]Gordon England, Secretary of the Navy; ADM Vern Clark, USN, Chief of Naval Operations; and Gen James L. Jones, USMC, Commandant of the Marine Corps. 2002. *Naval Power 21…A Naval Vision,* Department of the Navy, October.

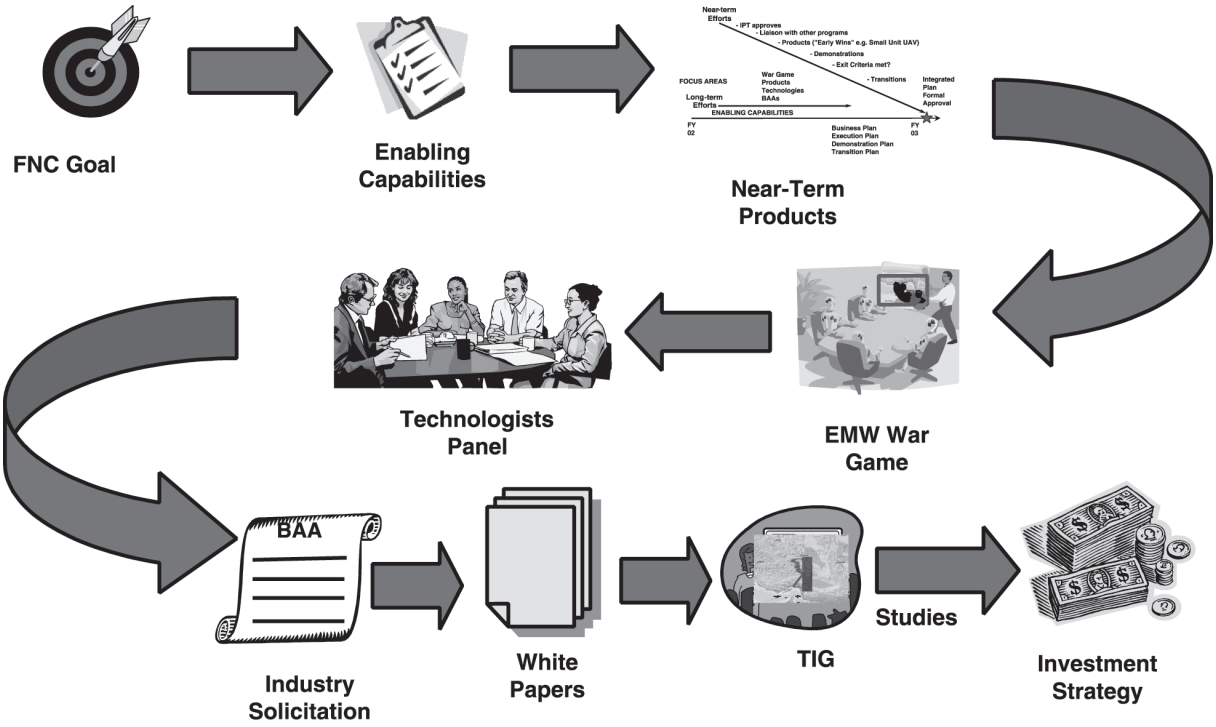

FIGURE 1.1 LC-FNC process for formulating an S&T investment strategy. SOURCE: Thomas O'Leary, Director, Expeditionary Warfare Operations Technology Division, Office of Naval Research, "ONR's Marine Corps Science and Technology Program: The Context," slide 10, presentation to the committee on May 13, 2003. NOTE: Acronyms are defined in Appendix C.

BAAs are a good mechanism for discovering novel ideas, overreliance on them as a source of all ideas that might be developed into an S&T investment strategy is a concern to the committee. Responses to BAAs are somewhat unpredictable. Because there is no guarantee that all areas of interest have been covered, simply rearranging the BAA responses does not constitute a valid planning process.

In a TIG, teams of users assessed the potential benefits of the BAA-proposed solutions in a STOM scenario. Those BAA solutions that TIG users judged would be of the greatest benefit to STOM operations (as represented in the war game) were then given the highest priority for support.

The results of this exercise, did not, however, appear to the committee to have been used extensively to select new research for the FNC to support. For example, the top-ranked BAA proposal, for development of a buoyant stratospheric vehicle, received no support from the MCS&T program office. Code 353 called this vehicle an "Army interest," and the LC-FNC offered no support for the effort. The second-ranked proposal, for advanced data compression, saw some funding but was not supported at a level commensurate with its high rankings. Development of Iridium phones for Marine Corps use had the lowest priority, but in recent action in Iraq, the Marine Corps praised Iridium highly and noted strong support for it or an equivalent technology.[10]

[10]Marine Corps Combat Development Command. 2003. *Field Report Marine Corps Systems Command Liaison Team, Central Iraq (April 20-25, 2003),* Quantico, Va., May.

Concerns About the Current Process and Recommendations for Improvements

While the current process, with its reliance on war games and external group review, is an excellent start on a much-needed formal process for developing an appropriate S&T investment strategy, the committee had two major concerns about which it has suggestions for improvement:

- The exclusive reliance on BAA responses to provide the candidate elements of a valid S&T strategy is a fundamental flaw in the process. Collecting BAA responses does not guarantee that all critical issues are being addressed, and simply rearranging them does not constitute a plan.
- The final evaluation of the proposed S&T investment strategy should not be made by a group of users (in this case, participants in the TIG). Users and technologists often have dramatically differing visions of the role of S&T and how best to leverage S&T to support military operations.

The issue of constructing valid S&T plans from user inputs touches on one of the major difficulties encountered at the interface between users and S&T—each community (S&T and users) speaks a different language. Each has its own goals, objectives, priorities, terminology, definitions of success, and so forth, and often one simply does not understand the other. Users typically want "things" that do something, are reliable, and are delivered on time, at cost, and with user manuals and other logistics support. The S&T community, on the other hand, more often delivers technologies and technical capabilities that allow the users to envision the "things" they seek. Only rarely does an S&T project result in an immediately useful gadget. A good example is the cell phone. It was built on a base of hundreds, if not thousands, of small technology advances—in plastics, analog and digital electronic circuits, communication algorithms, infrastructure (e.g., relay towers, antennas, and land lines), software, and so on. The cell phone did not emerge from a single S&T project.

The key to translating mission needs into S&T research lies in bringing to bear the talents of certain unusual people who understand and speak the languages of both communities. Such "bilingual" individuals listen to users, understand what they are seeking, and then turn to the S&T community with a knowledge of how the S&T research and development process works. By understanding the state of the art of the relevant technologies, they are able to help identify a series of specific projects that support the needs expressed by the users. It is hoped that Code 353 will continue to have as its director such an individual. Such people are often found among S&T workers who have undertaken management responsibilities that have brought them into intimate contact with the user community.

To improve the planning process, it is recommended that following a review of capability gaps by the panel of technologists, ONR replace the BAA solicitations and TIG analysis with a team of users/technologists who will consider user concerns, as expressed in the list of critical shortfalls identified at the front part of the process. Then, with the current state of the art and the capabilities of the organization in mind, they will propose a series of specific projects that represent the final S&T investment strategy. BAAs are a reasonable adjunct but should not be the only inputs considered. In addition, before it is submitted for approval by the LC-FNC IPT, the resulting investment strategy should be reviewed not by users but by another independent group of bilingual technologists.

In some contexts it was clear that ONR 353 had generalized to other planning exercises the basic structure of the planning process used for the FNC. The committee strongly supports this approach. The same comments on improving the process hold true for these other applications as well. With the back end of the process strengthened, this would certainly be an excellent and broadly applicable model for S&T planning.

Relevant to these suggestions, the committee notes that in parallel with the above LC-FNC planning

process, Code 353 also supported an Institute for Defense Analyses (IDA) study to identify critical capability shortfalls specific to STOM command, control, communications, computers, and intelligence (C4I).[11] The output of that study was another component for the LC-FNC investment strategy. In many ways the IDA study's approach duplicated the formal planning process—that is, it started with operational concepts and experience and ended with the identification of critical STOM deficiencies and candidate S&T initiatives to supply the needed capabilities. Importantly, no BAA process was invoked: The authors of the IDA study thought for themselves, and, thus, IDA's process closely resembles the modified planning process the committee is recommending to Code 353.

Recommendation. Code 353 should take the following steps to strengthen the LC-FNC strategy for investing in S&T.

- Avoid relying solely on Broad Agency Announcement solicitations and reorganization of the responses; instead, use a "translation" team of bilingual people skilled in understanding and interpreting the users' concerns and needs as the basis for identifying a series of specific projects representing a final S&T investment strategy.
- Ensure that the final review of the resulting S&T investment strategy is done by another independent group of appropriately bilingual (user/technologist) experts.

During the current review the committee felt that most of the projects presented (not just in the LC-FNC, but in Core Thrusts and Basic Research as well) were of interest to the Marine Corps. However, it also believed that more cohesion was necessary to develop the balance of effort needed to support the overall Marine Corps mission. In particular, the committee thought that the entire MCS&T program, including the Core Thrusts and Basic Research, would benefit from the consistent application of an S&T investment strategy formulation process based on the one recommended here for the LC-FNC. This overall planning process should enable Code 353 to identify critical Marine Corps capability gaps and to systematically plan S&T efforts to fill them.

Recommendation. Code 353 should develop a robust process for formulating an S&T investment strategy based on planning of the kind recommended for the LC-FNC and focused on Marine Corps capabilities needed for Expeditionary Maneuver Warfare. Code 353 should then apply that strategy to all aspects of the MCS&T program.

Effect of the LC-FNC on the Core Thrusts

The LC-FNC appears to have greatly benefited Code 353 through its sustained funding, its attention from the Navy, its strong focus on Marine Corps problems, and its creation of a promising S&T investment planning process. At the same time, however, the establishment of the LC-FNC also appears to have had an adverse impact on the content of Code 353's Core Thrusts efforts.

FNCs, in general, are focused on the near-term transitioning of products to address established and prioritized requirements rather than on the broad development of technology.[12] ONR's D&I initiative

[11]Institute for Defense Analyses. To be published. *Science and Technology Initiatives to Support Maneuver Planning and Execution in Naval Expeditionary Warfare*, draft, Arlington, Va.

[12]CAPT Stephen Hancock, USN, Head, Naval Expeditionary Warfare Science and Technology Department, Office of Naval Research, "Overview of Discovery and Invention and Future Naval Capabilities Programs," slide 8, presentation to the committee on May 13, 2003.

(which includes Basic Research and Core Thrusts), on the other hand, is closer to ONR's original mission and is intended to focus on long-term, basic scientific discovery to support the S&T base necessary for future Navy and Marine Corps technology exploitation and to engage in preliminary exploration leading to new technologies.

While valuable in themselves, the FNCs are intended to complement the remaining D&I portion of ONR's portfolio. However, the committee observed that the intended separation of efforts with different time horizons (near- versus long-term) and a different mission focus (transition versus discovery) into the FNC and D&I elements appears to have been weakened in many of the Core Thrust projects reviewed.

In particular, while Code 353 seems to have initiated in the Core Thrusts a strong focus on Marine Corps technology needs, several of the resulting projects have transition plans and short-term goals similar to those of FNC projects.[13] In addition, many of the short-term projects appear to the committee to emphasize minor improvements to existing hardware or to be focused on the integration of existing systems, which means that they are not developing the base-level technologies necessary for significant improvements in capabilities. It should be noted, in this context, that Code 353 plans to allocate approximately $15 million annually through FY07 to non-FNC 6.3 programs.[14] This support for FNC-like elements within Core Thrusts was a source of concern to the committee since it complicates the division of mission between the LC-FNC and the Core Thrusts elements of the MCS&T program.

The above concerns were first brought to the attention of Code 353 in the NSB 2000 review of the MCS&T. Among other things, that review recommended that Code 353 "eliminate . . . [from the Core Thrusts] activities that do not conform to the usual ONR S&T standards of innovation and technical aggressiveness . . . [and] embark on a discovery program to identify and refine technologies that can have a substantial payoff in achieving OMFTS."[15] Although Core Thrusts need not exclude all exploitation and transition initiatives, those projects supported should meet ONR's standards for quality and should remain more flexible in terms of program requirements and timelines than is typical for FNCs.

Recommendation. Code 353 should ensure that the MCS&T program's Core Thrusts and Basic Research components support the mission of discovery and invention, that is, exploration aimed at the long-term development of base-level technologies that could support future FNC and Marine Corps Warfighting Laboratory program initiatives. Thus, Code 353 should remove from the Corps Thrusts and Basic Research portfolios short-term, transition-oriented initiatives.

Aspects of Transitioning Products to Use

Although the concept of transitioning products to use in the field seems clear enough, it involves a few potential problems that must be avoided. Users who agree to accept a product in transition from the S&T community generally expect something that can be rapidly fielded, that is, a product similar to a fully commercial product. Such commercial products typically have integrated corrosion and shock resistance, detailed drawings, user guides, repair manuals, and the like. Reliability, manufacturability,

[13]One example is the tactical unmanned ground vehicles project, which was briefed to the committee as part of Code 353's Core Thrusts yet is also listed on other ONR documents as a project supported through ONR's Autonomous Operations FNC.

[14]Thomas O'Leary, Director, Expeditionary Warfare Operations Technology Division, Office of Naval Research, "ONR's Marine Corps Science and Technology Program: The Context," slide 14, presentation to the committee on May 13, 2003.

[15] Naval Studies Board, National Research Council. 2000. *2000 Assessment of the Office of Naval Research's Marine Corps Science and Technology Program,* National Academy Press, Washington, D.C., p. 2.

serviceability, and so on constitute a particular suite of capabilities, commonly referred to as the "-ilities," often found to be critical to use of products in the field. It was clear, however, that such capabilities were not being considered within any of the current products and evidently were assumed to be something that could be added later on during the acquisition program.

In the committee's experience, building in capabilities such as reliability can strongly affect the fundamental design of a product and typically cannot be done after the fact. The lack of such features can affect the utility of a product or slow its adoption. For example, during Operation Iraqi Freedom, Dragon Eye, a hand-launched unmanned air vehicle (UAV) supported by ONR, was deployed with several Marine Corps units; however, some of these UAVs were not used in theater because the controlling computer failed just before the unit crossed the line of departure and no one at the scene knew how to repair the system.[16]

The impact of the "-ilities" on products intended for transition should be considered up-front by anticipating and incorporating critical design features and perhaps then consciously deciding not to implement them fully in the interest of time and money. Code 353 also must work to ensure that the user really understands just what is to be transitioned as a result of the S&T development process.

Another aspect of transitioning products to use lies in the fact that almost all fielded naval equipment is supplied by contractors and not by the Navy or the Marine Corps itself. Thus it is critical that ONR-developed technology and products find their way as quickly as possible into the contractor community. Many of Code 353's projects aim to connect with and transition into this community, as much of the S&T work is performed out-of-house through various, often competing contractors. The committee encourages this effort.

Recommendation. For S&T development products intended for transition, Code 353 should develop technology transition plans that include up-front considerations of the "-ilities," such as product reliability, manufacturability, maintainability, and other capabilities necessary in the overall fielding of products to the user community.

Optimistic Use of Technology Readiness Levels

At several points during the committee's review, projects were presented with explicit timelines for meeting a series of technology readiness levels. Initially used by NASA in developing successful space and aerospace systems, the concept of technology readiness levels (TRLs) now finds wide application throughout the Services. Most organizations have converged on nine levels of technology readiness, from basic research to full operational use (see Appendix D), as benchmarks for assessing the maturity of a technology or product.

Customized TRLs incorporating explicit references to the technologies or applications involved have been generated by various organizations, including the Army.[17] No Marine Corps- or Navy-specific definitions of TRLs were offered during the committee's review, although NASA definitions are no doubt useful. Code 353 (and perhaps ONR in general) would benefit from tailoring TRLs to Marine Corps (or Navy) use.

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[16]Marine Corps Combat Development Command. 2003. *Field Report Marine Corps Systems Command Liaison Team, Central Iraq (April 20-25, 2003),* Quantico, Va., May.

[17]Caroline P. Graettinger, Suzanne Garcia, and Jeannine Siviy (Software Engineering Institute, CMU), and Robert J. Schenk and Peter J. Van Syckle (U.S. Army CECOM RDEC STCD). 2002. *Using the Technology Readiness Levels Scale to Support Technology Management in the DOD's ATD/STO Environments*, Special Report, CMU/SEI-2002-SR-027, Software Engineering Institute, Carnegie Mellon University, Pittsburgh, Pa., September. Available online at <http://www.sei.cmu.edu/pub/documents/02.reports/pdf/02sr027.pdf>. Accessed on August 20, 2003.

TRLs are valuable and their use is encouraged. The committee expressed two concerns, however: (1) the levels targeted for several projects (typically TRL 5, 6, or 7) seemed higher than can generally be expected for projects emerging from 6.2- or 6.3-funded efforts and (2) the time intervals for advancing between levels were unrealistically brief (1 year between each in several instances).[18] NASA has found that for most systems an increase by one level per year in technology readiness is rarely possible.[19] To avoid disappointment, use of TRLs should be carefully reexamined in light of NASA's long experience.

Recommendation. Code 353 should reexamine its use of technology readiness levels, define levels specific to Navy (or Marine Corps) missions, and develop means for estimating realistic time intervals for transitions between levels.

Responses to Issues from the 2000 NSB Assessment

During the current review, the committee noted that Code 353 was explicitly responsive to the recommendations made in the 2000 NSB assessment of the MCS&T program.[20] The presentations consistently mentioned and discussed the issues raised, indicating which recommendations had been implemented, and to what degree. Nevertheless, despite the importance of the 2000 review's primary recommendation—which was to "eliminate from the Code 353 program, at an orderly but determined pace, preacquisition and other activities that do not conform to the usual ONR S&T standards of innovation and technical aggressiveness (p. 2)"—the current committee found that many existing (and planned) programs still appear to be highly tied to preacquisition activities. In particular, the committee is concerned that the Core Thrusts component continues to support transition-focused, short-time-horizon technology development projects.

In the 2000 review, a number of high-level technical deficiencies in the overall MCS&T program were identified, including the following:

- A "lack of quantitative systems analyses" and of a strong two-way relationship with MCCDC (p. 11);
- The "relative neglect of joint operations"—that is, of network-centric operations and of non-organic support for operations" (p. 12);
- The "neglect of deception and concealment"—both OMFTS and STOM emphasize avoidance of the enemy (p. 12);
- The "relative neglect of MOUT [military operations in urban terrain]" (p. 12); and
- The use of "performer-determined goals"—that is, of priorities not systematically established by Marine Corps needs because of weak connections between ONR and MCCDC (p. 13).

By and large the current program is in the process of addressing these issues—some vigorously and effectively, others less so, but all nonetheless to some degree.

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[18]For example, see "Microchannel Methanol Fuel Cell" under the Logistics core thrust in Chapter 3.

[19]Deborah J. Peisen and Catherine L. Schulz (Science Applications International Corporation), and Richard S. Golaszewski, B. David Ballard, and John J. Smith (GRA, Incorporated). 1999. *Case Studies: Time Required to Mature Aeronautic Technologies to Operational Readiness,* Task Order 221, Final Report, National Aeronautics and Space Administration Headquarters, Washington, D.C., November. Available online at <http://aerospace.nasa.gov/library/study/221/finalrpt.pdf>. Accessed on August 20, 2003.

[20]Naval Studies Board, National Research Council. 2000. *2000 Assessment of the Office of Naval Research's Marine Corps Science and Technology Program*, National Academy Press, Washington, D.C.

2

Littoral Combat Future Naval Capability

OVERVIEW

The Littoral Combat (LC) component of the Littoral Combat and Power Projection Future Naval Capability (FNC), initiated in FY02, concentrates on the application of technology rather than its development and emphasizes achieving technology transition by delivering products on time, within budget, and with agreed-upon performance specifications. Given its goal to support "assured access and sustained operations in the littorals as the naval component to joint operations,"[1] the LC-FNC focuses on the concerns raised in *Naval Operating Concept for Joint Operations*[2] and, in particular, on Expeditionary Maneuver Warfare (EMW),[3] the Marine Corps capstone concept. Unlike other FNC efforts, the LC-FNC's mission requires that its initiatives cut across other systems-focused FNCs and leverage their critical technologies, products, and support.

As described in Chapter 1, a formal process put in place by Code 353 to convert LC-FNC goals into an S&T investment strategy uses war games and other similar concept-generating exercises to identify and prioritize current Ship-to-Objective Maneuver (STOM) capability shortfalls as input for a long-term, concrete plan of action for the LC-FNC program. Planning for long-term efforts involves the full process shown in Figure 1.1. Near-term efforts (to be completed in as little as 18 months) are intended to provide rapid results and a funding wedge for the LC-FNC, so that slowly ramped up funding can be allocated without limiting its future use for developing the long-term efforts identified in the planning process.

[1]Barry Blumenthal, Program Manager, Littoral Combat FNC, Office of Naval Research, "Littoral Combat Future Naval Capability," slide 13, presentation to the committee on May 14, 2003.

[2]ADM Vern Clark, USN, Chief of Naval Operations, and Gen Michael W. Hagee, USMC, Commandant of the Marine Corps. 2003. *Naval Operating Concept for Joint Operations*, Department of the Navy, March.

[3]Headquarters, U.S. Marine Corps. 2001. *Expeditionary Maneuver Warfare,* Department of the Navy, November 10.

LC-FNC Mission Focus

The committee noted that the LC-FNC is still in the early stages of development, as indicated by the near-term nature of the projects presented, most of which appeared to be a continuation of pre-FNC or commercial off-the-shelf (COTS) application efforts reasonably relevant to EMW goals. It was difficult to see in these projects the overall mission focus of the FNC—the EMW shortfalls being addressed, the criticality of each, the interrelationships among individual projects, and so on. A number of FY04 new starts were presented that may well have been outputs from the first steps of the long-term planning process but did not show direct linkage to the S&T priorities set as a result of the planning activities.

For example, Operational Maneuver From the Sea (OMFTS) and STOM—two concepts that represent specific goals and means for enabling EMW and are heavily used in capabilities analysis within the broader Marine Corps—were not explicitly referred to in many project descriptions. This omission caused the committee to be concerned about the level of integration between the LC-FNC and overarching Marine Corps needs, although the committee recognized that short-term projects might be indicative of only part of the current planning process guiding long-term program development. The formal planning process that is being used to develop the long-term investment strategy of the LC-FNC focuses explicitly on STOM as the driving concept of operation for the identification of capabilities shortfalls that could be addressed by the LC-FNC.

Although there is concern by the committee about the current near-term focus of the LC-FNC, the planning process introduced by the MCS&T program is well structured and promising. It should be improved and then applied rigorously across the FNC. The committee was pleased to learn that the Marine Corps will be communicating more directly about the near-term results it expects from the S&T community, particularly through the recently published *Expeditionary Maneuver Warfare Capability List*[4] and the soon-to-be completed Marine Corps S&T plan.[5]

Since the issuance of *Naval Operating Concept for Joint Operations* and *Naval Power 21,* the Marine Corps and the Navy have adopted Marine Corps Strategy 21 and Sea Power 21 as overriding Service-specific operational concepts. The committee is concerned that although the LC-FNC seems to be responding strongly to the principal Marine Corps concept of STOM,[6] it is not focused on the implications of EMW for the Marine Corps—in particular, the integral sea basing component, which is closely aligned with OMFTS and STOM. The absence of attention to logistical issues associated with sea basing was especially noted by the committee, given the recent statement by the Commandant of the Marine Corps that sea basing is one of the highest-priority Marine Corps development initiatives.[7]

Part of the reason for this lack of focus on sea basing within the LC-FNC is that the Department of the Navy's Science and Technology Corporate Board, which approves and prioritizes all FNCs, initiated a separate FNC component scheduled to start in FY05—the Expeditionary Logistics (ExLog) component of the Littoral Combat and Power Projection FNC—to examine issues related to sea-based logis-

[4]LtGen Edward Hanlon, Jr., USMC, Deputy Commandant, Combat Development. 2003. *Expeditionary Maneuver Warfare Capability List (ECL)*. Expeditionary Force Development Center, Marine Corps Combat Development Command, Quantico, Va., June 16. Available online at <https://www.mccdc.usmc.mil/ECL2003.pdf>. Accessed on December 12, 2003.

[5]See Chapter 1, subsection entitled "ONR and Code 353's Relationship with the Marine Corps."

[6]Air defense needs are not addressed in the current MCS&T program. Code 353 is actively coordinating with the Missile Defense FNC to address Marine Corps air defense needs.

[7]Special Projects Directorate, U.S. Marine Corps Headquarters. 2003. "The Marine Corps General," Vol. 15, April 14.

tics.[8] The ExLog-FNC is tasked to address gaps in critical logistical capabilities (such as deployment from and reconstitution of a sea base) for naval forces engaged in expeditionary operations.[9] Yet, although the LC-FNC and the ExLog-FNC are closely related in mission, they nevertheless have separate IPTs, separate performing organizations (the S&T lead for the ExLog-FNC is ONR Code 36—Industrial and Corporate Programs), and separate funding. The committee saw no evidence of interaction between these two FNC components. Considering the critical role logistics plays in enabling OMFTS and STOM, this separation seems unwise.

The LC-FNC consists of four enabling capabilities (ECs) under which the various projects are grouped: EC 1—Intelligence, Surveillance, and Reconnaissance (ISR) for the Amphibious Force; EC 2—Expeditionary Fire Support for the Marine Air-Ground Task Force (MAGTF); EC 3—MAGTF Maneuver in the Littorals; and EC 4—Command and Control (C2). These four ECs appear to the committee to provide a reasonable set of program areas for coordination and categorization of the shortfalls in EMW capabilities identified in the planning process.

The committee's general findings and recommendations for the LC-FNC are provided below. Each section after that reviews one of the four constituent ECs and the projects within each.

Recommendation for the Overall LC-FNC

Recommendation. The Department of the Navy's Science and Technology Corporate Board should (1) expand the LC-FNC's mission to include Marine Corps capability needs for all of Expeditionary Maneuver Warfare and (2) provide a means for strongly coupling the integrated product teams for the Littoral Combat and the Expeditionary Logistics components of the Littoral Combat and Power Projection FNC. At a minimum, it should assign Code 353 the co-S&T lead of the ExLog-FNC (with full voting rights) while retaining Code 353 as the S&T lead of the LC-FNC.

EC 1—INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE FOR THE AMPHIBIOUS FORCE

EC 1 is intended to provide enhanced autonomous and semiautonomous intelligence, surveillance, and reconnaissance (ISR) capabilities that can be locally assigned and controlled. It includes the Tactical Unmanned Aerial Vehicle Platform product line, which supports development of the hardware and software necessary for a deployable tactical unmanned aerial vehicle (UAV), and the Tactical Sensors product line, which supports development of sonar, electro-optic/infrared (EO/IR), radio frequency (RF), and chemical, radiological, and biological (CRB) sensor systems.

EC 1—Findings and Recommendations

The committee found that the EC 1 projects address many valid and critical Marine Corps ISR issues and should continue in the same general direction. However, four of the five EC 1 projects focus on the development of a Tier II UAV platform and its sensors. Based on lessons from recent operations

[8]The Department of the Navy Science and Technology Corporate Board is composed of the Vice Chief of Naval Operations, the Assistant Commandant of the Marine Corps, and the Assistant Secretary of the Navy for Research, Development, and Acquisition.

[9]Expeditionary Logistics (ExLog) component of the Littoral Combat and Power Projection Future Naval Capability (FNC). 2002. *Expeditionary Logistics,* Office of Naval Research, Arlington, Va., June 3. Available online at <http://www.onr.navy.mil/explog/explog/overview.asp>. Accessed on August 20, 2003.

in Afghanistan, the Marine Corps is considering redefining the requirements for the Tier II UAV project. The committee is concerned that the Tier II UAV's dominance within EC 1 is causing funding for other LC-FNC projects to be overly restricted. Specific recommendations for each project are offered in the relevant sections below.

In addition, the committee noted that the Tier II UAV and the chemical, radiological, and biological payload projects are in many cases significantly affected by directions prescribed by Joint Service offices. When asked, Code 353 said it did not have a thorough knowledge of these subjects and had only limited interaction with the relevant Joint Service offices.

Recommendation. Code 353 should reexamine EC 1, ISR for the Amphibious Force, and seek to expand its funding options beyond sensors and platforms tied to Tier II UAV development.

Recommendation. Code 353 should establish better coordination between EC 1, ISR for the Amphibious Force, and EC 4, Command and Control, as well as better coordination with related intelligence community, joint, and other Service research and development programs.

Tactical Unmanned Aerial Vehicle Platform Product Line

Tier II Unmanned Aerial Vehicle

The Tier II UAV project is focused on development of a mid-range vertical takeoff and landing capability with an emphasis on performance, endurance, and payload. It is viewed as mid-range between a Tier I (hand-launched, limited-performance) platform and the much more capable Tier III (longer-range, higher-performance) platform. Candidates for the Tier II UAV platform are the Dragon Warrior helicopter and a ducted-fan vehicle. Both prototype vehicles have demonstrated flight capability. Potential plug-and-play sensors being developed for the Tier II platform were described in briefing material presented to the committee.

Findings and Recommendations. The committee finds that Tier II platform development is well within the scope of the LC-FNC and represents a viable advanced development effort. Vertical takeoff and landing capability, autonomous flight, engines using heavy fuels, and modular plug-and-play payloads are all excellent objectives. Prototype tests of both candidate platforms appear to be making solid progress in establishing flight stability, endurance, and range. If the purpose of developing a 42-inch-diameter version of the ducted-fan vehicle is to demonstrate payload or performance levels comparable to those of the Dragon Warrior helicopter, then the committee views such a comparison as a useful endeavor that also enables cost and performance profiles for the larger fan system.

The Marine Corps currently envisions several levels of UAV support for its warfighters ashore. At the level of battalion and company, the man-portable Dragon Eye system has already proven its worth in the field. From the division down to the regimental level of the Marine Expeditionary Force (MEF), the Marine Corps appears to be supporting a vertical takeoff UAV system suitable for both ship-based and forward land-based use. A concern of the committee is that after-action reports from Operation Iraqi Freedom have indicated that tactical ISR systems (such as that envisioned here) often did not have the horizontal speed necessary to keep up with rapid ground operations.[10] Even if these vehicles cannot attain such high horizontal speeds, they might still play a valuable role in military operations in urban terrain.

[10]Marine Corps Combat Development Command. 2003. *Field Report Marine Corps Systems Command Liaison Team, Central Iraq (April 20-25, 2003),* Quantico, Va., May.

Recommendation. Code 353 should continue Tier II UAV development through a demonstration phase involving tests of both functional platforms (the Dragon Warrior helicopter and the ducted-fan vehicle) in tactical environments to thoroughly establish their potential military utility and roles.

Recommendation. Code 353 should examine the potential of the Dragon Warrior helicopter and the ducted-fan vehicle to support short-range missions such as military operations in urban terrain.

Recommendation. The Marine Corps should reevaluate the operational altitude objective for Tier II UAVs to determine if such vehicles can support their projected use as a communications relay.

Tactical Sensors Product Line

Tactical Hydrographic Survey Equipment

The tactical hydrographic survey equipment project is focused on the development of a next-generation underwater survey and mapping system to address the tasks of shallow water underwater reconnaissance and beach surveillance. For decades, these tasks have been personnel-intensive, with trained divers recording observations with grease pencils. The tactical hydrographic survey equipment integrates a 1.2-MHz sonar, a Global Positioning System (GPS) geolocation capability, data storage, a satellite communications (SATCOM) data link, and a 3-knot-capable diver propulsion device (DPD) into a single deployable package.

Findings and Recommendations. The committee finds that the tactical hydrographic survey equipment project addresses a key EMW requirement by providing timely knowledge of coastal bottom contours and beach conditions prior to amphibious landings, including the detection of various man-made obstacles. Furthermore, the committee views this effort as addressing a unique Marine Corps capability requirement.

Recommendation. Code 353 should continue development of the tactical hydrographic survey equipment as planned, with tactical marine environment experimentation and testing taking place at the earliest possible time.

Recommendation. Code 353 should initiate an analysis of systems-level communications and processing to define the trade-offs in local versus remote data processing, to identify data throughput requirements and the potential availability of satellite channels for transmission of sensor data to over-the-horizon receivers, and to consider an alternative (backup) communications path if satellite capacity is not available.

Tactical Littoral Sensing Payload

The tactical littoral sensing payload project is focused on the development of a high-resolution EO/IR sensor for ISR of mines, obstacles, terrain elevation, and bathymetry. Project components will include a lightweight EO/IR sensor, algorithms from the Airborne Remote Optical Spotlight System (AROSS), and, potentially, a small gimbaled system for sensor incorporation on a Tier II UAV. Operational enhancements include precision targeting, water depth and current speed measurements, and navigation aids for the advanced amphibious assault vehicle (AAAV) operations in threat areas. The

Army Night Vision and Electronic Sensors Directorate (NVESD), the Army Research Laboratory (ARL), several Department of Energy (DOE) laboratories, and various defense contractors have all done work in this area.

Findings and Recommendations. The tactical littoral sensing payload project offers a potential for wide-area surveillance of minefields and obstacles that the Marine Corps should pursue. In its present state of development, the sensor has demonstrated that it can detect minelike objects in daylight, although the algorithms need to be considerably improved in order to reach the desired real-time performance. Code 353 expects to transition the technology to the Coastal Battlefield Reconnaissance and Analysis (COBRA) program and/or a future UAV to provide mine detection, targeting, and other ISR capabilities.[11] Although this project is targeting COBRA for technology insertion, there are no preplanned product improvement (P3I) plans, nor has funding been identified in the COBRA program to incorporate the products described above.

The project appears to significantly overlap ONR's Rapid Overt Airborne Reconnaissance (ROAR) program. The Army NVESD is also developing an ISR system under the Airborne Standoff Minefield Detection System (ASTAMIDS) program that overlaps some objectives of the tactical littoral sensing payload project (terrain elevation, target tracking, high resolution, high dynamic range, and multisensor payload including EO/IR).

Recommendation. Code 353 should establish a clear collaboration between the tactical littoral sensing payload project, the Coastal Battlefield Reconnaissance and Analysis program, and the airborne standoff mine detection system project to minimize redundant efforts and to increase emphasis on the identification of fixed and moving targets without the need for overflight.

Recommendation. Code 353 should review the tactical littoral sensing payload project and the Rapid Overt Airborne Reconnaissance program to eliminate overlaps and to free much-needed resources.

Recommendation. Code 353 should maintain strong ties to and collaboration with the Army Night Vision and Electronic Sensors Directorate.[12]

Radio Frequency Emitter Mapping Payload

The radio frequency emitter mapping payload project is a follow-on to the recently completed mobile direction finding project.[13] The purpose of the current project is to develop a RF sensing payload based on COTS hardware that is compatible with the Tier II UAV development effort. The sensor will

[11]Jay G. Moore, Manager (Acting), Expeditionary Intelligence, Surveillance, and Reconnaissance for the Amphibious Force, "Littoral Combat Future Naval Capability—Intelligence, Surveillance, and Reconnaissance," slides 12 to 15, presentation to the committee on May 14, 2003.

[12]Army and Marine Corps cooperation in the development of countermine systems is cited in Army RDT&E Budget Item Justification (R-2 Exhibit), PE 0602712A—Countermine Systems, February 2003. Available online at <http://www.dtic.mil/descriptivesum/Y2004/Army/0602712A.pdf>. Accessed on August 20, 2003.

[13]See "Mobile Direction Finding" under the C4ISR core thrust in Chapter 3.

be designed to uniquely detect, identify, geolocate, and track battlefield RF emitters and thus create a map of these emitters for use by the tactical commander. Position measurements would be computed utilizing a combination of time and frequency difference of arrival methods. Time difference of arrival (TDOA) is a standard technique for establishing emitter bearing, and multiple measurement nodes (three or more points or a single extended aperture) are required to establish geolocation through intersection of the TDOA lines. Frequency difference of arrival (FDOA) positioning techniques measure Doppler-induced frequency differences produced by a moving source or receiver.[14] Key to this system is the development of a wavelet transform to allow for the generation of a unique signal pattern for each emitter. In addition, a system will be developed for combining each set of measurements to develop a multipoint, time-integrated picture of a given RF source.

Findings and Recommendations. The committee places the radio frequency emitter mapping payload project in the moderate- to high-risk category, given the project's stated goals. Unique detection, identification, geolocation, and tracking are exceedingly difficult in a noisy RF environment and generally require a multitude of sensing nodes collecting and correlating signal characteristics in near-real time. A complex urban environment typically leads to large numbers of multiple reflections arising from each emitter; this issue makes the project challenging. The committee finds that the current effort poses significant technical challenges that do not appear to have been sufficiently resolved.

Recommendation. Code 353 should initiate a systems-level analysis to determine the feasibility of the radio frequency emitter mapping payload project's objectives, including the feasibility of mapping RF emitters in a noisy RF environment to the degree planned for in the project's objectives. Analyses should establish the level of preprocessing needed at the sensing platform, the processing needed at the control node, and the performance characteristics of the connecting data communications and order links. The availability and quality of service of communications channels should be key factors in such a systems-type analysis.

Recommendation. Code 353 should work closely with related commercial, intelligence, and other Service initiatives aimed at radio frequency emitter mapping.

Chemical, Radiological, and Biological Payload

The chemical, radiological, and biological payload project is focused on the development of an integrated sensor package capable of detecting CRB agents from an airborne platform. The project is being performed in conjunction with the Tier II UAV platform project and represents one of the plug-and-play payloads envisioned.

Findings and Recommendations. The committee regards the chemical, radiological, and biological payload project as critically important at present in light of the potential battlefield use of CRB agents. Selected sensors are available with demonstrated capability to separately detect chemical, radiological, or biological agents. A complication is that, while radiological and chemical sensors can respond in near-real time, biological sensors generally cannot. The technical challenge is to integrate these indi-

[14]FDOA was used in the Navy navigation satellite system known as Transit.

vidual capabilities into a single unit with airborne potential while dealing effectively with the sensors' very different characteristic detection times. An added difficulty is that weight goals are often hard to meet with systems that combine CRB detection capabilities. The 100-lb weight limit postulated for this project appears to the committee to be overly ambitious for the current state of the art.

The management of S&T programs in chemical and biological defense is a congressionally mandated responsibility of the Deputy Assistant to the Secretary of Defense for Chemical and Biological Defense, in coordination with the Joint Science and Technology Panel for Chemical and Biological Defense.[15] This joint panel has representation from all the Services. It was clear to the committee that Code 353 had made no contact with these DOD and joint offices.

Recommendation. Code 353 should establish a clear working relationship with the Joint Science and Technology Panel for Chemical and Biological Defense and coordinate with its science and technology initiatives and programs.

Recommendation. With appropriate coordination, Code 353 should continue the chemical, radiological, and biological payload project as planned but should conduct a systems-level analysis to identify operational concepts for the airborne sensor and supporting infrastructure.[16]

Recommendation. Code 353 should reexamine the 100-lb weight goal for the planned chemical, radiological, and biological payload and determine how the UAV's performance would be affected by increasing the sensor weight.

EC 2—EXPEDITIONARY FIRE SUPPORT FOR THE MAGTF

EC 2 is intended to enhance fire support for elements of a Marine Air-Ground Task Force (MAGTF) operating ashore by providing improved ammunitions and by integrating and networking all legacy and future fire support systems. Meeting the objective of "first round fire for effect" requires five characteristic capabilities: accurate target location, accurate fire unit location, accurate weapon and ammunition data, access to accurate meteorological data, and accurate computational procedures. Designed to address technical demands associated with this range of objectives, EC 2 includes (1) the Improved Indirect Fire Weapon System product line, with three projects; (2) the Networked Fires product line, with two projects; and (3) the Improved Ammunition product line, with four projects.

EC 2—Findings and Recommendation

EC 2 is at an early stage of development, with three of the nine projects well under way, two at the requirements stage, and four scheduled to start in FY04. Much of the proposed work (market surveys, development of conceptual architectures, and assessment of existing tools) seems to have been done well enough to encourage effective application of new technologies. At the same time, it was difficult for the committee to see the proposed work in the context of other existing efforts.

[15]In accordance with 50 USC 1522, chemical and biological defense programs within the Department of Defense are overseen by a single office within the Office of the Secretary of Defense.

[16]For example, interrelationships between rate of air sampling (volume and time), flight profile, onboard processing, control node processing, and available communication links must be taken into account in such an analysis.

The more mature projects are taking advantage of existing technology for near-term transition. Many of the projects heavily leverage Army or DARPA efforts in guns and advanced munitions, and the Networked Fires product line, in particular, will require significant coordination with all the Services.

Recommendation. Before FY04, Code 353 should assess the feasibility of integrating the expeditionary fire support projects with those of other Service components and should review relevant prior Army and DARPA studies.

Improved Indirect Fire Weapon System Product Line

Advanced Materials for Indirect Fire Weapons Systems

The advanced materials for indirect fire weapons systems project seeks to improve gun weapon systems by using new alloys and a redesign to reduce weight and improve mobility and set-up time. The selected Isogrid technology uses a grid array of ribs, precisely machined from stainless steel, to enhance structural integrity and increase the strength-to-weight ratio. The specific objective is to reduce the weight and the manufacturing costs of the M777 trail (the long support arms needed to balance the cannon during firing) without sacrificing performance.

Findings and Recommendations. The Isogrid technology appears very promising. This technology for fabrication of lightweight, high-strength materials has been demonstrated to reduce M777 trail weight (from 15,758 to 6,700 lb) and manufacturing cost. Isogrid trail components implemented through the advanced materials for indirect fire weapons systems project are being prepared for field testing at Twenty-nine Palms, California, in mid- to late-2003.

Recommendation. Due to the significant weight changes resulting from use of Isogrid components, Code 353 should address the effect of weight reduction on the firing behavior of the M777 weapon.

Recommendation. Code 353 should engage in future testing and analysis of Isogrid components, paying particular attention to questions of component reliability and fatigue under operational conditions.

Recommendation. Code 353 should conduct a manufacturing cost study of Isogrid components to quantify the benefits of reduced weight in light of expected changes in production cost.

Improved Fire Control Systems

Improved fire control and indirect fire capability for existing weapons are critical to the success of a lightweight fighting force, as envisioned in STOM. One aim of the improved fire control systems project is to improve the first-round accuracy of existing gun systems by integrating the sensitive inertial guidance component of an automatic aiming and pointing system onto the base plate of 120-mm and 105-mm howitzers. Success in this activity would have the additional benefit of permitting digital integration with the Advanced Field Artillery Tactical Data System at the gun level. A second activity seeks a methodology for using direct-fire weapons in an indirect-fire mode. In particular, an MK-47 Striker machine gun is to be modified with software enhancements to allow beyond-line-of-sight (BLOS) targeting.

Findings and Recommendations. Both activities in the improved fire control systems project entail incremental changes to existing systems, with a potential for greatly enhanced performance. These concepts seem practical and are reasonable near-term transition objectives for the LC-FNC.

The introduction of an advanced material and mounting system for integration of an aiming and pointing system onto the gun base plate has the potential to reduce both circle-error probability and time to emplace and fire. A late 2003 demonstration with live fire was anticipated.

The proposed modification for the MK-47 Striker to allow beyond-line-of-sight targeting has just begun and is only at the requirements definition stage.

Recommendation. Code 353 should proceed with demonstration and the transition of the aiming and pointing system into existing howitzers as quickly as possible.

Recommendation. Code 353 should develop a quantitative error budget for the MK-47 Striker targeting requirements for use in beyond-line-of-sight targeting.

Mortar and Mobility Transport System

The mortar and mobility transport system project is focused on the development of a lighter, more maneuverable, towed mortar platform consistent with V-22 and CH-53E air transportability. The platform will incorporate advanced materials and designs for weight reduction and maneuverability to facilitate aircraft loading and unloading. The goal is to develop a platform that enables an air-delivered weapon to rapidly transition to a mobile system, with the ability to be integrated with existing COTS mortars.

Findings and Recommendations. The mortar and mobility transport system project is ambitious, requiring the development of gun system models and engineering analysis for the design and fabrication of tires, wheels, axles, wheel maneuvers, and an adjustable suspension track system to facilitate loading from V-22s and CH-53Es. Because the goal of this system is to enable rapid maneuver, the committee noted that aspects of it may be better served through the EC 3 (Maneuver) of the LC-FNC.

Recommendation. Code 353 should develop a schedule to determine if the mortar and mobility transport system project can be realized in the relatively short time frame typical of FNC programs.

Recommendation. Code 353 should examine if some aspects of the mortar and mobility transport system project should be transferred to EC 3 (Maneuver) or to the Maneuver core thrust.

Networked Fires Product Line

Advanced Target Acquisition

The advanced target acquisition project has three activities. One is to produce an all-digital sensor-to-shooter system by integrating a Viper II eye-safe laser range finder, a rugged handheld computer, and a PRC 148 radio in a single handheld package. The second activity is to produce a handheld meteorological station to use on the battlefield; the station would measure environmental parameters critical to achieving firing accuracy—parameters such as atmospheric pressure, temperature, wind direction, and velocity. The wind-speed measurements are seen as especially important to the warfighter in calculating

firing solutions. The third activity is to enhance the existing target location, designation, and handoff system with a new target designator system and interoperability protocols to enable joint target handoffs.

Findings and Recommendations. A prototype of the digital sensor-to-shooter system currently deployed with operational forces sounds promising. The system has provided near-real-time targeting data from a forward observer for U.S. attack aircraft operating in Operation Iraqi Freedom to establish GPS coordinates for joint direct attack missiles and for close air support, and this system was reported to "significantly improve upon current CAS [close air support] capability."[17]

The handheld meteorological station is a new start scheduled for FY04, and no in-depth descriptive materials were presented.

The target location, designation, and hand-off system enhancement project is a new start for FY03 and has just completed the requirements definition phase.

Recommendation. Code 353 should continue advanced target acquisition project activities through their testing phase.

Recommendation. Code 353 should continue to support the handheld meteorological station through development and field-testing. Code 353 should also collaborate with the Army on small handheld meteorological devices.

Recommendation. Code 353 should continue the project for enhancing the target location, designation, and hand-off system and transition the system into operational use as soon as possible.

Recommendation. Code 353 should reexamine and improve the Viper II/RHC/PRC 148 integrated sensor-to-shooter system in light of recent reports on Operation Iraqi Freedom.

Recommendation. Code 353 should conduct testing of the Viper II/RHC/PRC 148 integrated sensor-to-shooter system in the context of the required target location error tolerance for the joint direct attack missile.

Integration with Naval Fires Network

The integration with the Naval Fires Network project aims to develop interoperability between the Marine Corps Advanced Field Artillery Tactical Data System (AFATDS) and the Air Force/Joint Forces' Theater Battle Management Core System (TBMCS). This project will enable naval forces to better integrate their air, surface, and ground C2 systems. The objective is to provide a means for robust planning, replanning, and deconfliction within a networked system to ensure that fire support resources are available to the warfighter when needed. The project is expected to proceed with a series of hardware and software improvements to each system that will facilitate coordination between systems.

Findings and Recommendation. The integration with Naval Fires Network project appears to fill a verified Marine Corps need and is slated to start in FY04. An external factor that could have a large impact on this project is the Department of the Navy's FORCEnet program, which now oversees large-

[17]Vickie Williams, Manager, Expeditionary Fire Support for the MAGTF Enabling Capability, Office of Naval Research, "Fires Enabling Capability," slide 20, presentation to the committee on May 14, 2003.

scale interoperability and systems integration efforts throughout the naval community in the context of implementing network-centric operations, of which the Naval Fires Network will inevitably be a part.

Recommendation. Code 353 should reexamine the integration with Naval Fires Network project to ensure that it will complement the utility of planned and developing FORCEnet integration and interoperability projects and to avoid duplication of efforts or, worse, incompatible solutions.

Improved Ammunition Product Line

Work aiming toward improved ammunition is focused on increasing the lethality of Marine Corps ammunition to improve the probability of a first-round kill by the warfighter. It includes four projects: lethality and advanced warheads, advanced kill mechanisms, extended-range mortar munitions, and advanced ammunition packaging.

Lethality and Advanced Warheads

The lethality and advanced warheads project will compare the lethality of advanced and existing expeditionary fires' kill mechanisms. The objective is to compare the effectiveness of potential materiel solutions for expeditionary fire support needs.

Findings and Recommendations. Much of the raw information was gained through live-fire testing. These tests have been completed for 120-mm rifled mortar rounds, and testing for munitions of other sizes is ongoing. The information gained should prove useful in the development of advanced munitions as well as in the application of firepower in combat situations.

Recommendation. Code 353 should proceed with the lethality and advanced warheads project through completion, as planned.

Recommendation. Before starting any new, related initiatives, Code 353 should coordinate more closely in warhead development with operational experimentation initiatives at the Marine Corps Warfighting Laboratory and prior live-fire testing performed by the Army and DARPA.

Advanced Kill Mechanisms

The advanced kill mechanisms project supports a study of fragmentation technology to optimize warhead lethality. It is evaluating existing fragmentation concepts and development; appropriate modeling and simulation of fragmentation patterns; and the design of novel codes to describe the fragmentation process within exploding shells and is comparing the above models with live-fire tests. The objective is to provide an Expeditionary Fires Support System (EFSS)-compatible munition having optimal lethality and decreased logistics demands.

Findings and Recommendation. The advanced kill mechanisms activity is scheduled to start in FY04. The committee sees this effort as the beginning of a new large-scale research program to develop advanced fragmentation warheads by Code 353. While there is Marine Corps need in this area, the field is dominated by Army input. Hence, care must be taken to examine Army initiatives in this area to avoid duplication of effort. Part of this initial stage of the activity should focus on the identification of possible new technologies and design approaches that have not been fully evaluated or pursued.

Recommendation. Before continuing or expanding its research allocations in the field of warhead fragmentation, Code 353 should review prior Army and DARPA studies and development programs to ensure that Code 353's efforts add new knowledge to this large and heavily studied area.

Extended Range Mortar Munitions

The Marine Corps, as part of EMW, has expressed a desire for longer-range organic (i.e., locally tasked) fires to enable fast and independent movement of forces around the battlespace. The extended range mortar munitions project is focused on improvement of mortar ammunition, with the specific goal of developing a rocket-assisted mortar to extend the warhead range from the current 8 km out to 17 km.

Findings and Recommendations. The extended range mortar munitions project will build on an existing Army rocket-assisted 120-mm munition. Its planned late FY04 start is dependent on the choice of munition for the EFSS. The committee notes that the Army's Future Combat System (FCS) program's goals for extended-range munitions are similar to the Marine Corps goals espoused in this project for EMW.

Recommendation. Code 353 should continue with the extended range mortar munitions project as planned.

Recommendation. Code 353 should monitor and attempt to leverage Army Future Combat System program efforts to develop organic, longer-range mortar munitions.

Advanced Ammunition Packaging

Current long-range munitions must be individually packaged for routine storage and transportation. In some cases, these packaging systems add significant weight and volume to the logistics burden of the warfighter. The advanced ammunition packaging project aims to develop advanced materials and package designs to reduce weight and improve handling and protection for munitions. One benchmark goal of the project is a significant reduction in packaging volume along with a 50 percent reduction in packaging weight. An additional goal is to devise interlocking packaging so that large groups of munitions can be handled easily and safely.

Findings and Recommendations. The advanced ammunition packaging project will include requirements definition, package modeling, studies of hinge design for interlocking packaging, and evaluation of materiel solutions for transport and protection. Care must be taken with the packaging design to ensure that significant reduction in packaging volume will not lead to an increased probability of accidental detonation of munitions. This project is scheduled for an FY04 start.

Recommendation. Code 353 should continue with the advanced ammunition packaging project as planned.

Recommendation. Code 353 should establish and maintain close coordination between this project and similar Army efforts related to munitions packaging.

EC 3—MAGTF MANEUVER IN THE LITTORALS

EC 3 is intended to enhance the maneuverability of landed elements of a MAGTF through knowledge-based situational awareness and improved mine- and obstacle-breaching capabilities. The capabilities being developed and demonstrated are intended to allow assault forces to dynamically plan and execute STOM operations, which will require collaboration and distributive planning along with integration of situational awareness, logistics, and mission objectives.

Several technology gaps have been identified that could impair STOM execution in 2010, including (1) a lack of common and integrated dynamic planning, rehearsal, and execution systems, (2) the inability of lower echelons to get relevant data, (3) a lack of a common relevant operational picture (CROP) at all echelons, and (4) a navigation and object location system that is currently unable to afford a precise and responsive approach during amphibious operations at night, in adverse weather, or in obstructed or mined waters.

Enhanced maneuverability, based on dynamic planning and adaptive execution at the mission planning level, will require support at all phases of expeditionary marine warfare, multiple plans (what-if alternatives), collaborative planning, rapid replanning, execution monitoring, near-real-time changes based on enemy activities, up-to-date environmental data, and actual situational awareness. Further, this capability must be flexible, distributable, and easy to use.

EC 3 includes the Knowledge-Based Situational Awareness product line, with one project; the Maneuver Systems product line, with three projects; and the Landmine Countermeasures and Breaching product line, with one project.

EC 3—Findings and Recommendations

Initial efforts in EC 3 are aiming for a significant advance in STOM capability by 2006, to be supported by dynamic planning and adaptive execution, precise navigation tools, and development of an advanced CROP. Evolutionary development of existing software tools and COTS hardware should lead to rapid returns for MAGTF maneuver in the littorals. Particularly promising are the EX-45 stable weapon mount, which has long been in development,[18] and the AAAV collision avoidance system. The remainder of the EC 3 projects started in FY03 or are set to start in FY04, so there are few final results to report.

Recommendation. Code 353 should continue to pursue situational awareness efforts with vigor.

Recommendation. Code 353 should accelerate efforts to support the needs of mine countermeasures and military operations in urban terrain by systematically addressing the many identified shortfalls.

Knowledge-Based Situational Awareness Product Line

Adaptive Expeditionary Maneuver Warfare System

The adaptive expeditionary maneuver warfare system project is a software development initiative aimed at enabling the combined amphibious task forces, combat logistics forces, and their staffs to better coordinate their decision making during the planning, evaluation, and execution of all phases of

[18] A weapon with two-axis stabilization was demonstrated in May 2001.

EMW. The objective is to integrate the technologies required to synchronize operations for dynamic planning and adaptive execution using collaborative and distributive planning. The expected warfighting benefits include reduced planning time and increased speed and accuracy of command to allow rapid decisions and replanning, in-stride assault guidance, and reduced fratricide.

Findings and Recommendation. The adaptive expeditionary maneuver warfare system project is developing evolutionary software tools that are currently undergoing field testing. Capabilities presented to the committee demonstrated the individual software tools being implemented as part of the project. The software tools supported overall mission objectives as well as visualization with real-world imagery of a landing area and overlays of assault lanes, tactical areas, and an execution timeline; demonstrated the ability to incorporate surf models that support beach selection and the identification of available assets; and supported landing force landing plans, including organizing into landing waves and the order of offload.

One particular tool was the augmented reality tool, which is being developed to improve navigation and situational awareness for fast sea approaches to desired landing areas. The deployed experimental system enables georegistered data to be presented on a cockpit monitor and enables the operator to see the approach path clearly, via computer-generated guard rails.

Although a milestone and schedule timeline was presented, it was difficult for the committee to determine when and how the individual software tools would be integrated into a dynamic system synchronized across platforms, echelons, missions, and components. Early success and accomplishments included a software-generated program-to-program interface library with Secure Socket Layer status that had been deployed in an amphibious ready group. Code 353 also presented evidence of strong fleet and Fleet Marine Force support with transitions planned in the out-years.

The committee endorses the adaptive expeditionary maneuver warfare system project. The overall concept of dynamic planning and adaptive execution is worthwhile but complex, and it will require extensive integration. In the end, all components of the integrated system will have to be field-tested.

Recommendation. Code 353 should generate a detailed overall plan for development of the adaptive expeditionary maneuver warfare system that clearly establishes the funding and schedule required for integrating individual tools into an integrated system that can be validated in the field.

Maneuver Systems Product Line

Maneuver Systems includes three separate projects: the advanced amphibious assault vehicle (AAAV) collision avoidance system, the EX-45 stable weapon mount, and urban maneuver. All three are aimed at improving the ability of existing systems or systems under development to maneuver freely through a battlespace.

AAAV Collision Avoidance System

The AAAV collision avoidance system project builds on prior work in the development of the Airborne Laser Mine Detection System (ALMDS) and the AQS-20(A) system. All three of these systems rely on blue-green grazing-incidence laser light detection and ranging (LIDAR) coupled with a streak tube imaging system to enable detection and localization of floating and submerged objects. The objective of the AAAV collision avoidance system project is to develop an integrated sensor system that reduces the size of the existing AAAV collision avoidance system, is integrated with AAAV onboard

GPS and navigation systems, and prepares data that can be easily transmitted off-board to the battlefield commander.

Findings and Recommendations. The AAAV collision avoidance system project represents an important technology for improved mine and obstacle avoidance. The fundamental properties of the streak tube imaging and detection geometry of the LIDAR system represent a reasonable approach to detecting floating and submerged objects, yet not what would be described as a conventional LIDAR concept. The LIDAR appears to have been developed over a long period, passing through two phases of a small business innovation research effort, with claims of being able to transition quickly to TRL 7/8 to support AAAV low-rate initial production. No evidence was presented to confirm the maturity of the technology.

While this project claims "to build on ONR-developed technology in ALMDS," there appears to be no ongoing sharing of information between the two efforts. The committee expressed concern that given the advanced TRL projected, coupled with a lack of integration with other activities, the system would be unlikely to meet the expectations of ONR.

Recommendation. Code 353 should coordinate the AAAV collision avoidance system project with the Airborne Laser Mine Detection System Program Office to establish a detailed description of near-term technology milestones and transition plans for both systems.

Recommendation. Code 353 should work with the Airborne Laser Mine Detection System Program Office to investigate mutually beneficial opportunities to leverage streak-tube LIDAR development.

EX-45 Stable Weapon Mount

The EX-45 stable weapon mount is designed to be an integrated weapon mount offering increased gunner accuracy from a moving platform. The goals of the final system will require four-axis stabilization (for patrol craft use); remote firing capabilities (to remove the gunner from harm's way and the elements); forward-looking infrared surveillance; auto-tracking; light weight; and low visual signature. The system will also incorporate a nonlethal laser dazzler effective day or night at up to 400 meters. The primary technical challenges are to design the four-axis and six-axis sensors necessary for four-axis stabilization, appropriate interfaces to the servocomputer, and algorithms for four-axis gun stabilization and auto-tracking.

Findings and Recommendations. The EX-45 stable weapon mount is a worthwhile project designed to increase gunner accuracy from a moving platform. The product objective, system requirements, characteristics, and benefits are clear. Individual technologies such as a laser dazzler to blind the opponent's infrared detectors, a remote-firing control panel, and a gun-mounted imager appear to be on track.

Recommendation. Code 353 should establish a clear definition of the near-term technology milestones and transition plans for the EX-45 stable weapon mount.

Recommendation. Code 353 should develop a clear plan for the development and testing of the full four-axis stabilization and auto-tracking algorithms. This plan should involve appropriate leveraging of existing commercial and military work on motion-stabilized systems.

Urban Maneuver

The urban maneuver project is focused on technology systems that will assist maneuver elements in urban terrain. To date, efforts have focused on identifying technology and capability gaps. Six high-priority objectives were developed based on results of a war-game seminar designed to understand the nature of the urban environment: the ability to see inside a building, weapons optimized for MOUT, enhanced urban protection, reliable BLOS communication, MOUT decision support tools, and MOUT nodal analysis tools.

Findings and Recommendation. The urban maneuver project is in the early stages of identifying capability/technology gaps and priorities, which will then have to be turned into individual projects that address Marine Corps-specific needs and that are coordinated with ongoing projects in ONR, DARPA, and other agencies. This is a fruitful area for the introduction of new technology.

Recommendation. Code 353 should establish new technology projects to achieve the six high-priority objectives identified in the gap analysis exercise of the urban maneuver project.

Tailored Explosive Systems

The aim of this new-start project is to develop a family of tailored, organic, MAGTF explosive systems for attacking suspected mine fields or individual antitank mines and neutralizing detected side-attack, top-attack, and antihelicopter mines. This multiphase project will investigate various explosive antimine mechanisms as well as issues related to system delivery accuracy and target mine vulnerabilities, such as shock-induced mine fuze actuation.

Findings and Recommendations. The tailored explosive systems project is of joint Army-Marine Corps interest and focuses on the nullification of landmine threats. The committee noted that the project's examination of explosive kill mechanisms seems to be highly related as well as to the lethality and advanced warheads project and the advanced kill mechanisms project described above under EC 2.

Recommendation. Code 353 should pursue the tailored explosive systems project through completion, as planned.

Recommendation. After initial phase investigations are complete, Code 353 should consider broadening the tailored explosive systems project to examine how it could be made to also operate in the surf zone.

Land Mine Countermeasures and Breaching Product Line

Lightweight Mechanical Breaching Systems

The objective of this new start is to develop a lightweight mechanical breaching system for use on Marine Corps vehicles against all buried mine types regardless of mine fuzing technique. The current man-portable mine breaching system used by the Marine Corps weighs in excess of 65 lb and can clear

only a single 25-m-long track. Marine Corps field reports from Operation Iraqi Freedom noted that due to this high weight and short clearance length the systems were little used.[19]

Findings and Recommendation. Like the tailored explosive systems project, the lightweight mechanical breaching systems project is of joint Army-Marine Corps interest and is focused on the nullification of landmine threats to Marine Corps operations.

Recommendation. Code 353 should work cooperatively with the Army to support mine-breaching and nullification initiatives that will lower the system weight and lengthen the cleared path to address the concerns noted by marines during Operation Iraqi Freedom.

EC 4—COMMAND AND CONTROL

EC 4 is intended to enhance the commander's capability to command all elements of the MAGTF by increasing the reliability of BLOS communications and achieving near-real-time situational awareness and an improved data network with optimized information flow. The focus of this EC is C2 at the element level[20] of the MAGTF.

Currently funded within EC 4 are three product lines: Beyond-Line-of-Sight Communications Connectivity, with two projects; Enhanced Individual, Unit, and Collective Situational Awareness, with three projects; and Data Flow Optimization, with two projects.

EC 4—Findings and Recommendation

The eclectic collection of topics presented ranged from the forthright exploitation of COTS products to new-start projects that would develop improved software tools. It was by no means clear that this extremely critical area of C2 was being approached in a systematic manner in response to identified operational shortfalls. Also, since the C2 enabling capability clearly depends on inputs from the ISR enabling capability, the two should be closely coordinated.

Recommendation. Code 353 should review all C2 enabling capability projects to ensure coordination with ISR enabling capability projects and alignment of the outputs of both enabling capabilities to Expeditionary Maneuver Warfare.

Beyond-Line-of-Sight Communications Connectivity Product Line

Secure Mobile Networks

The secure mobile networks project aims to integrate advanced protocols and applications, frequency conversion, low probability of intercept (LPI)/low probability of detection (LPD), and spectrum compatibility into a secure system. The resultant connectivity enhancements will increase efficiency and allow for expeditionary maneuver warfare by providing on-the-move connectivity, seamless mobility

[19]Marine Corps Combat Development Command. 2003. *Field Report Marine Corps Systems Command Liaison Team, Central Iraq (April 20-25, 2003),* Quantico, Va., May.

[20]MAGTF elements range in size from a platoon to a division, depending on mission requirements.

and roaming capability for subscribers in and around a command post, and wireless connectivity from a command post to a remote antenna/radio location. Implementing the capability within a MAGTF architecture will eliminate network setup time and reduce the embarkation footprint by decreasing the amount of support cabling and equipment needed to support the network.

Findings and Recommendations. The secure mobile networks project grew out of the advanced concept technology demonstration on enhancing the littoral battlespace and has focused on gaining National Security Agency type 1 certification for an off-the-shelf Harris SECNET-11 secure wireless local area network (LAN) system. Performance tests have successfully allowed technical characterization of network performance even to the point of identifying an unforeseen falloff in performance in the multicast mode. There was no indication in presentations to the committee that this project consisted of more than a series of technical evaluations of equipment obtained from commercial sources; however, this effort does appear to have been very closely coordinated with potential Navy and Marine Corps customers. As part of this effort, a secure wireless LAN test facility has been co-located with the Marine Corps Tactical Systems Support Activity (MCTSSA) and has been selected as the DOD secure wireless LAN beta test site, suggesting that this project is somewhat mature.

Recommendation. Code 353 should continue the secure mobile networks project as planned through testing and down-selection of candidate secure wireless LAN systems.

Recommendation. Code 353 should, no later than late FY04, solve any problems identified in the first round of testing.

Recommendation. If project limitations are resolved by FY04, ONR 353 should proceed with the transitioning of these secure wireless LAN systems into existing Navy and Marine Corps C2 architectures.

Innovative Relays

The innovative relays project aims to field wideband and narrowband relay capabilities suitable for rapid, expeditionary use. The project seeks to integrate the relay functions of the Enhanced Position Location and Reporting System (EPLRS), the Single Channel Ground and Airborne Radio System (SINCGARS), and the Joint Tactical Radio System wideband network waveform (JTRS WNW) into a single payload for a UAV that will provide long-range and secure voice and data communications during STOM.

Findings and Recommendations. The current plans for the innovative relays project are aimed at providing an integrated radio relay payload for use on a Marine Corps tactical UAV to enable tactical (line-of-sight) communications from the UAV out to 100 nautical miles. Originally a DARPA initiative, the concept of developing UAVs as airborne communications nodes is being heavily studied by all the Services.

Satellite relays are an extremely high altitude instance of this airborne relay concept. Satellite communications served the marines well during Operation Iraqi Freedom as they were always available (although their use was limited owing to the fixed number of communications channels operated by the Services). The advantage of traditional radios (for example EPLRS and SINCGARS) is that they are fully deployed at all levels of the Marine Corps; however, without an elevated relay, they suffer greatly from difficulties in maintaining reliable line-of-sight connections. The innovative relays project seeks to

enhance the performance of overhead relays in a straightforward, logical manner. Since this is an integration effort, the committee expressed concern that Code 353 had not included weight and volume constraints for specific UAV platforms in the design goals for the innovative relays project.

Recommendation. Code 353 should conduct a critical review of the innovative relays project with the Navy and Marine Corps (e.g., First Marine Expeditionary Force and Commander, Third Fleet) to determine if, in view of the success of the satellite radios in Operation Iraqi Freedom, this project continues to be viable.

Recommendation. If the innovative relays project is viable, Code 353 should establish priorities for the remaining engineering studies and tests.

Enhanced Individual, Unit, and Collective Situational Awareness Product Line

Common Relevant Operational Picture

The common relevant operational picture project is an effort to develop a near-real-time display with an active matrix organic light-emitting diode (AM OLED) that can be used uniformly in a broad variety of military vehicles and ground stations. The initial stage (to be performed during 2003) is to support and coordinate with industry and with the other Services on AM OLED display technology and to assess (jointly with the Marine Corps Systems Command and MCCDC) current Marine Corps needs for display technology.

Findings and Recommendation. This project's title is a bit misleading, as it addresses the issue of displaying a common relevant operational picture but not that of assembling it. The current project is an offshoot of a 5-year DARPA investment (completed in 2002) that evaluated AM OLED technology. AM OLED displays are expected to have numerous advantages over commonly used liquid crystal displays, including greater brightness control (necessary for a range of day and night operations); reduced weight, power consumption, and heat dissipation; and potential flexibility. Code 353 also noted that it is monitoring work on heads-up displays and dismounted data terminals being performed under the Force Protection FNC, as well as similar work on AM OLED display initiatives by the Air Force and the Army.

The committee is concerned that the project is predicting faster progress for the technology than is likely, with predicted progress going from trade-off studies of AM OLED technologies and Marine Corps needs in 2003 to production of AAAV displays by the end of 2005.

Recommendation. Code 353 should reevaluate the timeline proposed for the AM OLED advanced display technology after completion of the surveys, studies of trade-offs, and roadmaps scheduled for 2003.

Position Location Information/Range Instrumentation

The position location information/range instrumentation project aims to support development of a communications infrastructure for the acquisition and archiving of position location information at Marine Corps live-training ranges. This project will include development of the necessary communications infrastructure, precision weapon location and orientation devices, and information management systems to allow for accurate real-time and after-action analysis of live training exercises.

Findings and Recommendation. The system developed in connection with the position location information/range instrumentation project should greatly enhance the ability of training managers to conduct after-action reviews of live exercises and, thus, the ability of the Marine Corps to conduct training. This project appears to be primarily an integration activity aimed at synthesizing the responses of various communications and location determination systems. The committee noted that although the communications and information management systems were being pursued aggressively (with the prototype demonstration scheduled in 2003), the indirect fire weapon position and orientation systems were not discussed. While deployment of this prototype system at the MAGTF Training Center at Twenty-nine Palms, California, will be a necessary step in the program development, the committee believes that the short timeline for this complex and integrated system may be overly optimistic.

Recommendation. Code 353 should conduct a critical progress review of the position location information/range instrumentation project with the Marine Corps Warfighting Laboratory to establish a firm timeline for integration of the diverse systems under development.

Deployable Virtual Training Environment

The deployable virtual training environment project supports development of automated, rapid, location-specific terrain database generation, enhanced digital voice communications, and improved visualization tools. All these activities aim to improve the quality and utility of mobile virtual training systems. For example, one goal is to improve the speed at which high-fidelity geo-registered terrain data can be acquired, processed, and disseminated for use in multiuser, deployed training sessions.

Findings and Recommendation. The deployable virtual training environment project is building on prior ONR development efforts. These initiatives, if successful, will improve the ability of the Marine Corps to support distributed mission rehearsal as well as training. Testing will include two shipboard trials, critical for testing the responsiveness of the distributed system to the needs of the trainees, who must have high-quality, real-time interactions. Coordination must be ensured between this project and other ONR, other Service, and Joint Forces Command initiatives to push technology in this fast-moving subject field.

Recommendation. Code 353 should coordinate in the area of distributed virtual training with the MCS&T program's Human Performance, Training, and Education core thrust as well as with other ONR, Service, and joint initiatives.

Data Flow Optimization Product Line

There are two projects in Data Flow Optimization, both new starts scheduled for FY04: improved network management tools and improved decision support tools. Neither of these two initiatives was formally briefed to this committee, although they were included in the supplemental material provided.

Recommendation. Code 353 should provide a quantitative brief of the Data Flow Optimization product line to the LC-FNC integrated product team for determination of priority in terms of supporting vision and requirements compatible with Expeditionary Maneuver Warfare. Program results should also be briefed to appropriate elements of the Joint Forces Command as a means to foster collaboration and leveraging.

3

Core Thrusts

OVERVIEW

The Core Thrusts part of the Marine Corps Science and Technology (MCS&T) program has organized its 6.2 and 6.3 funds to support six core thrusts:

- Maneuver,
- Firepower,
- Mine Countermeasures,
- Logistics,
- Human Performance, Training, and Education, and
- Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR).

Although there is no mission statement for the Core Thrusts, each thrust focuses on the development of advanced technology (see Table 1.2). This focus is consistent with the goals of ONR's Discovery and Invention (D&I) organizational element.

Given below are overall findings and recommendations for the Core Thrusts. Each core thrust is then discussed, and findings and recommendations are presented along with a detailed review of each thrust's constituent projects.

Core Thrusts—Findings and Recommendations

The Core Thrusts part of the MCS&T program was generally of high quality, and all the thrusts seemed to address topics of interest to the Marine Corps. However, although many of the projects reviewed were technically aggressive, several—such as the tactical unmanned ground vehicle—appeared to the committee to be focused on near-term transition-dominated goals that do not correspond to

the D&I mission of the Core Thrusts. As noted in Chapter 1, the committee considers it important that the Core Thrusts projects do not all take on the short-term, product-oriented characteristics of the Future Naval Capabilities (FNCs), since the technologies that the FNCs exploit must emerge from Core Thrusts (6.2 and 6.3) and Basic Research (6.l).

The committee also notes that the overall Core Thrusts did not appear to represent a structured response to significant shortfalls in Ship-to-Objective Maneuver (STOM) or Expeditionary Maneuver Warfare (EMW) capability. In addition, for those cases where presenters mentioned shortfalls, the links appeared to be ad hoc rather than the result of a planned process. The lack of an apparent overall investment strategy for the Core Thrusts concerns the committee.

A number of Core Thrusts projects were leveraged against much larger U.S. Army or Defense Advanced Research Projects Agency (DARPA) efforts. For most projects, the extent of the Code 353 influence on the Army and DARPA efforts was unclear. In most Core Thrusts projects, committee members were aware of related activities in the Navy, other Services, and/or DARPA, but the presenters, when questioned, seemed to have little or no knowledge of such activities. This lack of coordination concerned the committee, particularly in regard to potential duplication of efforts.

As for the individual thrusts, the committee applauds the explicit recognition of the key roles played by the Logistics and the Human Performance, Training, and Education thrusts, and it believes that the separation of Mine Countermeasures (MCM) from Maneuver is sensible, given the extreme challenges inherent in the MCM problem.

Recommendation. Code 353 should ensure that the MCS&T program's Core Thrusts and Basic Research components support the mission of discovery and invention, that is, exploration aimed at the long-term development of base-level technologies that could support future FNC and Marine Corps Warfighting Laboratory program initiatives. Thus, Code 353 should remove from the Core Thrusts and Basic Research portfolios short-term, transition-oriented initiatives.

Recommendation. To better structure its support for the underpinnings of Expeditionary Maneuver Warfare as well as Ship-to-Objective Maneuver, Code 353 should establish an S&T planning process for the MCS&T program's Core Thrusts, similar to that recommended above for the LC-FNC, that is suitably focused on the long-term capability needs of the Marine Corps.

Recommendation. In its Core Thrusts projects, Code 353 should enable broad coordination of efforts beyond Code 35 (and beyond ONR), where possible and practical, with relevant S&T activities in the other Services and in government agencies.

MANEUVER THRUST

The Marine Corps Expeditionary Maneuver Warfare concept focuses on the development of operational capabilities that enable speed, stealth, precision, and sustainability, with emphasis on improving the efficacy of the Marine Air-Ground Task Force (MAGTF). Desired operational capabilities include enhanced deployability, reduced fuel consumption, multispectral tactical awareness, reduced gross weight, improved survivability, autonomous systems, reduced logistical footprint, and improved mobility. The Maneuver thrust focuses on research and development of tactical and combat vehicles in the area of mobility, materials, survivability, unmanned ground vehicles, and electric technologies.

Maneuver Thrust—Overall Findings and Recommendation

The two projects associated with the MAGTF Expeditionary Family of Fighting Vehicles (MEFFV)—(1) lightweight materials and (2) modeling, simulation, and analysis—were both reasonable D&I efforts. In particular, the committee was impressed by the modeling, simulation, and analysis effort and strongly supports it. The other two projects—reconnaissance, surveillance, and targeting vehicle (RST-V) and tactical unmanned ground vehicle (TUGV)—with their current short-term transition goals (FY04), seemed more suited to receive funding as an FNC rather than as D&I, as is currently the case. The RST-V and TUGV projects, however, are making important contributions to the development of hybrid-electric drives and autonomous operations on the battlefield.

Recommendation. Code 353 should transition the reconnaissance, surveillance, and targeting vehicle project and the tactical unmanned ground vehicle project out of the Maneuver thrust as planned, but should continue support of initiatives in hybrid-electric and unmanned vehicles.

MAGTF Expeditionary Family of Fighting Vehicles

Lightweight Materials (6.2)

The lightweight materials project is developing advanced lightweight armor, structural-armor materials, and multifunctional material concepts that will improve the survivability of current and future armored vehicles. The project aims to select candidate materials by the end of FY03 and to hand prototypes ready for live-fire testing by the end of FY05. Testing of the final materials as integrated onto vehicles will be performed by FY07. The expected benefit of this project is lighter armor that will give future Marine Corps ground vehicles increased maneuverability and survivability.

Specific materials and processes being evaluated include fabrication of high-strength aluminum by cryomilling; use of nano- to meso-scale powders and plasma spraying of carbon/carbon nanocomposites to increase hardness; development of metal-matrix composites (aluminum and boron carbide) for structural material applications (increased toughness and strength); development of aluminum oxide/boron carbide graded composites; and development of metal-ceramic-matrix composites and polymer-metal-matrix composites for combined structural and armor applications.

Findings and Recommendations. Collectively, these activities in the lightweight materials project represent a variety of potentially useful materials technology options for increasing the survivability of ground combat systems. In Phase I of the project, several materials options have been identified and are being developed for testing. Benefits of the proposed materials have been adequately described relative to the performance of current materials. In addition, individual material or fabrication properties, including hardness, strength, fracture toughness, and elongation, are being measured and evaluated relative to the end-use. The committee found it difficult to draw any conclusions from the initial laboratory material testing results, given the technical issues that might arise in fabricating the larger areas and complex shapes required for structural platforms.

Transition of these materials is planned to occur through the Marine Corps Systems Command, and the Army's Future Combat System program and scheduled to be accomplished by the end of FY07.

Recommendation. Code 353 should continue the lightweight materials project through down-selection and require that grantees clearly articulate the fabrication issues and overall costs associated with

different materials options. The technical issues associated with large-scale fabrication of these novel materials should be identified and addressed early.

Recommendation. Code 353 should ensure that the vehicle-testing phase of the lightweight materials project involves the field-testing of vehicles equipped with final armor materials.

Modeling, Simulation, and Analysis (6.3)

The modeling, simulation, and analysis project aims to develop a simulation-based acquisition toolkit that supports the development of an advanced family of vehicles optimized for lethality, survivability, mobility, sustainability and reliability. The MEFFV is expected to replace the light armored vehicle and the M1A1 Abrams tank over the next 15 years.

Modeling, simulation, and analysis software tools are being developed in four technical areas: operational simulation and analysis, mobility modeling, conceptual design tools, and decision support. The resulting modeling and simulation capabilities are to be used for vehicle life-cycle analysis, advanced technology trade-off evaluations, and generation of appropriate investment strategies.

Findings and Recommendations. The operational simulation and analysis tool aims to integrate the joint conflict and tactical simulation (JCATS) with appropriate inputs such as satellite imagery, weapons data, and survivability performance. Post-processor improvements are also being developed to expand the capabilities of the tool. An initial survivability analysis has been performed using a sample MEFFV in an integrated infantry close-combat urban environment.

The conceptual design tool is being developed to enable early mission-specific design optimization of the MEFFV. This software tool enables rapid visualization and rapid evaluation of vehicle designs with different crew compartments, turret configurations, weapons, armor, and sensors.

Mobility modeling capabilities are being developed to predict and evaluate vehicle dynamics for potential MEFFV designs in realistic Marine Corps mission terrains. These models will help to evaluate the impact of technology trade-offs on mission performance; vehicle fuel efficiency and power requirements; and vehicle stability, ride, and handling. This activity has utilized existing commercial modeling software to simulate vehicle dynamics, to define performance envelopes, to assess technology options, and to evaluate life-cycle issues.

The multilevel decision support tool integrates a variety of input options and scenarios, such as vehicle design performance parameters, with proposed advanced technologies and allows for their examination through various survivability scenarios. The goal of this software tool is to collect information necessary to produce an evaluation matrix that help to determine technology trade-offs in relation to overall vehicle strengths and weaknesses.

Code 353 is scheduled to down-select the simulation design and development tools by the end of FY03 and to complete the preliminary platform designs in FY04.

Recommendation. Code 353 should move aggressively to support the modeling, simulation, and analysis project as a means to provide initial design evaluation relevant to the MEFFV.

Recommendation. Code 353 should continue to support future modeling, simulation, and analysis activities that build on existing tools and should strive to integrate the four existing activities in order to develop a unique set of longer-term Marine Corps modeling and simulation tools that support the MEFFV.

Recommendation. Code 353 should coordinate the modeling, simulation, and analysis project, where appropriate, with existing transportation modeling efforts at the Defense Modeling and Simulation Office, the U.S. Army Tank-Automotive and Armaments Command, the National Automotive Center, and other federal and industrial agencies.

Reconnaissance, Surveillance, and Targeting Vehicle (6.3)

The objective of the RST-V project is to develop and demonstrate survivable hybrid-electric technologies suitable for lightweight manned military reconnaissance and scout vehicles. The emphasis is on the development of a vehicle that can be carried into the theater by a MV-22 Osprey aircraft. The primary performance objectives for this phase of the RST-V project include demonstration of increased fuel economy and range relative to earlier versions of the RST-V and of the ability to sustain 20 miles of silent (battery or fuel cell) movement.

This project has resulted in the construction of four demonstrator vehicles. The final design relies critically on its hybrid-electric drive—a lightweight diesel engine dedicated to electric power generation coupled with advanced rechargeable lithium-ion batteries and individually controlled in-hub motors. The choice of in-hub drive motors allows for incorporation of a pneumatic folding suspension enabling the vehicle's wheelbase and clearance to be collapsed significantly in order to meet the combined requirements of rough terrain operation and V-22 transportability. The in-hub motors also reduce the size of the engine compartment, thereby increasing the interior cargo capacity of the vehicle. Vehicle safety certification, followed by operational user testing and evaluation, is scheduled to be conducted throughout 2003.

Findings and Recommendations. The RST-V is a mature technology demonstration project that has progressed steadily over the last 3 years. Initiated in the early 1990s, it is a heavily leveraged joint DARPA/Marine Corps project (currently 70 percent DARPA, 30 percent MCS&T funds). It also effectively uses results from other related efforts, including the National Automotive Center AHED 8×8, the Combat Hybrid Power System, and the hybrid-electric high-mobility multipurpose wheeled vehicle (HMMWV), as well as the elements of the Army's Future Combat System.

The third and fourth prototype vehicles were completed in FY03 and are scheduled for evaluation and testing in the first quarter of FY04. Initial vehicle cost is expected to be very high (primarily owing to lithium-ion batteries), and the transition plan at the end of the project is unclear. There are no plans for continuing this project beyond the first quarter of FY04.

In the view of the committee, this project seems to be more a technology integration, demonstration, and assessment project than a D&I project.

Recommendation. Code 353 should transition the reconnaissance, surveillance, and targeting vehicle project to an appropriate FNC (such as the Electric Vehicle FNC) or to the Marine Corps Systems Command for further development and testing. This transition plan should identify applications where advanced hybrid-electric drive vehicles are desirable and productive and should also address the timing, performance, and cost targets required of individual technologies (e.g., lithium-ion batteries).

Recommendation. Code 353 should continue to support the development of advanced hybrid-electric vehicles and systems for Marine Corps use.

Tactical Unmanned Ground Vehicle (6.2 and 6.3)

The tactical unmanned ground vehicle project's objective is to support the development of an unmanned, teleoperated, semiautonomous ground vehicle for remote combat tasks in order to reduce risk and neutralize threats to individual marines. The TUGV is planned to be capable of performing scouting missions; reconnaissance, surveillance, and target acquisition; nuclear, biological, and chemical reconnaissance; obstacle-breaching; and direct fire. The desired operational capabilities include mobility (go anywhere a marine needs to go), affordability, survivability, deployability, transportability, robust communications, an easy-to-use man/machine interface, and mission modularity (ability to alter the vehicle for mission-specific capabilities while in the field).

It should be noted that the DOD Joint Robotics program, which is led by the Army, strongly overlaps the goals and technologies of this project.

Findings and Recommendations. To date the TUGV project has gone through design award and Phase I technology development, design, and demonstration. Phase II down-selects have reduced design concepts from four to two. The designs will be further refined and then subjected to integrated testing and demonstrations. In FY04, finished TUGV prototypes are scheduled to undergo basic platform mobility testing and scout and surveillance demonstrations. The critical nature of the TUGV mission has led the Marine Corps to commit to the purchase of 101 TUGVs beginning in FY06.

The committee recognizes that the TUGV provides a variety of capabilities to the Marine Corps, the most notable of which is to remove marines from hostile, high-threat areas. The project has progressed well over the last 2 years and has strong transitional support. The committee looks forward to the Phase II performance evaluation and demonstration results. After completion of the Phase II development of prototype vehicles (late FY04), the TUGV project is scheduled to be transferred to the Marine Corps System Command, Unmanned Ground Vehicle Systems Joint Projects Office.

Although the TUGV project was presented to the committee as a part of MCS&T's Core Thrusts, the committee notes that the TUGV is also listed in several ONR documents as being part of the Autonomous Operations FNC.

Recommendation. Code 353 should clarify whether the tactical unmanned ground vehicle project is operating to meet D&I or FNC expectations. Because the D&I and FNC elements of the MCS&T program have somewhat different goals, care should be taken to avoid mixing missions.

Recommendation. Code 353 should continue to support the tactical unmanned ground vehicle project as planned, and coordination with the DOD Joint Robotics program should be maintained.

FIREPOWER THRUST

Expeditionary Maneuver Warfare relies heavily on long-range, accurate, and responsive naval surface firepower support (NSFS). Robust, around-the-clock, all-weather, sea-based firepower is the only joint capability that can fully meet the requirements of expeditionary maneuver operations and be integrated with other joint-force firepower over an extended littoral battle space. The Navy's current NSFS capability, however, is inadequate in terms of range, volume, and accuracy. Currently there is no funded program of record that will meet Marine Corps requirements in this area.[1]

[1]Gen Michael W. Hagee, USMC, Commandant of the Marine Corps. 2003. *Marine Corps Concepts and Programs 2003,* Headquarters, U.S. Marine Corps, Washington, D.C. Available online at <http://hqinet001.hqmc.usmc.mil/p&r/concepts/2003/TOC1.htm>. Accessed on August 20, 2003.

Ground-based, indirect firepower is irreplaceable when forces are joined in close combat, particularly in the early phases of a sea-based operation. Nothing else is as responsive to a commander's needs, or as reliable. As such, firepower is a key component in extending the reach and lethality of the MAGTF. The MCWL's *Experimentation Campaign Plan* states that "the Lab continues to explore technology solutions to address improvements in fire support to improve precision, terminal effects, responsiveness and mobility. The focus of effort has been to address these areas with respect to Expeditionary Maneuver Warfare (EMW) and specifically STOM as well as the subset of Military Operations in Urban Terrain (MOUT)."[2] Realizing the full potential of EMW will require a developmental effort focused on improving command and control, maneuver, intelligence, integrated firepower, logistics, force protection, and information operations.[3] Among the firepower examples recently cited by the Commandant of the Marine Corps as potentially supportive of the Sea Strike and Sea Basing concepts are the Littoral Combat Ship and the DD(X) land-attack destroyer, which will provide long-range precision and high-volume naval surface firepower to support OMFTS.[4]

Clearly, improved ship-launched and ground-launched firepower is critical to support the EMW concept and STOM.

Firepower Thrust—Overall Findings and Recommendations

Although many of the individual projects under way in the Firepower thrust seem to be pursuing worthwhile objectives, the relationship between these projects and Marine Corps warfighting concepts such as EMW and STOM was unclear. Given the importance of NSFS and ground-based indirect fire, the committee finds it strange that no Firepower thrust projects support weapons to fulfill this need (for example, projects on improved propellants, guidance systems, or munitions with increased range and/or precision).

A number of the projects seemed to be adding incremental upgrades to already-existing capabilities, with near-term transition targets, as opposed to pursuing long-range science and technology that could bring transformational improvements. The time scale and transition goals of some projects seemed more characteristic of an FNC project than a D&I project.

Many of the projects described were adjuncts to Army efforts, and the MCS&T projects seemed to be riding the coattails of other sponsors. Many of the systems needed by the Marine Corps are similar to those needed by the Army, and funding levels dictate that the Army will be the principal driver.

Recommendation. Code 353 should immediately transition near-term projects in the Firepower thrust to an appropriate FNC.

Recommendation. Code 353 should establish leveraging opportunities to support broad ONR and/or DARPA initiatives in the area of naval surface firepower support.

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[2]BrigGen Frank A. Panter, USMC, Commanding General, Marine Corps Warfighting Laboratory. 2003. *Marine Corps Warfighting Laboratory Experimentation Campaign Plan: 2003,* Marine Corps Combat Development Command, Quantico, Va., January 31, p. II-1. Available online at <http://www.mcwl.quantico.usmc.mil/divisions/expplans/ecp/ecp_complete/ecp2003.pdf >. Accessed on August 20, 2003.

[3]Gen James L. Jones, USMC, Commandant of the Marine Corps. 2001. *Expeditionary Maneuver Warfare,* Department of the Navy, November 10.

[4]Special Projects Directorate, U.S. Marine Corps Headquarters. 2003. "The Marine Corps General," Vol. 15, April 14.

6.2 Firepower

M1A1 Firepower Enhancement

Results from Operation Iraqi Freedom were predominantly favorable for those firepower enhancement systems already fielded. For example, an operator in actual combat conditions commented as follows: "Position location capability and the ability to range a target and get a ten-digit grid were . . . very useful. It proved valuable in fire missions and situational awareness." One criticism of the existing firepower enhancement system was that it took 4 minutes for the Far Target Locator to align.[5]

Code 353 is pursuing two projects to further improve the M1A1 fire control components: (1) electronic image stabilization via improved image signal processing for second-generation thermal imaging systems and (2) an improved high-performance, uncooled, forward-looking infrared (FLIR) sensor to increase the acquisition range and overmatch capability for Marine Corps combat vehicles under all battlefield conditions.

As part of M1A1 firepower enhancement, the Firepower thrust has made a limited investment (Code 353 input is approximately 1 percent of the total program dollars) in a much larger program at DRS Technologies, Inc., for application of the second-generation thermal imaging target information system. The Gen II M1A1 FLIR system is used in the gunner's primary sight. The focal plane array consists of a cooled (77 K) HgCdTe sensor. Of special interest to the Marine Corps are improvements in options for increased targeting range and field of view, as well as automated image enhancement and rugged packaging. This thermal imaging system is designed to be retrofitted on the M1A1. The funding will run through FY04.

Electronic Image Stabilization (6.2). The objectives of the electronic image stabilization project are to improve the second-generation thermal imaging systems on Marine Corps combat vehicles through system image stabilization, scene-based nonuniformity correction, and moving target indication capability. Accomplishments to date were said to include interpolation algorithms for improved electronic zoom and software algorithms to enhance broad area contrast.

Recommendation. Code 353 should reexamine the rate of progress of the electronic image stabilization project.

High-Performance, Low-Cost, Uncooled Forward-Looking Infrared (FLIR) Project (6.2). The objective of this project is to introduce a high-performance, low-cost, uncooled FLIR into the Gen II M1A1 FLIR, presumably in place of the current Gen II HgCdTe focal plane array, which must be cooled to 77 K. If performance is adequate, there are significant advantages in acquisition cost, logistics, and convenience to be achieved.

Findings. Limited information was presented on expected performance improvements or retrofitting for the second-generation thermal imaging system, making it difficult to assess the impact of the MCS&T investment in this very large scale, long-term effort. Nonetheless, unique Marine Corps needs for operating in adverse conditions and for retrofitting of the M1A1 make it worthwhile for the Marine

[5]Marine Corps Combat Development Command. 2003. *Field Report Marine Corps Systems Command Liaison Team, Central Iraq (April 20-25, 2003),* Quantico, Va., May.

Corps to invest in the development of the latest thermal imaging systems. Given the important role of thermal imaging systems, it is important for Code 353 to be cognizant of the latest developments and their impact on Marine Corps weapons systems as well as to maintain the expertise to monitor ongoing programs throughout the joint Services.

If this project is the only one currently addressing the potential insertion of an uncooled focal plane array into the second-generation FLIR, then it could be truly significant. No transition plans were discussed, although this appears to be yet another Core Thrust effort with strong emphasis on transition goals.

Recommendation. Code 353 should reexamine the high-performance, low-cost, uncooled FLIR project to ensure that it does not duplicate other Service efforts to develop and apply uncooled focal plane arrays.

Non-Lethal Weapons

The 2000 assessment of ONR's MCS&T program noted that although the Marine Corps had been designated as the lead Service for non-lethal weapons in the Department of Defense, there were nevertheless no Marine Corps projects supporting work in this area.[6] The committee is pleased that Code 353 is now investigating non-lethal weapons.

Code 353's work in non-lethal weapons supports mission needs statement (MNS) 1-85, Operational Capability in Military Operations Other Than War. MNS 1-85 expresses the need for a capability to incapacitate human threats in a less-than-lethal manner, through the use of electromuscular disrupters. The MNS requires a system that is effective at up to 100 meters and non-lethal from the muzzle of the system to maximum range—in effect a point and/or area crowd control capability. The system should be compatible with the modular M-16 rifle to give the small unit/individual rifleman a complementary non-lethal capability. The overall objective is to increase the decision space before using lethal means to change the behavior of hostile groups.

A non-lethal weapon that injects electrical energy into a human at high voltage, high frequency, low current, and with very short pulses is generally known as a stun gun. There are approximately a dozen manufacturers of such weapons and each uses slightly different pulse parameters. The stun gun incapacitates an individual by stimulating nerve cells proximate to the discharge region and temporarily overriding normal motor control signals, causing uncontrollable muscular contractions. Complete recovery occurs within about 15 minutes after the stun gun is turned off.

Off-the-shelf stun guns are widely used in law enforcement because of their great effectiveness. Their safety has received a moderate amount of attention in safety documentation by manufacturers, but little or no data are found in the peer-reviewed literature, and the basic mechanisms are not well studied. The effectiveness of these systems is severely limited in military operations by the fact that they can be used only at arm's length. A somewhat greater standoff distance is afforded by newer stun gun munitions, which can be projected as darts (two per round with trailing wires) and which have an effective range of 12 to 15 meters, or air lasers with a range of about 20 meters, although 90 to 100 meters would be more useful for military applications. A more novel concept is a proposed cylindrical dart mine, which, when triggered, would spew darts in all directions for area denial. Its effectiveness remains to be established.

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[6]Naval Studies Board, National Research Council. 2000. *2000 Assessment of the Office of Naval Research's Marine Corps Science and Technology Program*, National Academy Press, Washington, D.C.

Code 353, in collaboration with the Marine Corps Systems Command, has selected three projects—two with fairly conventional, low-risk approaches and one that, should the concept be viable, would be a leap ahead in neuromuscular disruption (NMD) capability. The work was designed to be done in four phases. At the time of this review, it was in Phase 2 and was scheduled to transition to the Marine Corps Systems Command upon the completion of Phase 2.

The MCS&T program's non-lethal weapons efforts are coordinated with the Joint Non-Lethal Weapons Directorate and with ONR Code 341, the Medical Science and Technology Division. In view of the relatively limited valid medical data on the effects of stun guns, collaboration with ONR's Medical Science and Technology Division becomes very important.

Neuromuscular Disrupter System for the M203 Launcher (6.2). Phase 1 of this project focused on the development of a miniaturized neuromuscular disruption system projected by the M203 launcher and ultimately capable of engaging multiple targets simultaneously. One approach included dispersing and energizing chaff, determining the suitability of various chaff materials, and investigating size, substance, and energy output. In addition, the effects of various surfaces, footwear, and clothing were analyzed to guide the design effort. Another approach investigated chaff-like strands. The strands deliver a regulated pulsating shock. The investigation assessed whether a charge could be delivered throughout the target set without achieving lethal levels in one or more of the targets, whether the charge might simply arc to the ground, and targeting mechanisms.

The work in Phase 2 focused on high-voltage generation, the optimization of preliminary circuitry, and multiple-target effectiveness. The feasibility of using a diagnostic sensor to provide an externally visible system check on the munition is also being explored.

Smart Dart System (6.2). This system is a pneumatically launched, nontethered dart that can engage targets from 0 to 100 meters away with accuracy and variable velocity. The electrode is designed to attach itself to the target and deliver a non-lethal but incapacitating electrical shock upon impact. The neuromuscular disruption technology that is employed in this concept is relatively mature and proven. However, a need exists to miniaturize the equipment and optimize it for this specific intended use. In addition this NMD dart will provide an optional capability—namely, to have its output energy controlled by an operator in real time.

Development of Long-Range TASER (6.2). Phase 1 of this project involved waveform development and testing. Waveforms were designed to test the key variables in neuromuscular disruption of mammalian subjects. The commercially available M26 TASER was used to establish a baseline. Various waveforms were subsequently applied to determine waveforms that would cause neuromuscular disruption more efficiently.

Phase 2 involves development of a proof of concept focusing on electronic circuit design, ballistic design testing, electrode design, and impact management.

Recommendation. Code 353 should continue its non-lethal weapons projects—neuromuscular disruption system, smart dart system, and long-range TASER—through completion of Phase 2 development.

Recommendation. After the non-lethal weapons projects have been transferred to the Marine Corps Systems Command, as scheduled, Code 353 should undertake new efforts in non-lethal weapons technology. A recently published study by the Committee for an Assessment of Non-Lethal Weapons

Science and Technology (of the Naval Studies Board) contains extensive recommendations for research in the area of non-lethal weapons S&T.[7] The current committee sees no need to restate these recommendations. However, it does recommend, in the strongest terms, that Code 353 review those recommendations and structure a robust program based on them.

Infantry Reconnaissance Round (6.2)

The objective of the infantry reconnaissance round project is to give small units of Marine Corps infantry a responsive aerial reconnaissance capability by integrating a high-resolution miniature camera with an M853A1 81-mm mortar round. The project is developing a round (e.g., a modified M853A1 81-mm mortar cartridge) that has a charge-coupled device camera and data link transmitter to be used to sense and transmit an image of the battlefield. For night operation, it can be coordinated with an illuminator round.

Findings and Recommendations. The committee believes that the infantry reconnaissance round project can provide useful images, probably enabling a properly equipped receiver to view the battlefield, detect enemy presence, and ascertain battle damage. That it will be controllable by a small unit, compatible with available equipment, and able to quickly provide an image will probably make it a useful device. However, as described, the concept for determining location, if needed, was sketchy, and no error analysis was provided. The potential for its transition to the LC-FNC or the Expeditionary Fire Support System was mentioned, although no time frame was indicated.

Recommendation. Code 353 should ensure that the infantry reconnaissance round project's development goals support Marine Corps warfighting strategy and needs. If they do, Code 353 should continue the project as planned.

Recommendation. Code 353 should ensure that the design of the infantry reconnaissance round is compatible with readily available signal receivers and display hardware.

6.3 Firepower

Objective Crew Served Weapon

The objective crew served weapon (OCSW) is the weapon subsystem portion of the Army's Land Warrior System. Considered the next-generation, crew served weapon system, it was planned and is managed by the Joint Small Arms Program Office. The OCSW is a 25-mm gun with laser range finder and day/night sight for full-solution fire control and is envisioned to replace select 44-mm MK19 automatic grenade launcher machine guns, .50-caliber M2 heavy machine guns, and medium machine guns. It is an Army S&T Objective program and a Defense Technology Objective program, as well as an ATD program organized principally by the Army, with General Dynamics as the prime developer.

Findings and Recommendations. It was not clear from the presentation what the role of Code 353 and the Marine Corps is in this well-funded and mature Army program. The review materials claimed

[7]National Research Council. 2003. *An Assessment of Non-Lethal Weapons Science and Technology,* National Academies Press, Washington, D.C.

impressive improvements in terms of reduced weight (144 lb for the MK 19 grenade launcher to 35 lb for OCWS) and a reduced logistical tail that resulted from increased lethality (111 lb of ammunition per kill to 6 lb of ammunition per kill). But these gains appeared to result from the overall Army program, not just this project. At the end of FY03, after user evaluations are in and a milestone I/II decision is completed, the U.S. Army Product Manager for Small Arms will assume responsibility for managing the engineering and manufacturing development phase of the OCWS.

It would seem that Code 353's contribution is intended to be a reconfiguration of the existing 25-mm OCSW into a .50-caliber weapon. The objective of this redesign is to provide a dismounted warfighter with a .50-caliber crew served weapon system that provides overwhelming lethality and improved accuracy and that is significantly lighter than the current M2 machine gun.

The OCSW can be converted to a 0.50-caliber weapon by changing out only six components. Both versions (25-mm and .50-caliber) now exist as prototypes. Although it has a lower rate of fire than the M2, the .50-caliber OCSW weighs significantly less (28.5 lb versus 108 lb) and has better targeting and less recoil (250 lb versus 1,000 lb). The lower recoil may make the weapon more operator friendly and may allow it to be mounted on aircraft such as the V-22 that would otherwise not have a weapon. It was noted that prototypes of the 25-mm and .50-caliber weapons are available from General Dynamics.

Recommendation. Code 353 should pursue leveraging of the objective crew served weapon through completion and transition to the U.S. Army Product Manager for Small Arms.

Recommendation. Code 353 should reexamine small arms development in order to support needs for urban warfighting.

Proposed FY04 Firepower Projects

M1A1 Firepower Enhancement

M1A1 firepower enhancement will be an extension of the firepower enhancement project described above under Firepower Enhancement (6.2). Its objectives are to improve the accuracy of far-target location and improve detection of camouflaged and hidden targets.

Findings and Recommendation. It is unclear whether the objectives of M1A1 firepower enhancement require S&T research or if development within an existing program would better serve firepower enhancement goals.

Recommendation. Code 353 should rigorously examine the need for M1A1 firepower enhancement in light of the current firepower enhancement effort. If S&T research is needed, it should proceed. Otherwise, this development effort should be transitioned to the Marine Corps program manager for tanks.

Micromechanical Flying Insect

The proposed approach in the micromechanical flying insect project is to incorporate the results of a successful ONR/DARPA Multidisciplinary University Research Initiative (MURI) (6.1) effort that indicated the feasibility of building a prototype 100-mg platform, about 2 cm in maximum dimension, capable of autonomous flight and equipped with an integrated communication payload. This device

would fly out to a hostile location, perch on a convenient surface, and clandestinely monitor an area. While it was perched, the solar cells would recharge the internal batteries and enable a later burst of energy for flight to another location. As such, these devices would be persistent, autonomous deployed sensors.

Findings and Recommendations. The proposed approach, if successful, would produce, in effect, a large field (two to four dozen planned per group) of forward-deployed, unattended ground sensors, which could be of great value during the conduct of MOUT. The committee notes that this effort also plans to leverage earlier ONR efforts on swarming behavior.

Data links that use the inherently small, low-gain antennas and the low-power transmitters that are needed for these mechanical flying insects are likely to have great difficulty operating in an urban environment. Further, more sensors with dimensions of the size needed on a single mechanical flying insect are likely to generate a high rate of false alarms. Past designers of arrays of forward-deployed, unattended ground sensor systems have used complex tracking algorithms to reduce the false alarm rate. The committee anticipates that unless similar techniques are developed for arrays of mechanical flying insects, serious false alarm problems will be encountered.

Recommendation. Code 353 should continue its mechanical flying insect project after reassessment of the project's goals to ensure useful operational ranges (on the order of 1,000 meters) and the ability to carry useful sensor and communications payloads.

Recommendation. Code 353 should undertake additional supportive work such as the following:

- Continued leveraging of earlier ONR and other Service work on swarming in order to define the networking requirements for large groups of autonomous systems. Work should include network physical location and synchronization algorithms, the link margins and optimal frequency choices necessary to provide a reliable data link out to 1 km in an urban (and/or jungle) environment, and provision for the identification of a method of polling multiple mechanical flying insects for their sensor readout information.
- A comprehensive study to develop techniques for mitigating the impact of the high false alarm rate that is likely with a mechanical flying insect array.

Hypervelocity Gun Projectiles

The objective of the work on hypervelocity gun projectiles is to develop an improved projectile to maximize penetration and defeat reactive armor. This project is tied to ongoing development of a hypervelocity electromagnetic propulsive weapon system by the Army and for potential use by the Marine Corps on the MEFFV.

Findings and Recommendation. The committee expressed concern that the hypervelocity gun projectiles project, while interesting in its own right, relied heavily on the development of an advanced Army weapons system.

Recommendation. Code 353 should ensure that the hypervelocity gun projectiles project is consistent with Marine Corps requirements. If it is, the project should proceed.

High-Mobility Artillery Rocket System Fuze Design

The objective of the high-mobility artillery rocket system fuze design project is to design a fuze assembly for High-Mobility Artillery Rocket System (HIMARS) submunitions to meet NATO/U.S. Navy requirements for shipboard transport of dud-producing ordnance. The use of microelectromechanical systems (MEMS) technology is proposed, the same technology as used in automobile airbags.

Findings and Recommendation. The high-mobility artillery rocket system fuze design project's use of MEMS technology suggests an interesting D&I project.

Recommendation. Code 353 should proceed with the high-mobility artillery rocket system fuze design project through completion, as planned.

MINE COUNTERMEASURES THRUST

Overview

In the 3 years since the last NSB review of MCM initiatives,[8] the Navy-Marine Corps team has underscored the importance of MCM as one of 11 capabilities needed to enable the naval transformational concepts of Sea Strike, Sea Basing, and Sea Shield, as well as the Marine Corps EMW capstone concept. As a potential impediment to conducting effective EMW operations, the hostile mine threat spans all physical environments and provides common challenges to Marine Corps, Navy, and Army forces.

This almost intractable problem has been the subject of R&D for a couple of generations or so, with only limited success. It is ideas-limited, not funding-limited, and continues to be a serious problem. It is necessary to keep trying and to follow up on any promising new ideas. Marine Corps efforts in 6.1 and higher funding categories are not unique. Every approach offers some advantage and usually suffers from several disadvantages. Broadly speaking, some approaches suffer from too many false alarms, some are not sensitive enough, and some are too specific—that is, limited to certain types of mines.

To address the questions, What MCM capabilities exist? and What is needed?, the Institute for Defense Analyses (IDA) and ONR conducted a study to frame 2002-2003 MCM programs in the context of future expected operations.[9-11] The study evaluated the capabilities needed by MAGTF to support STOM, starting at the beach exit zone (BEZ) and continuing inland. This effort uncovered eight capability gaps that have to be addressed for adequate MCM operations: deterrence and intimidation, standoff detection, close-in detection, handheld detection, neutralization, marking, C4I for MCM, and

[8]Naval Studies Board, National Research Council. 2001. *Naval Mine Warfare: Operational and Technical Challenges for Naval Forces,* National Academy Press, Washington, D.C.

[9]David C. Heberlein, Institute for Defense Analyses, Technical Advisor, Expeditionary Warfare Operations Technology Division, Office of Naval Research, "ONR Code 353 Naval Science Board Review, Mine Countermeasures (MCM) Thrust," slide 6, presentation to the committee on May 14, 2003.

[10]Phone conversation between John Casko, committee member, and T. Joseph Singleton, Thrust Leader, Expeditionary Warfare Operations Technology Division, Office of Naval Research, June 23, 2003.

[11]Phone conversation between John Casko, committee member, and David C. Haberlein, Institute for Defense Analyses, Technical Advisor, Expeditionary Warfare Operations Technology Division, Office of Naval Research, June 23, 2003.

enhanced survivability. The ability to meet five of these was judged as inadequate, and the ability to meet three was judged as marginal; thus, none of the eight capability gaps could be met adequately.[12]

Of the efforts with MCM content reviewed by the committee, the Core Thrusts part of the MCS&T program currently supports the advanced mine detector project and the advanced signature duplication project.[13]

MCM Thrust—Overall Findings and Recommendations

The research, both basic 6.1 and applied 6.2, is well planned. The division between 6.1 and 6.2 is opportunistic, meaning that ideas come from all directions and any plausible ideas are worth investigating. The committee noted that the new starts are planned to attack the well-known problem of mine clearance and to encourage development of novel mine clearance and neutralization systems. In a recent Marine Corps after-action report, field officers noted that current mine neutralization systems in use by the Marine Corps were inadequate to the task.[14]

There were no programs presented that addressed unique Navy-Marine Corps warfighting problems in the area between the ship and the BEZ. While this area is the responsibility of the Navy, the committee noted that there was no mention of the importance of such research or of any leveraging with the Navy to support shallow water demining.

In the area of land mine detection, a mutually beneficial relationship exists between the Marine Corps Systems Command and the Army Night Vision and Electronic Sensors Directorate (NVESD) that

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[12]David C. Heberlein, Institute for Defense Analyses, Technical Advisor, Expeditionary Warfare Operations Technology Division, Office of Naval Research, "ONR Code 353 Naval Science Board Review, Mine Countermeasures (MCM) Thrust," slide 8, presentation to the committee on May 14, 2003.

[13]The MCS&T Mine Countermeasures thrust and other programs with MCM content that were reviewed by the committee are spread across 6.1, 6.2, and 6.3 investments as follows:

- 6.1 basic research
  - — Environmental issues for seismic mine detection
  - — False indicators in acoustic/seismic land mine detection
  - — Seismic detection of buried land mines
  - — Acoustic detection of buried land mines
  - — Impulse or ultrawideband radar research
- 6.2 and 6.3 core thrusts
  - — Advanced mine detector
  - — Advanced signature duplication
- 6.2 and 6.3 LC-FNC
  - — EC 1, tactical hydrographic survey equipment
  - — EC 1, tactical littoral sensing payload
  - — EC 3, family of tailored explosive systems
  - — EC 3, lightweight mechanical breaching system
  - — EC 3, AAAV collision avoidance system.

The 6.1 basic research projects are focused on the use of radiated waves (electromagnetic, seismic, and acoustic, singly or in combination) and are described in detail in Chapter 4. The LC-FNC components supportive of MCM are reviewed in Chapter 2 under their respective enabling capabilities (EC 1 and EC 3).

Additional ONR investments include a dedicated MCM FNC. However, neither this FNC nor the relationship between it and other MCS&T efforts was described to the committee.

[14]Marine Corps Combat Development Command. 2003. *Field Report Marine Corps Systems Command Liaison Team, Central Iraq (April 20-25, 2003),* Quantico, Va., May.

could serve as a model for future synergy. In the mid-1990s, ONR conducted the Coastal Battlefield Reconnaissance and Analysis (COBRA) ATD, whose objective was to apply multispectral imaging technology to the mines-on-the-beach problem. At that time, the Army was developing a small, lightweight, precision pointing gimbal compatible with Pioneer-sized UAVs. Together, the two efforts provided the means to package a mine detection capability that became the current COBRA program. A modification of this sensor package design to add a midwave infrared imaging camera, a laser illuminator, and a range finder subsequently became the solution selected for the latest NVESD Airborne Standoff Minefield Detection System (ASTAMIDS) development and demonstration program. The ASTAMIDS sensor package, in turn, has enhanced ISR capabilities that provide a preplanned product improvement opportunity for the COBRA program by enabling nighttime capability. This symbiotic leverage spanned 10 years and resulted in solutions that address common Army/Marine Corps MCM problems and that are proceeding toward production.

The preponderance of systems supported by Code 353 are ground-based, deployable by individual marines or from a ground vehicle. While this is an important capability for marines, little support was evident for technologies useful for wide-area surveillance (WAS) to initially detect minefields. WAS technologies should be a high priority for the Marine Corps, particularly for maneuver unit commanders. Unlike some other approaches, WAS can tolerate less-than-perfect performance and still be very helpful operationally.

Recommendation. Code 353 should seek to leverage research on development of wide-area surveillance detection systems for use in mine countermeasures.

Recommendation. Code 353 should collaborate with DARPA; the Army; Naval Sea Systems Command, PMS-210; Coastal Systems Station (CSS) Panama City; Naval Air Systems Command, PMA-263; and the Marine Corps Warfighting Laboratory, the Organic Mine Countermeasures FNC, and the other ONR codes to address mine countermeasures at the Naval Enterprise level with a view beyond the 3-year horizon that seems to pervade current MCM efforts. The S&T planning process described in Marine Corps Order 3900.15A[15] contains the structure to allow such collaboration.

Recommendation. Code 353 should develop an overall mine countermeasure strategy involving all research and development programming levels.

Projects Reviewed

The advanced mine detector project, the single 6.3 project addressing the shortfalls identified in the IDA-ONR study, was characterized by Code 353 as a congressional-interest project and a spiral development block upgrade to the Army's handheld standoff mine detection system, the nuclear quadrupole resonance confirmation sensor.[16] The 6.2 project reviewed, advanced signature duplicator, is a new start for FY03.[17]

[15]Gen James L. Jones, USMC, Commandant, U.S. Marine Corps. 2002. *Marine Corps Order 3900.15 A*, re *Marine Corps Expeditionary Force Development System,* Headquarters, U.S. Marine Corps, Quantico, Va., November 26, p. 10.

[16]David C. Heberlein, Institute for Defense Analyses, Technical Advisor, Expeditionary Warfare Operations Technology Division, Office of Naval Research, "ONR Code 353 Naval Science Board Review, Mine Countermeasures (MCM) Thrust," slide 45, presentation to the committee on May 14, 2003.

[17]Phone conversation between John Casko, committee member, and David C. Heberlein, Institute for Defense Analyses, Technical Advisor, Expeditionary Warfare Operations Technology Division, Office of Naval Research, June 24, 2003.

Advanced Mine Detector (6.3)

The objective of the advanced mine detector project is to develop a man-portable system capable of detecting metallic and nonmetallic buried mines using nuclear quadrupole resonance (NQR). There has been considerable focus on leveraging the Army's investment in the NQR technique for direct detection of the explosives in land mines. Continued reductions in equipment weight may be obtainable, but intrinsically long relaxation times for the NQR response to several common explosives (among them, TNT) and the need to interrogate from immediately over a mine could significantly limit the usefulness of this technique. NQR and ground-penetrating radar (GPR) detection can also accidentally set off some classes of common mines.

Findings and Recommendations. A strong bias toward sensor investigation was evident in the MCM briefings. Sensors are important, but not at the expense of other system considerations such as signal processing and algorithm development related to effective detection and clutter rejection. Multisensor/phenomenology approaches are more promising and are under development by the Army NVESD and possibly also the Army Research Laboratory.

Recommendation. Code 353 should focus future nuclear quadrupole resonance detection efforts on research and development needed to reduce the time necessary for signal lock. This research may be best suited to the 6.1 level as it may well require novel physics or excitation methods.

Recommendation. Code 353 should support modification of the nuclear quadrupole resonance detection system to avoid accidental mine activation.

Advanced Signature Duplicator (6.2)

The advanced signature duplicator project is a new start with the objective of developing advanced signature duplicators for MAGTF tactical vehicles to activate and neutralize top-attack, side-attack, antihelicopter, and bottom-attack land mines. The project will focus initially on countering magnetic-influence antitank and off-route mines and then include acoustic, seismic, millimeter-wave radar, and other types of mines. Initial activity will include the purchase and evaluation of existing equipment.

Findings and Recommendations. The advanced signature duplicator project is of interest to both the Army and the Marine Corps for operation of ground vehicles through potentially mined terrain.

Recommendation. Code 353 should work cooperatively with the Army to pursue this project on mine activation by electromagnetic signal duplication until it is completed.

Recommendation. Code 353 should consider how mine activation technologies could be incorporated in systems applicable to the surf zone.

LOGISTICS THRUST

To achieve EMW requirements for flexible and rapid logistics, the Marine Corps has to reduce the logistics footprint and maximize the return on its investment in acquisition of combat service support systems. The Logistics thrust aims at capturing emerging and "leap-ahead" technologies in areas related to materials, energy conversion, and chemistry, such as polymers and membranes.

A discussion of the general findings and recommendations for the Logistics thrust is followed by detailed discussion of the logistic projects presented. For this assessment, the committee placed the logistics effort in four groups: expeditionary energy, transportation, materials, and bulk liquids.

Logistics Thrust—Overall Findings and Recommendations

The committee is pleased to see logistics explicitly addressed as a core thrust. Code 353 has constructed the overall logistics effort with attention to several significant Marine Corps logistics problems. However, the Logistics thrust prioritization process appears to be informal and to rely heavily on targets of opportunity.

Code 353 Basic Research also contains a number of efforts that address logistics. The projects on lightweight power sources reviewed in Chapter 4 could reduce the logistics burden of deployed forces.

The committee noted that several logistics areas relevant to the Marine Corps—including selective off-loading at sea and issues related to fuel supply during STOM—were not covered in current programs. Selective off-loading, in particular, is an area of tremendous concern to the Commandant of the Marine Corps and other senior Marine Corps officers.[18] ONR is initiating the ExLog-FNC as a separate program component to address critical logistical capability gaps (such as deployment from and reconstitution of a sea base) for naval forces engaged in expeditionary operations.[19] To date there is no coordination of effort between the Logistics thrust and the ExLog-FNC.

Recommendation. Code 353 should coordinate with the Expeditionary Logistics component of the Littoral Combat and Power Projection FNC regarding implications of Expeditionary Maneuver Warfare for Marine Corps logistics.

Recommendation. Code 353 should support new Logistics thrust projects in expeditionary on-shore fuel logistics and on-shore materials transportation.

Recommendation. Code 353 should, in a timely manner, transition relevant MCS&T Basic Research projects on lightweight power sources into 6.2- and 6.3-supported programs.

Expeditionary Energy

Microturbine 3-kW Generator (6.2 and 6.3)

The microturbine 3-kW generator project seeks to provide variable rate (1.5-3.0 kW) tactical electric power for onshore and offshore MAGTF applications. The microturbine power-producing subsystem is also being designed as a principal engine for a low-power mechanical system in hybrid power systems or as a bottoming cycle engine for a very-high-efficiency combined gas turbine cycle engine.

The major technical risk for the proposed system is achieving the required performance (efficiency) levels for the turbine and the compressor. The main objective for year 1 is to demonstrate that these performance goals have been achieved. The main objectives for year 2 are to demonstrate, in breadboard

[18]Gen Michael W. Hagee, USMC, Commandant of the Marine Corps. 2003. *Marine Corps Concepts and Programs 2003,* Headquarters, U.S. Marine Corps, Washington, D.C. Available online at <http://hqinet001.hqmc.usmc.mil/p&r/concepts/2003/TOC1.htm>. Accessed on August 20, 2003.

[19]For additional information on the Expeditionary Logistics (ExLog) component of the Littoral Combat and Power Projection Future Naval Capability (FNC), see *Expeditionary Logistics,* 2002, Office of Naval Research, Arlington, Va., June 3. Available online at <http://www.onr.navy.mil/explog/explog/overview.asp>. Accessed on August 20, 2003.

form, a complete power system running on diesel fuel and generating electric power and to package the system and test it in the laboratory and in the field. This project requires the development of electromechanical (including variable-speed technology) and hybrid power technologies (such as a fueled engine-driven generator set and a renewable energy source such as photovoltaics or thermophotovoltaics), which can be integrated into a system configuration to generate continuously variable rated output from 1.5 to 3.0 kW. The current 3-kW tactical quiet generator set serves as a baseline for the analysis of these power technologies.

Findings and Recommendation. The committee agrees that development of lightweight power sources is a valid Marine Corps need in line with EMW mission characteristics. The current program is midway through its funding cycle, having achieved initial testing of the turbine and compressor. Future efforts are aimed at integration of the alternator into a completed system test. System tests are scheduled to be complete by late 2004.

As with many Marine Corps needs, for this system to enter full-scale development, the Army—which is the lead Service for military generator development—must eventually support it as an Army program.

Recommendation. Code 353 should increase its interaction with Army research and development programs in advanced power generation technologies in order to best leverage ONR's investments.

Hybrid Zinc/Air Battery (6.3)

To achieve a safe, compact, light, and longer-lasting power source, Code 353 is funding the development of a hybrid power source combining a high-energy-density Zn/air battery with a high-power-density ultracapacitor. Zn/air batteries alone have not been a viable solution because of intrinsically low peak-power rates available from Zn/air systems. Batteries operate best during static, low power loads, and newly emerging electronic equipment often requires dynamic, high power loads. If a battery is forced to power a device under dynamic load conditions, the battery can polarize, and the voltage will drop below the operational voltage of the device. To allow for high peak powers, a Zn/air battery alone would have to be significantly larger than needed for its routine use. A hybrid approach would utilize the Zn/air battery to store energy in an ultracapacitor when power demands on the system are low. At times when high power is needed, the ultracapacitor would be discharged to augment the Zn/air battery.

Findings and Recommendation. The hybrid zinc/air battery project appears to be a relatively short (2-year) demonstration project, combining an existing state-of-the-art Zn/air battery with a to-be-developed ultracapacitor. This is an engineering effort to find the best combination of power sources in terms of two distinct performance parameters, specific energy and specific power.

The hybrid concept is not new and is under study in several DOD and DOE programs. In general, battery and capacitor sizing is very specific and dependent on the load profile of the application and the characteristics of the components. However, a demonstration of the principle for a simulated mission is a worthwhile endeavor.

Integration of this work with the power system modeling effort, described in Chapter 4, should be considered. The modeling could aid in sizing of elements for a sample load profile. Testing of the resulting system could then serve to validate the model. Code 353 should ensure that the range of performance parameters is consistent with the power requirements of the equipment that will be in the field for the next decade.

Recommendation. Code 353 should pursue the hybrid zinc/air battery project through completion as planned.

Microchannel Methanol Fuel Cell (6.2 and 6.3)

Energy and power requirements for future Marine Corps needs are predicted to be considerably greater than at present. This translates into increasingly heavy batteries for the marines to carry. Fuel cell technology could reduce this burden by a factor of between 5 and 10. In addition to power for individual marines, quieter and more efficient power for battery charging and C41SR requirements is required.

Current standard high-power-density battery systems are losing ground in their ability to provide enough power for the electronic systems that were to be carried by individual marines in future warfighting missions. The long-range approach to this dilemma, pursued in 6.1 basic research, is fuel cells that use available JP-8 diesel fuel and thus take advantage of the very high energy density present in hydrocarbon fuels. The shorter-range objective of this project is to develop a methanol fuel cell system that can be tested under field operational conditions. The principal goal will be to assemble a power system containing a fuel processor, fuel cell, essential controls, and auxiliary equipment that can produce 100 W using methanol fuel.

Findings and Recommendations. The initial FY03 goal of the microchannel methanol fuel cell project is to demonstrate the planned characteristics by combining previously developed fuel cell stacks and methanol fuel processors with off-the-shelf components into a working 100-W system. In FY04 and FY05, the size and weight of the stack, processor, and components are to be reduced and more features, such as water recovery and more sophisticated controls, are to be added.

Although most of the basic technology required has been demonstrated, this is still a very ambitious project. To achieve an improvement from technology readiness level (TRL) 5 to TRL 7 within 3 years will require a major effort in size and weight reduction, controls development, and ruggedization. No final goals were provided for size, weight, and fuel consumption. It was not evident that steps were being taken to ensure that hydrogen/methanol content and storage units satisfy the safety requirements for man-portable systems.

DARPA is funding a similar program based on the direct oxidation of methanol.

Recommendation. Code 353 should pursue the microchannel methanol fuel cell project through completion, as planned.

Recommendation. Code 353 should establish clear metrics to measure progress for development of fuel cell systems.

Recommendation. Code 353 should monitor and support the DARPA direct methanol power system program as well as monitor industry and DOE fuel cell programs.

Recommendation. Code 353 should reevaluate the risks of the schedule for the microchannel methanol fuel cell project, given the extremely ambitious plans for moving through TRL levels—TRL 5 in FY03, TRL 6 in FY04, and TRL 7 in FY05.

Transportation

Rapidly Deployable Nonstandard Composite Bridging (6.2)

Traditional bridging techniques are based on using standard components or engineering with locally available materials. The rapidly deployable nonstandard composite bridging project is exploring an alternative to enable quick fabrication of bridging components on-site as a new means to solve unique bridging challenges.

The current project involves developing and documenting design, manufacturing, and repair procedures for nonstandard, modular military bridges composed of lightweight, low-cost composite materials. The project is focused on development of technologies and procedures to enable bridge components to be manufactured at (or near) a bridging site. In principle, this could speed up deployment, reduce the need for large off-site depots, and allow for more convenient tailoring of components for each bridge site. The bridging components must also meet all Naval Construction Force requirements as well as take into account the unique capabilities of the composite materials.

Findings and Recommendations. The underlying notion of on-site manufacturing of bridge components reflects an interesting shift of perspective. One concern that has been recognized by Code 353 is the trade-off between shipping prefabricated components and shipping raw materials and manufacturing capability. The logistics footprint of the manufacturing capability and the raw composite materials and molds may be larger than that of traditional prefabricated components.

The committee saw this bridge system as an engineering effort rather than a typical development project.

Recommendation. Code 353 should pursue the rapidly deployable nonstandard composite bridging project through completion, as planned.

Recommendation. Code 353 should focus subsequent efforts on the deployment of a composite bridge manufacturing capability to a forward location. The project should have performance goals or criteria so that the capabilities of this new system can be compared to those of traditional bridge construction and repair techniques. These criteria should include time to complete construction and the overall logistics footprint for materials, equipment, and personnel.

Materials

High-Velocity Particle Consolidation (6.2)

High-velocity particle consolidation (HVPC) is a technology whereby metal and metal/ceramic layers can be applied to structural substrates after manufacture in order to enhance surface properties such as corrosion resistance, wear resistance, and ballistic performance. In general, HVPC utilizes an extremely high velocity gas jet combined with a solid material powder feed to spray materials onto the surface of a substrate material. At the speeds involved, the metal powders consolidate via extreme deformation and cold-welding during impact. Thus, HVPC can be used to build up thin or thick homogeneous or graded layers, or to apply metal coatings to ceramics. In military application, HVPC coatings have also been used to alter the infrared and/or acoustic signature of substrate materials. HVPC is currently under development to produce wear-resistant coatings for AAAV components and corrosion-resistant coatings for the amphibious assault vehicle. In these uses HVPC has resulted in cost

avoidance and longer mean time between repairs. The current project will team with ARL and the Marine Corps Maintenance Directorate to design and develop a depot-level capability to enable HVPC wear-, erosion-, and corrosion-resistant coatings to be applied at depot-level maintenance installations.

Findings and Recommendation. Based on the high-level description provided for its review of the high-velocity particle consolidation project, the committee believes that the potential to address corrosion problems for Marine Corps equipment is significant. The first-order assessment of cost and footprint indicates the potential for practical application of this technology. The project summary did not characterize the targets of application or the criteria that will be examined to evaluate success. The committee did note that the project includes an effort to develop a process model and a generic business model to evaluate HVPC and related technologies.

Recommendation. Code 353 should continue current work on high-velocity particle consolidation after developing a set of performance criteria.

Bulk Liquids

Expeditionary Unit Water Purification (6.3)

The mobility essential to EMW and STOM requires deployable systems to provide potable water to forward units. Current systems (large reverse-osmosis water purification systems and numerous bulk storage and distribution systems) are adequate for relatively fixed forces but are inadequate for the rapidly mobile units envisioned in EMW and used so effectively in Operation Iraqi Freedom.

The expeditionary unit water purification system is being developed to meet a tri-Service requirement to produce 100,000 gallons of potable water per day and be C-130 transportable. This system is intended to give operational forces a reliable, responsive, and portable means to produce and distribute water to forward-deployed Marine Corps forces.

Findings and Recommendations. The committee believes that the Marine Corps participation in development of the expeditionary unit water purification system is consistent with expeditionary warfare needs. The demonstration system target capacity of 100,000 gallons per day should provide a strategic-level capability. It was not evident that Code 353 was considering technologies to reduce water usage, either by reducing basic demand or by cycling water through different applications.

Recommendation. Code 353 should complete development of the expeditionary unit water purification system and transition it as soon as possible.

Recommendation. Code 353 should seek opportunities to leverage similar water initiatives in DARPA, the Army, and the other Services.

HUMAN PERFORMANCE, TRAINING, AND EDUCATION THRUST

Overview

In the 1997 Naval Studies Board report of the Panel on Human Resources of the Committee on Technology for Future Naval Forces, a key recommendation was that the Navy and the Marine Corps

should "[i]nvest more in the conversion of conventional forms of training to technology-based, distributed training."[20] That report pinpointed where research and development must be done to provide the best possible training for future naval forces. Among that report's recommendations was the need for R&D investments in the following areas:

- Embedded training,
- Intelligent training systems,
- Virtual reality and simulations,
- Human performance assessment,
- Portability, and
- Technology-mediated authoring, delivery, and management of education and training.

Given the scanty funds available for MCS&T, it is proper that these resources be focused in those areas that have the greatest potential benefit for the Marine Corps.[21]

Human Performance, Training, and Education Thrust—Overall Findings and Recommendations

In reviewing current Code 353 investments in R&D for training and education, the committee noted the investment of significant resources in virtual reality and simulations and in portability. These appear to be good areas for the investment of scarce resources and are well matched to Marine Corps needs, especially if the Marine Corps can influence and exploit research investments by the other Services that impinge on the areas listed above.

Code 353 has clearly made an effort to respond to the recommendations of the NSB review committee in 2000 regarding the programs in place at that time.[22] That report also recommended four new programs. The current MCS&T program also includes a significant new effort in the DARPA augmented cognition project, which is partially managed by Code 353.

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[20]Naval Studies Board, National Research Council. 1997. *Technology for the United States Navy and Marine Corps, 2000-2035, Volume 4*: *Human Resources*, National Academy Press, Washington, D.C., p. 40.

[21]Two other FNCs include work on human factors: Capable Manpower and Autonomous Systems. In addition, some of the other Services have related programs—for example, embedded training, team training, and research on the efficacy of computer-based, close-combat games. The Army continues to explore the utility of embedded training for many weapons and platforms. Effective embedded training systems could reduce costs by reducing or eliminating the need for training systems apart from the weapons and platforms for which they are produced and by allowing the Marine Corps to enhance its ability to "train as it fights."

Team training continues to be an area of large investment on the part of the other Services. For example, the U.S. Air Force is rapidly developing distributed mission training (DMT) to enable its pilots to train in linked simulators. Marine Corps aviators could make use of the Air Force's large investment in DMT to improve human performance in multiaircraft operations. Similar programs can be found in the other Services (e.g., the U.S. Navy's Battle Force Tactical Trainer).

Both the Naval Postgraduate School and the Institute for Creative Technologies are continuing their development of computer-based games for recruitment and possible use in close-combat training. The greatest lack to date has been the limited research on the effectiveness of such games compared with other kinds of training. It is likely that the Marine Corps could serve as a testbed for research in this area funded entirely or in part by the Army.

[22]Naval Studies Board, National Research Council. 2000. *2000 Assessment of the Office of Naval Research's Marine Corps Science and Technology Program*, National Academy Press, Washington, D.C.

It appears that Code 353 has discontinued its training program in MOUT even though training specific to MOUT continues to increase in importance. Cooperation and coordination with the other Services should allow the Marine Corps to reap substantial rewards with small investments. At the very least, the Marine Corps could consider becoming a testbed for the evaluation of Army-developed MOUT training technologies and could strive to influence work done in support of Special Operations forces in other Services.

Recommendation. Code 353 should keep abreast of ONR and other Service investments in training and education in order to be able to influence them. In addition, programs in intelligent tutoring systems by ONR and the Army (especially the FY04 Science and Technology Objective in this area managed by the Army Research Institute) could offer significant benefits to the Marine Corps if appropriate personnel from Code 353 were placed on the relevant integrated product teams.

Recommendation. On a very basic level, the Marine Corps should monitor the reorganization of all Navy education and training and the deployment of asynchronous distributed learning capabilities by both the Army and the Navy. The Marine Corps will probably have to develop some content that is specific to its doctrine and training needs, but the payoff from appropriate leveraging could be very large.

Recommendation. Code 353 is strongly urged to leverage and influence research on human performance assessment, both within Code 353's current portfolio and in relation to all Marine Corps training and education. Research on human performance assessment should be an integral part of all human performance, training, and education research sponsored by Code 353, could be accomplished with relatively small investments, and would certainly yield large dividends in terms of the feedback provided to current and future programs.

Recommendation. Code 353 is encouraged to become familiar with the Commandant of the Marine Corps's Special Projects Directorate programs in training and education. Code 353 should also solicit the active participation of senior Marine Corps leadership in the S&T development process for training and education to ensure that innovative ideas and systems can be rapidly readied for testing by operational forces.

Projects Reviewed

The projects in the Human Performance, Training, and Education thrust fall into four categories:

- Tactical decision-making technology and simulations,
- Training instrumentation and situational awareness,
- Synthetic environments, and
- Augmented cognition.

Tactical Decision-Making Technology (6.2) and the USMC Family of Tactical Decision Simulations (6.3)

The projects in the first category constitute the USMC family of tactical decision simulations (TDSs) and are being supported to develop and demonstrate technology for a series of low-cost personal computer (PC) games that provide realistic scenario-based training in decision making for individual marines, small units, and MAGTF staffs. They are intended to enhance formal instruction; to support

multiechelon, multiplayer, network-compatible TDS with robust after-action review; and to provide multiscenario, high-repetition cognitive skills training for all MAGTF elements. The current objectives include the following:

- Develop and demonstrate a low-cost squad-to-platoon-level TDS by leveraging the Close Combat III commercial PC game.
- Develop and demonstrate a PC-based, low-cost, multiplayer company-to-battalion level TDS.
- Develop and demonstrate a low-cost, PC-based, multiplayer battalion-level and brigade-service support group TDS.
- Develop and demonstrate a low-cost, PC-based, multiplayer TDS that will support the interactions required for multiagency coordination and training related to the missions of the 4th Marine Expeditionary Brigade/Anti-Terrorism (4th MEB AT).
- Develop and demonstrate a low-cost, PC-based, multiplayer battalion-level Combat Engineering TDS that will reflect Marine Corps Combat Engineering doctrine through tactics, techniques, and procedures (TTPs) related to mobility, countermobility, field fortifications, and engineer support functions.

Findings and Recommendations. The tactical decision-making technology and tactical decision simulations project has significant potential to impact the availability and relevance of Marine Corps training in tactical decision making. There is no evidence that the project is leveraging similar activities sponsored by the Army at the Naval Postgraduate School, the Institute for Creative Technologies, and the University of Southern California. Although the briefings to the committee stated that evaluations were ongoing, no data were presented.

Recommendation. Code 353 should continue the work on tactical decision-making technology and the USMC family of tactical decision simulations while monitoring the many similar efforts by the Army at the Naval Postgraduate School and the Institute for Creative Technologies and should consider seeking synergistic interactions to meet Marine Corps needs.

Recommendation. Code 353 is urged to fund a third party (such as a university, the Army Research Laboratory, or the Naval Air Systems Command) to conduct objective evaluations of the tactical decision simulation systems being developed.

Training Instrumentation and Situational Awareness Technology (6.2)

The goal of the training instrumentation and situational awareness project is to develop technologies for the generation, communication, and display of position location information (PLI) in a live-fire training environment. The PLI includes information not only on geographic position but also on orientation (azimuth and elevation) for select weapons. Display and reporting technologies will also be developed that allow recording, displaying, and reporting the information from each training exercise, which in turn enables training commanders to replay and revisit training exercises and increase training effectiveness.

Findings and Recommendations. This work can be valuable for training and safety at live-fire ranges and will be essential for the planned integration of the Marine Corps Air Ground Combat Center with the Army's National Training Center. However, the committee is concerned about the value of the data

collected for after-action reviews. If the data are simply presented to the trainee without benefit of interpretation and comparison to baseline expectations, it may be of little value for after-action review purposes. The committee noted that this project, originally scheduled to start in FY02, has been delayed until FY04; the committee expressed concern that this delay might signal a low priority for this effort.

Recommendation. Code 353 should continue the training instrumentation and situational awareness project, taking special note of the planned integration of the Marine Corps Air Ground Combat Center and the Army's National Training Center. This project offers an excellent opportunity for the Marine Corps to modernize its data collection and analysis technologies for use in live-fire exercises.

Recommendation. Code 353 should fund the development of intelligent agent technology to access, digest, and organize data from the network of intelligent sensor nodes funded by this project. This postevent analysis stage should enhance the value of data collected for after-action reviews.

Synthetic Environment Technology (6.2) and Synthetic Environments (6.3)

The purpose of the work on synthetic environment technology and synthetic environments is to develop technology for rapid and automated three-dimensional scene generation for capturing and converting real-world terrain and cultural features into three-dimensional images suitable for real-time training on urban settings. Desired capabilities include near-real-time scene generation, a common database format, real-time video integration, and trainee immersion to allow interaction with synthetic opposing forces. Rapid terrain generation from contemporary data sources is essential for the creation and adaptation of useful synthetic environments.

Findings and Recommendations. It was not clear to the committee whether the contractor was developing all of the elements needed in this project or was making use of some COTS products and/or the products of other research groups inside or outside the military. The development of a common database format is important but should not be done in isolation from similar activities in other Service programs and in industry. The project on indoor position location information is necessary to support training for MOUT. The integration of live and virtual environments could lead to large savings in training development costs and to low-cost improvements in fidelity.

The briefings delivered to the committee stated that evaluations were ongoing, although no evaluations or evaluation criteria were presented. Apparently it is the developers that are conducting the evaluations. The briefings did not provide any insight into the degree to which the synthetic environment technology would support the imposition of stressors on the trainees to more realistically simulate the combat environment.

Recommendation. Code 353 should continue the synthetic environment technology and synthetic environments projects, but with a clear understanding and leveraging of what is under development by other Services, industry, and academia.

Recommendation. Code 353 should ensure that training tools for mission rehearsal take account of human factors.

Recommendation. Code 353 should fund a third party (such as a university, the Army Research Laboratory, or the Naval Air Systems Command) to conduct objective evaluations of the systems being developed under the synthetic environment technology and synthetic environments projects.

Recommendation. Code 353 should augment the synthetic environment technology and synthetic environments projects so that they can introduce combat-related stressors to high-fidelity visual scenes.

Augmented Cognition (6.2)

Code 353 has recently begun supporting DARPA's augmented cognition project. The purpose of this effort is to develop and demonstrate novel brain/machine symbiosis that would augment human cognition and performance. The goal is to enable asymmetric thinking, intuitive decision making, rapid pattern recognition, and dominant intellectual maneuver in volatile, uncertain, complex, and ambiguous warfare environments.

Findings and Recommendation. To date the augmented cognition project has been funded mostly by DARPA and has produced impressive results in cognitive monitoring and performance enhancement. It was not clear to the committee how the next phase of this project will connect to the other 6.1, 6.2, and 6.3 investments being made by Code 353. In Phase 2 the augmented cognition project will address ways to manipulate the cognitive states of individuals. This effort could have profound implications for training, but how will it inform current and future Code 353 R&D? The briefing indicated that ONR will "focus on defining requirements and assessing the most successful components" of the project. ONR is committing $5.8 million to the project through FY08.

Recommendation. Code 353 should develop a clear understanding of how the augmented cognition project could contribute to current and future R&D on training and education. The ONR investment should ensure that products of the augmented cognition project fill specific Marine Corps needs and can be transitioned both to the MCS&T program and to appropriate FNCs. In addition, some 6.1 investments could complement the larger investment in the augmented cognition project by focusing on neuropsychology.

COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS, INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE (C4ISR) THRUST

Tactical expeditionary warfare places heavy demands on a commander's ability to provide effective command and control of assigned forces operating according to the advanced tactical warfare doctrines of STOM and OMFTS. One reason for this is that the commander's forces may be dispersed over an area extending several hundred miles in width and depth and encompassing different types of terrain and sea conditions. Integral to effective expeditionary warfare are capabilities associated with a comprehensive and timely knowledge of the battle region, the status and location of friendly forces, and the status, location, and intent of enemy forces.

Technology associated with the development of new capabilities to support C4ISR is of paramount importance to realizing the goals of tactical expeditionary warfare.

C4ISR Thrust—Overall Findings and Recommendation

ONR's MCS&T C4ISR thrust has directed its limited 6.2 and 6.3 resources to (1) projects concerned primarily with new communications technology and (2) projects more or less unique to Marine Corps needs. The committee finds that while this strategy is certainly the preferred approach, at the same time it means that ONR program managers must interface with the other Services and DARPA research efforts in C4ISR to ensure that Marine Corps technology needs are being addressed.

Recommendation. Code 353 should continue to invest its research resources in C4ISR areas that are tightly coupled to the Marine Corps operational concepts of Ship-to-Objective Maneuver and Operational Maneuver From the Sea. Especially in the domain of C4ISR, a small investment in a critical area, coupled with other Service and Department of Defense investments, could produce significant results for the Marine Corps.

The projects reviewed are grouped into the following three functional categories and are discussed below in the order shown:

- Communications
  —Conformal antennas
  —Mobile network management
  —Wearable antenna
  —Joint Tactical Radio System
  —Ultrawideband radio assessment
- Command and Control
  —Magnetic random access memory
  —Marine Corps C3 S&T testbed
- ISR
  —Mobile direction finding

Communications

Conformal Antennas (6.2)

The conformal antenna research project is intended to provide broadband antennas (30 to 512 MHz) for application to armored vehicles, such as the M1A1 tank and the AAAV, in a conformal configuration that lacks a distinctive visual signature. Two approaches are being pursued. The first is the use of artificial magnetic conductors as an inductive backplane to produce relatively flat broadband UHF and VHF performance across the band in a multiarmed spiral antenna. This effort also includes development of a VHF slot antenna. The second approach uses low-temperature cofired ceramics as a textured impedance-matching receiver to allow a spiral planar conformal antenna to have tunable performance over both UHF and VHF bands. Considerable broadband capability exists in the class of antennas known as frequency independent, and the parameters of planar equiangular spiral antennas are well understood.

Broadband antennas are used primarily in practical applications, one of which is point-to-point communications in the VHF-UHF range. The total arm length of a finite equiangular spiral antenna determines the lowest frequency of operation. Whether the antenna consists of two metallic arms in free space or a spiraling slot on a large conducting plane, the radiation patterns are bidirectional, single-lobed, and broadside, assuming a balanced feed structure. Polarization varies from linear through elliptical polarization to circular as frequency increases or the on-axis direction of the beam is approached. When cavity backing is included in the design, the configuration becomes unidirectional. The artificial magnetic conductor back-plane in development is presumably intended to serve this same purpose and to enable mounting the antenna on a vehicle surface.

Findings and Recommendations. The antenna is planned to consist of a flat panel mounted to the surface of a ground vehicle such as a tank and for this reason is referred to as conformal. Since this project represents an initial study to develop feasible conformal antennas, the proposed antenna location on the vehicle and the degree to which the antenna surface may depart from a plane were not discussed. Full-scale radiation pattern measurements of the tank-mounted configuration should be provided, together with such additional data as beam width, gain, radar cross section, polarization, voltage standing wave radio as a function of frequency, and so on.

The committee also found that although one of the objectives was to provide flexible, reasonable-cost, low-observable apertures for ground vehicles, there was no mention of any effort to study cost trade-offs among the back-plane materials and/or antenna designs that are being considered. Affordability has proven to be a critical factor in the development of broadband antennas, especially when the intention is to create a conformal configuration on the surfaces of vehicles where multiple antenna faces are required to achieve acceptable multidirectional capabilities.

The suggested configuration (i.e., conformal planar spiral antenna) is promising as a military communications antenna with low observable characteristics.

Recommendation. Code 353 should obtain, at the earliest possible time, the measured properties of a single conformal antenna configuration mounted on a tank surface and determine the properties of arrays of such configurations. The project should explore the trade-offs inherent in selecting a set of locations and the number of elements in a suitable array.

Recommendation. Code 353 should conduct an antenna affordability analysis to accompany the selection of antenna materials and should specifically address how cost will be traded off against performance objectives.

Mobile Network Management (6.2)

Commercial wireless networks using cell phones are growing in popularity all over the world. Technology for such networks is ubiquitous, has been well developed, and is still being developed. International protocols vary, and it is hoped that only a very few, possibly only two, will become standard the world over. These commercial networks have used fixed nodes (base stations) that relay messages between any two participating customers. Commercial fixed, dedicated base stations make routing tables possible and permit seamless connections between any two users. On a fluid battlefront, however, such fixed base stations do not exist, and the objective is to enable seamless routing through mobile backbone nodes with the Joint Tactical Radio System and legacy radio networks, with nodes that can communicate seamlessly through ad hoc multihop networks. The preferred solution is to make every user a potential node for other users. Code 353 is currently negotiating a contract with an industry performer that would build on previous ad hoc networking concepts developed through DARPA. Because this project promises a software solution to enable automated control over dynamic network formation and maintenance, and seamless routing among subnetworks, it offers the potential for significant increases in network scalability and robustness. Recently, ad hoc networks have begun the transition from military research to commercial applications, and commercial systems are expected to be available soon.

Findings and Recommendations. The mobile network management project will be a new start on a vital capability. A Broad Area Announcement is expected by the end of FY03.

Recommendation. Code 353 should continue with its plan to start work on the management of mobile networks, but should incorporate into the criteria for project selection the wireless networking results of the recent experiment on extending the littoral battlefield.

Recommendation. Code 353 should seek to leverage Army S&T efforts in the area of mobile networks.[23]

Recommendation. Code 353 should consider the impact on mobile networks of the increased battery power required when users double as distributed network nodes.

Wearable Antenna (6.2)

The wearable antenna project, intended to develop a wideband antenna wearable by ground forces to reduce exposure of radio personnel to potential threats, was concluded in early FY03 and transferred to the U.S. Army's Communications Electronics Command.

Findings and Recommendation. The current wearable antenna configuration approximates a Faraday cage, so there is expected to be zero electromagnetic field strength where the wearer is. However, that claim cannot be made for the wearable antenna configuration that was presented. The committee was informed that the field inside the vest had been measured and was "quite small." The briefing materials stated that user safety had been documented at Brooks Air Force Base, but the committee expressed concern that wearer safety cannot be assured without longitudinal studies of the wearable antenna's effects on vital human internal systems and processes.

Recommendation. If the Marine Corps is still interested in a wearable antenna system above and beyond the work transitioned to the Army, Code 353 should carefully monitor the Army's efforts in this area. If wearable antenna projects are to be pursued, Code 353 should investigate alternative antenna configurations that reduce or eliminate potential human safety issues.

Joint Tactical Radio System (6.2 and 6.3)

The Joint Tactical Radio System (JTRS) is a joint Service effort to develop a software programmable radio that will accommodate most existing tactical waveforms. The ONR JTRS research effort has focused largely on supporting Marine Corps participation in integrated product teams (IPTs) for JTRS waveform standards, development of a system-level architecture for a Marine Corps JTRS-based mobile radio network, and communications models to evaluate alternative architecture approaches. The effort began in FY01 and is planned to transition to Marine Corps development programs in FY04.

Findings and Recommendations. The development of an interoperable tactical communications wideband network based on the JTRS architecture should receive the highest priority in the MCS&T research program. The committee considers continued involvement in the JTRS effort to be critical to the development of future tactical communications systems. The presentations indicated that Marine Corps-

[23]For example, the Communication and Networking Collaborative Technology Alliance program established by the Army Research Laboratory, U.S. Army Material Command, Adelphi, Md., May 2001.

based JTRS network architectures, network protocols, and network architecture development models were under way and would be concluding in early FY04.

Recommendation. Code 353 should examine alternative Marine Corps tactical architectures employing the JTRS standards and protocols that are emerging from the Army's Cluster I effort.

Recommendation. Code 353 should continue Marine Corps participation in the joint Service efforts to establish JTRS standards.

Recommendation. Code 353 should use the results of the architectural studies funded by this project to guide the Marine Corps position on JTRS standards.

Ultrawideband Radio Assessment (6.3)

The ultrawideband (UWB) radio assessment is an advanced development activity for demonstrating the use of UWB radios in communicating limited distances in urban environments and in selected command center applications. UWB radios operate by emitting very short pulses that have extremely large bandwidths. Such radios may have fractional bandwidths of over 50 percent. A dual-use contract funded by Code 353 from FY 99 to FY01 produced several UWB radios, some of which operate at a center frequency of 50 kHz and others of which operate at a center frequency of 2 GHz. The potential benefits of UWB radios are that they offer some degree of low probability of intercept and low probability of detection, and they may be useful in MOUT for communicating through building walls, and they may have low power requirements and low cost. This project aims to verify the manufacturer's technical specifications and determine the military uses of UWB radios. UWB radios require very precise timing synchronization (on the order of nanoseconds for microwave pulses) between stations, which places limits on how far apart the stations can be located.

Findings and Recommendations. UWB radio technology offers several significant advantages in tactical communications. While no specific information on the performance of these radios was available, clearly much more effort is needed to quantify how well these radios perform.

The committee endorses Code 353's plan to perform such tests in FY03 and FY04. One critical test should be a controlled experiment to determine the technical feasibility of establishing UWB radio links and networks (at the bit error rate level) in various tactical environments (with structures, vegetation, trees, and so forth) to quantitatively measure and demonstrate communications performance. Military utility should be demonstrated first through the use of UWB radio system and propagation models and then in selected field experiments involving military operations in urban terrain and other settings, including background signal environments. Consideration should also be given to an analysis of mobile applications of UWB radios. The committee believes that Doppler effects could have a significant impact on precise timing synchronization in such a mobile network.

Recommendation. Code 353 should proceed with the ultrawideband radio assessment through completion, as planned.

Recommendation. Code 353 should ensure that the ultrawideband radio assessment tests examine the influence of multipath and background signal environments on radio performance.

Command and Control

Magnetic Random Access Memory (6.2)

The extreme environments of Marine Corps warfighting take a heavy toll on electronic equipment. One especially sensitive component has been magnetic hard-drive data-storage devices. These devices have proven difficult to ruggedize to enable their routine use by individual marines in the field. While durable solid-state memory elements, such as memory sticks, are available, they employ a serial data-storage format (all data stored after a file was stored must be reread to reach and read a given file). As an alternative high-density storage media, ONR and other federal funding agencies are investing in the development of magnetic random access memory (MRAM) chips. In the early 1990s, basic research on multilayer magnetic films led to the discovery that the orientation of magnetic layers in a multilayer stack could be used to store bits of data. Bit densities of up to 400 Gbits/cm^2 have been projected.

Findings and Recommendations. The 3-year magnetic random access memory project seeks to integrate current chip manufacturing techniques to enable volume production of MRAM chips. Leveraging past ONR basic and applied research, it aims to develop and field a set of complete 80-kb MRAM data storage chips. The results of the project are being measured appropriately against existing solid-state devices and ruggedized hard drives to assess issues of potential durability and data density as well as ease and cost of manufacture. This project could impact the Marine Corps and other Service components.

Recommendation. Code 353 should proceed with the magnetic random access memory project through completion, as planned.

Recommendation. After concluding the magnetic random access memory research effort, Code 353 should closely examine the project and address how data-storage density, device durability, power needs, and the influence of stray radiation affect the devices.

Recommendation. Owing to the rapid progress in the area of magnetic data storage and in new competing technologies, Code 353 should closely monitor other federal and industrial research programs in this field and should seek out potential leveraging opportunities.

Marine Corps C3 S&T Testbed (6.3)

The Marine Corps C3 S&T testbed was described as a physical facility for testing and evaluating software designed for Marine Corps C2 systems. The testbed is located at the Marine Corps Tactical Systems Support Activity, Camp Pendleton, California, the site of the System Integration Environment where the Marine Corps Systems Command evaluates software for insertion into acquisition programs. The testbed was described as being able to replicate equipment and software associated with Marine Corps regimental-level C2 systems. No specific descriptions of the architecture, the supporting software, or the hardware for the testbed were given during the review.

Findings and Recommendations. A stand-alone Marine Corps C3 software advanced developmental testbed could greatly reduce the technical risk in emerging tactical demonstrations and acquisition programs. The committee endorses the need for a testbed as a means of investigating and validating new

software concepts and implementation approaches and providing a proof-of-concept capability for demonstrating military utility prior to insertion in an acquisition program. Such an investment is entirely appropriate in light of Marine Corps requirements and developmental objectives for state-of-the-art C3 capabilities and should have a significant impact on achieving these objectives.

The effort exhibits reasonably close integration with similar ongoing Navy and other Marine Corps testbed activities, although the presentations did not specify any results of integration efforts thus far. The fact that the testbed is located adjacent to the Marine Corps system integration environment indicates that there is at least a potential for experimentation using a direct feed from systems that are in developmental testing. Also, interaction is planned with a similar Navy C3 testbed at the SPAWAR Systems Center in San Diego (SSC-SD), which could lead to improved interfaces with Navy supporting software. The review indicated that SSC-SD was one of the supporting performers, and thus interactive testing is entirely possible, although it was not brought up during this review.

The documentation and briefing material on the testbed were not adequate for the committee to evaluate the size of the effort and compare it with other testbed activities. Development of the testbed was scheduled to take place over 4 years, but no specific milestones were presented in the briefing material. The final testing phase was presented as starting in FY03 and being completed in late FY04. Specific tests and test results obtained up to that time were not presented.

Technical risk is considered to be moderate at this time, given the lack of specific information on testbed architecture, infrastructure, interoperability among supporting software routines, and measures of effectiveness and performance.

Recommendation. Code 353 should proceed with development of the Marine Corps C3 S&T testbed through completion and testing, as planned.

Recommendation. Following completion, Code 353 should transition this project to a Future Naval Capability or to the Marine Corps Systems Command as soon as is feasible.

Recommendation. Code 353 should establish, at the earliest possible time, a set of specific test objectives for the testbed and a plan to achieve them. Intrinsic to this plan should be a series of interface demonstrations showing the ability of the testbed to take direct feeds from the system integration environment and, accordingly, the advantages of new software approaches and concepts for Marine Corps tactical utility. The plan should also provide qualitative and quantitative measures of performance to demonstrate the testbed's utility and operational effectiveness.

Intelligence, Surveillance, and Reconnaissance

Mobile Direction Finding (6.2 and 6.3)

The goal of the recently completed/transferred mobile direction finding project was to develop hardware and software for mobile direction-finding operations. The activities included development of software for compression and characterization of signals and hardware for antenna and system timing. In general, the direction of arrival of a radio wave can be deduced by pointing a directional antenna or from the time difference of arrival of the wave at three (or more) points of a base array. For typical systems, the larger the antenna or array, the more accurate the direction finding will be. Errors tend to increase as the signals environment becomes more complex, usually because of external noise or multiple reflections.

Findings and Recommendations. Code 353 has undertaken to improve the hardware and software necessary for improved direction finding and to develop signal characterization and compression algorithms efficient enough to run on a personal computer. It was not clear which antennas or mobile platforms were used in this project, which terrain models were being considered, or what the total system looked like. The Army also has a vital interest in mobile direction finding, but Code 353 indicated that relevant Army work was not being monitored.

This project has since been transferred to the LC-FNC as a follow-on effort that is reviewed in Chapter 2, in the section titled "EC 1—Intelligence, Surveillance, and Reconnaissance for the Amphibious Force," under the radio frequency emitter mapping payload project, where related recommendations are presented.

4

Basic Research

OVERVIEW

Since FY00, Code 353 has been supplying Navy Basic Research (6.1) funds to support Marine Corps future technology capabilities, as the Marine Corps itself has no allocated 6.1 funds.

The Marine Corps Basic Research Focus Program, referred to throughout this report as the Basic Research portion of the Marine Corps Science and Technology (MCS&T) program, seemed to the committee to be a useful program of research with much interesting science that was presented with enthusiasm. The presenter impressed the committee with the breadth and depth of his understanding of the many projects—both the technologies and the programmatics. Basic Research, though relatively new in the MCS&T program, is likely to serve the Marine Corps well if it is given the right opportunities and adequate funding for transitioning into future Marine Corps capabilities.

Overall Findings and Recommendations

Code 353's Basic Research appears to be a useful addition to the larger Navy 6.1 program. The Marine Corps 6.1 program manager's physical location at ONR headquarters enables close interaction with other well-qualified scientific officers. However, leveraging appears to the committee to be handicapped by the limited 6.1 funding allocated to Marine Corps needs.

Some of the work presented as basic research, although potentially useful, did not appear to the committee to be "basic." Much the same impression was noted in the NSB's earlier review of the MCS&T program.[1] Basic research is intended to answer fundamental questions relating to future developments that are not yet fully formulated. It might also be used to assist development work that is

[1]Naval Studies Board, National Research Council. 2000. *2000 Assessment of the Office of Naval Research's Marine Corps Science and Technology Program*, National Academy Press, Washington, D.C.

handicapped for want of some fundamental knowledge. In both cases feedback from 6.2 and 6.3 to 6.1 is essential to identify critical research areas.

Basic Research could also coordinate better when it comes to transitioning results into 6.2 and 6.3 applications. Marine Corps personnel could guide strategic planning of the 6.1 program by steering it not to projects but to technology areas likely to impact long-term combat needs.

In addition, to be effective despite its size, a Marine Corps-oriented 6.1 program must be leveraged as much as possible. Code 353 is well aware of the need for leveraging, but Basic Research appears to the committee to be handicapped by the low funding levels.

Recommendation. Code 353 should broaden its Basic Research focus areas to create a more robust and sustainable series of efforts. The new focus areas should result from a careful assessment of Marine Corps needs. A suggested reorganization of focus areas and sample topics is provided in Table 4.1. In addition,

- Code 353 should strive to set aside a small amount of uncommitted 6.1 funds (perhaps a few hundred thousand dollars) to foster additional flexibility in program support and to enable quick looks (e.g., a few months to a year) at new, unforeseen, novel concepts that arise from time to time.
- Code 353 should establish a formal mechanism to allow continuing feedback of 6.2 and 6.3 findings to the 6.1 office to help identify fruitful new areas of 6.1 research.
- Code 353 should work aggressively to expand the funding base for Basic Research so that a coherent set of significant Marine Corps-related projects can be supported.
- The Marine Corps should be involved in all aspects of the Code 353 research and development process, including the strategic development of the Basic Research part of the MCS&T program. In support of this goal, Code 353 should participate in (or encourage the Marine Corps leadership to participate in) meetings of the Defense Committee on Research, which currently has representatives from all the Services except the Marine Corps.
- As a means of fostering leveraging with basic research efforts outside ONR, Code 353 should regularly review the biennial Department of Defense Basic Research Plan.[2]

PROJECTS REVIEWED

Code 353's Basic Research program is currently organized into eight research areas and contains 29 projects. The research areas were chosen because they are critical areas that could be of use to the individual marine rather than for platforms or combat systems. These areas are reviewed here in the order they were presented to the committee:

- Communications,
- Lightweight power sources,
- Information efficiency,
- Sensing,
- Human sensory enhancement,
- Land mine detection,
- Laser eye protection, and
- Energetic materials.

[2]Office of the Deputy Under Secretary of Defense (Science and Technology). 2002. *Basic Research Plan (BRP),* Department of Defense, Washington, D.C.

TABLE 4.1 Suggested Reorganization of Basic Research Focus Areas and Sample Topics

Focus Area	Sample Topics
C4I	Ad hoc wireless networking Beyond-line-of-sight communications Short-range, high-density, low-power communications Antijam protection Information assurance
Energy	Lightweight power sources and rechargeable electric storage devices Energy-efficient devices and techniques High-energy-density storage
Sensing	Sensors for situation awareness (pre-attack) Sensors for damage assessment (post-attack) Sensors that work in an urban environment Mine detection: fundamental physical mechanisms and phenomenology in surf and on land Unmanned surveillance/reconnaissance vehicles Non-communications use of ultrawideband radar
Materials	Materials and structures Sensing materials Corrosion prevention
Human Factors	Non-lethal weapons Psychological profiling to identify potential terrorists Human sensory enhancement
Oceanography and Environment	Shallow-water oceanography: bottom structure in the surf zone, bottom interactions, and surf and current characteristics Effects on warfare of hostile or unusual climates (weather)
Weapons	Enhanced lethality Aim-point accuracy

After a brief discussion of each project, the committee's findings and recommendations are presented below.

Communications

Research in communications supports the development of capabilities to ensure robust communication links that will support the individual warfighter. As it is currently constituted, communications research focuses on bringing wireless capabilities to a variety of sensors while also developing the necessary supporting network technologies. A key element is the explicit recognition of the limits imposed by the finite energy capacity of battery systems. There are only so many "bits per battery." Addressing this limitation from the start makes very good sense.

Ultrawideband Radio Ranging Studies

Ultrawideband (UWB) radios could offer the Marine Corps a communications capability with a low probability of being intercepted and jammed, and they might also be useful in difficult conditions, such as MOUT. Radio-ranging studies will be conducted with varying electromagnetic environments and signal path obstructions, to support the development of ranging algorithms for minimizing the effects of false signals or noise. Although research on UWB radios has been conducted for a number of decades, very few real systems based on this approach have been developed or deployed, primarily because other highly developed competing approaches (direct-sequence, spread-spectrum communications, for example) have been adopted by the public communications sector. However, because it promises to place the entire radio on a single, low-power chip, UWB communication has found renewed favor in the wireless world.

Findings and Recommendation. This project focuses on developing empirical models for ultrawideband channels. These models will be critical in establishing reliable UWB links, particularly in developing the necessary receiver algorithms.

The committee notes a lack of integration across ONR and other potential sources of research on UWB radios. A number of alternative wideband models already exist but were not mentioned.

Recommendation. Code 353 should compare the models emerging from the ultrawideband radio ranging studies with existing UWB models.

Channel Coding and Estimation for Ultrawideband Impulse Radios

Ultrawideband radio receivers must have sophisticated capabilities for estimating the time of arrival of short-duration pulses. In the laboratory, this is a relatively straightforward procedure. However, in any real-world application, multipath and channel dispersion makes the problem of identifying time of arrival to a resolution of nanoseconds a significant technical challenge.

Findings and Recommendation. The channel coding and estimation project aims to use previously derived channel models to develop coding. Channel coding and estimation techniques in use for 30 years in conventional narrowband communication systems must be extended to ultrawideband systems if such systems are to have any meaningful capability.

Recommendation. Code 353 should incorporate channel coding and estimation into a test system for thorough evaluation of the channel coding and estimation for ultrawideband impulse radios.

Low-Power CMOS Implementation of Ultrawideband Impulse Radios

For UWB radios to have any future value to the Marine Corps, they will have to be small in size and consume little power. This project aims to develop a basic UWB radio system contained in its entirety on a single chip using complementary metal oxide semiconductor (CMOS) circuit technology. The design application is for short-range (less than 5 meters) data communications at a scalable bit rate (100 to 100,000 bits per second).

Findings and Recommendations. UWB radios remain a complex and difficult area of research. The

low-power CMOS implementation project is important for developing a prototype UWB radio that can be used later for critical Marine Corps evaluation and testing. The current plan, which is nearing completion, is to develop a prototype CMOS chip UWB transceiver. The results of this effort should be integrated with related Code 353, other Service, and industry efforts aimed at producing similar UWB technologies. Even with the successful completion of the single-chip prototype, several questions remain about efficient implementation of the receiver algorithms necessary for UWB radios. The committee noted that this issue is alleviated, in part, by the radio's planned short-range operation.

The committee also expressed concern that the stated goals of this effort, while interesting in their own right, were not consistent with the criteria for a Basic Research project. The committee observed that prototype development of integrated systems is typically supported through 6.2 or 6.3 funding.

Recommendation. Code 353 should transition further work on single-chip implementation of ultrawideband radios to a 6.2 or 6.3 program as soon as possible.

Recommendation. Code 353 should ensure that follow-on ultrawideband radio projects appropriately monitor relevant industry, other Service, and ONR efforts to produce similar radios.

Energy-Efficient Wireless Networking

Energy budgets have been an important part of wireless communications system design, especially for the cellular telecommunications industry. The energy-efficient wireless networking project will develop a model for a mobile ad hoc network that allows independent evaluation of the resulting energy needs of the nodes, based on systematic alteration of network and node behaviors. In this manner, the operational consequences of network design for node power can be assessed more realistically. Information efficiency is important not only to the military but also to the much larger wireless commercial industry.

Findings and Recommendation. The energy-efficient wireless networking project aims to extend work initiated under a DOD Multidisciplinary University Research Initiative (MURI) program[3] by introducing finite energy budgets for each mobile node as well as modeling network response to the feedback between receiver and transmitter, event-driven network loading, interference from other nodes, and so forth. Because this project is a new start for FY03, it is difficult to draw any conclusions about progress, although the project seems promising in its stated goals and methods.

Recommendation. Code 353 should continue the energy-efficient wireless networking project as planned and carefully monitor related industry and other Service programs in this area.

Game Theoretic Analysis of Radio Resource Management for Ad Hoc Networks

Wireless ad hoc networks have been the subject of intense study over the last decade, with a variety of approaches taken to determine their efficacy and robustness. Game theory has been used to study, model, and optimize networks, and ad hoc networks can benefit from extensions of that earlier work.

[3]Low Energy Electronics Design for Mobile Platforms, DOD MURI.

Findings and Recommendation. The game theoretic analysis of radio resource management for ad hoc networks project started in early 2003 and has not shown any novel results to date.

Recommendation. Code 353 should continue the game theoretic analysis of radio resource management for ad hoc networks project, as planned.

MEMS-Based Athermal Modulating Retroreflector

Free-space optical communications have long promised low-power, high-data-rate digital communication links, yet many developmental challenges remain and the actual applications have been few. In particular, current methods to create free-space optical retroreflectors have been based on semiconductor materials that have significant temperature variability, which severely limits their potential application in uncooled low-power systems.

Findings and Recommendation. The MEMS-based athermal (temperature independent) modulating retroreflector project proposes a novel concept—a MEMS device that, through the small, controllable reflections of an array of tiny MEMS mirrors, is capable of modulating a reflected beam of light. The primary application is for line-of-sight, high-data-rate communications with sensors by individuals who have limited energy capacity. An additional benefit is covertness for the sensor or the individual. The device itself could be very low power, since there is no need to generate light by the information sensor. The system would be interrogated by an external source and would act passively, impressing information as modulations on the reflected beam. This is an interesting project, with obvious potential benefits for the Marine Corps.

Recommendation. Code 353 should continue the MEMS-based athermal modulating retroreflector project, as planned.

Lightweight Power Sources

Today's individual marine is increasingly dependent on electronic devices, which demand an increasing supply of portable electric energy. This effort addresses fundamental issues in several of the most promising technology options—rechargeable batteries, fuel cells, and biomechanical energy—and investigates the modeling of power systems of all kinds.

High-Energy-Density, Rechargeable, Thin-Film Batteries for Marine Field Operations

The ability to store portable electrical energy is essential for marines in field operations, where energy is required for the operation of sensory enhancement equipment, automatic weapons, communications systems, and so on. The weight of these batteries is a major problem. The lithium polymer battery is an attractive option for the distributed power storage needs of marines in field operations, because it has projected practical energy densities of greater than 300 Wh/kg, low safety risks, and great flexibility in battery configuration. However, significant materials and processing challenges must still be overcome to achieve these performance advantages. Recently, efforts have shifted to a graft copolymer electrolyte as a practical approach for achieving the favorable properties of both large-scale rigidity and small-scale liquidity that were not achieved by earlier nanocomposite approaches. Test results

indicate that thin-film batteries with energy densities approaching 400 Wh/kg could be fabricated using a graft co-polymer approach.

Findings and Recommendation. Work on rechargeable batteries appears to have resulted in materials advances and a fabrication technology that offer a significant increase in energy density over today's batteries. However, the data presented were not clear about what was included in the energy density analysis. This project was planned to end in mid-FY03.

Recommendation. Code 353 should continue the rechargeable battery development project at the 6.2 or 6.3 level to prepare it to the point that it can be evaluated by industry for commercialization.

Fuel Cells for the Direct Electrochemical Oxidation of Strategic Fuels

The Department of Defense would very much like to standardize on JP-8 as the single source of energy on the battlefield. Research on fuel cells is motivated by the complexities of reforming fuels such as JP-8 to produce hydrogen for fuel cell consumption. Solid-oxide fuel cells have the potential for eliminating or reducing the need for a separate, energy-intensive reforming step by direct insertion and oxidation of hydrocarbon fuels at the anode. This project was initiated to address key issues associated with expanding the applicability of solid-oxide fuel cells to directly oxidize logistically available fuels such as JP-8.

Findings and Recommendations. The fuel cells research project has been very successful. Early on, a significant breakthrough was achieved in the direct oxidation of logistic fuels. It was discovered that substituting ceria and copper for the nickel catalyst on the anode facilitated the oxidation reaction without catalyzing the formation of anode-clogging graphite. This breakthrough in the ability to directly oxidize a hydrocarbon fuel in a solid oxide fuel cell represents a significant contribution to the fuel cell state of the art. Based on these results, DARPA has initiated a major effort to develop a complete JP-8-fueled prototype fuel cell system utilizing the anode catalyst developed by the Marine Corps/ONR. In addition, the contractor has entered into agreements for commercialization of the technology.

Recommendation. Code 353 should continue, and if possible expand, support for an examination of the effects of sulfur and other JP-8 impurities on the coking, performance, and stability of the catalyst.

Recommendation. Code 353 should investigate novel means to reduce the sulfur content of JP-8 to a level acceptable for input into fuel cell devices. This effort should aim to enable the use of high-sulfur-content indigenous fuels, which in turn would ease the logistics burden by enabling use of whatever fuels are available during a conflict.

Recommendation. Code 353 should continue to participate in DARPA program reviews and, together with the Army, should look into transitioning the DARPA JP-8 prototype fuel cell to an FNC program.

Polymer-Moderated Aluminum Anode

In comparisons of the energy densities of batteries, aluminum/air cells stand out as having an extremely high theoretical energy density yet only modest actual performance. In fact, among common

battery types, nowhere is the discrepancy between the theoretical and actual energy density greater than with aluminum/air cells. Consequently, even small improvements in efficiency would make a large difference in the total energy yield. In current aluminum/air cells, once the anode and electrolyte make contact, the cell must be used immediately since aluminum corrodes so rapidly as to significantly reduce the energy available. This feature currently limits aluminum/air cells to use as single-shot reserve batteries. Reducing corrosion requires modifying the cell electrolyte or the aluminum anode. The polymer-moderated aluminum anode project aims essentially to encapsulate particles of aluminum within an ionic-conducting polymer (polyacrylic acid). In the ideal case, such encapsulation would retard the corrosion reaction and sequester the reaction product during discharge. In preliminary tests, it has been shown to lengthen anode life and maintain electrolyte conductivity, for a more constant discharge potential.

Findings and Recommendations. The polymer-moderated aluminum anode research is an interesting and, the committee believes, a unique approach to improving the anode of an aluminum/air battery. The integrity of the polymer encapsulation during the requisite volume expansion of aluminum as it is transformed to aluminum hydroxide by corrosion is a point of concern. The amount of water tied up as aluminum hydroxide will also be a major contributor to the weight of the battery. The proposed approach may be able to minimize this weight penalty through the general reduction of corrosion.

Recommendation. Code 353 should evaluate corrosion rates and discharge capacity at low discharge rates of the polymer-moderated batteries.

Recommendation. Code 353 should continue work on the polymer-moderated aluminum anode and examine the effects of electrolyte water uptake on energy density.

Modeling of Power Systems for Marines

Modeling of power systems for marines involves the optimization of electrical power systems and loads for future Marine Corps applications. It includes the development of concepts suitable for modeling the increasingly complex electrical systems of future dismounted soldiers and land vehicles. Modeling concepts will be explored that are capable of ascertaining the total system consequences of technical advances in various system components, including both power generation and use. As such, the modeling will be used as a tool for linking decisions on power technology to future operational consequences for Marine Corps forces during expeditionary operations. The approach to optimizing advanced power sources and to understanding the performance of the systems using those sources is the creation of comprehensive and versatile simulation models that can be used to study the total system performance as used in a mission source. In addition, the project has looked at meeting the power needs of the dismounted marine by providing portable battery charging sites and hybrid power sources comprising two or more energy storage or production elements and associated power electronics that control the power demanded from the various energy resources and its distribution to the various loads.

Findings and Recommendations. The project on power systems for marines will finish in FY03. This very worthwhile project could have wide applicability across DOD. Historically, the power system designer has had little success in obtaining the load profiles of users in an actual mission. This power modeling project allows for synthesizing of the load profile from a user's equipment package within a mission scenario. The modeling of power systems for marines project then can optimize, for the mission

scenario, the power system configuration of a given set of power generation and energy storage components.

Recommendation. Code 353 should continue support of efforts to model power systems for warfighters and make the results available to the other Services.

Recommendation. Code 353 should validate the power systems model by collecting power data directly from a marine participating in a simulated mission.

Biomechanical Energy Conversion

No conventional energy supply is capable of providing the individual marine with continuous and indefinite electrical energy for mobile communications and electronics. Since mobile units lack wired access to generated electricity, they must carry it with them or harvest it from the environment. One possible solution is to use biomechanical energy—the energy generated by the movement of the human body. However, such exploitation of biomechanical energy should not place added demands on the human body or alter its biomechanics. The biomechanical energy conversion project proposes to explore biomechanical energy conversion in a systematic and integrative manner. The target will be prototype energy converters that charge conventional energy sources and provide short bursts of energy for communications. The proposed converters would offset some of the mass associated with portable sources of energy such as batteries, capacitors, and fuels. They would complement other possible portable electric power now under investigation so as to become part of a total hybrid energy delivery system. This project will be carried out through a unique collaboration of experts in power electronics and biomechanics.

Findings and Recommendations. The biomechanical energy conversion project is a new start, and no results were available. An initial step is an assessment of the energy available from the motion of various body elements (arm, leg, and heel strike). The committee sees potential duplication between this project and one for harvesting electrical energy (described below) since both are conducting kinematic analyses of human motions to determine energy availability.

Recommendation. Before proceeding, Code 353 should review the biomechanical energy conversion project in light of Marine Corps emergency power and energy requirements as defined in the modeling of power systems for marines project.

Recommendation. Code 353 should undertake a careful analysis of the biomechanical energy conversion project and the work on harvesting electrical energy to avoid duplication of efforts in the analysis of human kinematics.

Electrical Energy Harvesting

The electrical energy harvesting project attempts to steer and exploit developments in polymeric materials for potential use as electromechanical actuators or (in reverse) as generators. Unlike many other actuator/generator materials and devices, polymers could optimize the mechanical coupling with natural human motion. The range of motion over which such polymers generate electricity, together with their elastic resistance, can be tailored to both the displacement and the force of human muscles.

The project will evaluate the three most likely points at which energy could be harvested (backpack, heel, and knee) and will measure how important variables (such as compliance of the polymer) affect biomechanics. An optimal design will be developed taking into account ergonomics and power conversion efficiency. In parallel, the project will measure human biomechanics to obtain a range of ergonomic solutions and will determine critical parameters affecting energy harvesting and conversion. With both sets of information in hand, an optimal solution will be sought. The project will then test the physiological and ergonomic effects of the polymer device and establish a quantifiable set of criteria for its evaluation.

Findings and Recommendations. The project on electrical energy harvesting is a new start in FY03, and no results were available. The committee notes that DARPA recently conducted similar research on the use of electrostrictive polymers for energy recovery from heel strike. As noted above, the committee also sees potential duplication between this project and the biomechanical energy conversion project since both are conducting kinematic analysis of a person walking to determine energy availability.

Recommendation. Code 353 should review the report of the electrical energy harvesting project in order to gain valuable insight on recent developments in this area.

Recommendation. Typically, polymeric materials generate very high voltages, so Code 353 should at the same time study the size, weight, and efficiency of the voltage down-converters necessary to convert these materials into systems usable by the warfighter.

Recommendation. Code 353 should undertake a careful analysis of the electrical energy harvesting project and the biomechanical energy conversion project to avoid unnecessary duplication of efforts in the analysis of human kinematics.

Information Efficiency

As the Marine Corps develops the highly mobile and agile force envisioned for EMW, the need to acquire and disseminate large amounts of digital data could overwhelm the warfighter. One of the critical problems from the standpoint of the individual marine is that all energy required to power his or her RF links must be carried. This imposes on the deployed marine a stringent, energy-limited data-rate budget. To ensure that communications systems deliver the right information at the right time to the right people without overly taxing the ability of a marine to carry more batteries, research on information efficiency has been undertaken in five individual projects.

Information Theory for Aim-Point Selection

The information theory for aim-point selection project focuses on developing the theory of data fusion based on maximizing information expressly for application to aim-point selection. Another goal of the project is to develop metrics for the loss of target information as the surrounding clutter increases. The expected payoff of the project is a systematic means of sensor design and resource allocation.

Findings and Recommendation. Information theory has been used for decades to optimize data fusion. The project on information theory for aim-point selection represents a new application of information theory that can lead to new insights. The project finishes in FY03.

Recommendation. Code 353 should closely evaluate the results of the information theory for aimpoint selection project before proceeding with future investments in this area.

Compression of Digital Elevation Maps Using Nonlinear Wavelets

The work on compression of digital elevation maps using nonlinear wavelets focuses on developing efficient and flexible compression algorithms for digital terrain elevation data based on nonlinear wavelet algorithms. This project aims to develop algorithms for image compression that allows an end user to query the image at a resolution less than that of the original image. Often, the marine requesting an image does not necessarily need to have the image at the full resolution available from digital terrain elevation data. Image compression would allow users to more easily share map information across bandwidth-limited communication links.

Findings and Recommendation. The use of wavelets has dramatically reduced the size of various image files. The option of downloading images at less-than-original resolution is a good approach for further reducing the bandwidth necessary for image transport. It is expected that this application will deliver measurable payoffs in terms of map data size and efficiency. This project will finish in FY03.

Recommendation. Code 353 should demonstrate the algorithms for image compression with operational Marine Corps units to determine when maps and images at lower than original resolution would be useful to the warfighter.

Information Management in a Mobile Environment

The objective of the work on information management in a mobile environment is to develop software to assist the rapid analysis of imagery with respect to segmenting images into regions containing various terrain features. For example, if a marine needs a map highlighting wooded areas within an urban setting, a map could be sent that shows only the boundaries of the wooded areas. This segmented map would then improve the efficiency of communicating and sharing information derived from digital imagery over bandwidth-limited links.

Findings and Recommendation. Data from digital imagery have the potential to overwhelm the limited communication capacity of a highly mobile military. The combination of wavelet compression (discussed above) and the results of this project can significantly reduce the amount of data that must be distributed throughout the battle space. This project will be complete by the end of FY03.

Recommendation. Code 353 should integrate the results of the project on information management in a mobile environment and the project on compression of digital elevation maps using nonlinear wavelets as a means of transitioning both to a 6.2 or 6.3 program.

Region-Based Image Compression Subject to Energy and Bandwidth Constraints

The objective of the region-based image compression project is to investigate how to best generate images in which the resolution of the image can be varied across the field of the image. For example, an image of a farming area may be saved at lower resolution over the farmland and higher resolution over

the farmhouses and roads. This project would allow for less data overall to be transmitted to the marine without sacrificing resolution over important areas.

Findings and Recommendation. The region-based image compression project utilizes nonlinear wavelets concentrating on maxima and minima (e.g., of terrain heights and valleys) to organize the compressed data in such a fashion that the information not transmitted can be reconstructed later. The project also seems closely coupled to the preceding two efforts in wavelet compression and region segmentation. This was a new start in FY03, so there are still no results.

Recommendation. Because the region-based image compression project is at an early state of development, Code 353 should use the results of the two preceding projects to assist in its development.

Semantic Source Coding

Mobile sensor networks, an important element of future battle space awareness systems, can be large consumers of both energy and bandwidth. Because of the overwhelming amount of information that will be gathered, it will be important to extract, at the source, the essential information content (semantic information) for transmission so as not to overwhelm the communications system. In the semantic source coding project, raw sensor data is processed into information content categories and descriptions, at varying levels of resolution, about battlefield objects and their behavior. Increasing levels of data compression used in the processing are based on wavelets, formal languages, and codebooks.

Findings and Recommendation. The research on semantic source coding could be useful for understanding how new and future compression and coding techniques can reduce the demands on communication capacity and energy resources. This project is a new start and should be monitored closely.

Recommendation. Code 353 should continue the semantic source coding project through completion, as planned.

Sensing

As battlefields become more diffuse and the Marine Corps begins to operate more in heavily populated areas, the need arises to more carefully track and monitor the movement of people and equipment. Research in four projects related to sensing addresses the need for systems and materials that will help a marine to identify and track potential threats as well as assist in the monitoring of equipment of interest to potential enemies.

Fluorescent Rare-Earth Chelates as Encoded Marking Materials

Several rare-earth chelate materials have been found to have tailorable, time-sensitive fluorescence. The principal mechanism for decay is photobleaching of the fluorescence of the rare-earth ion; that is, the material's fluorescence decays in response to light. Thus each new exposure of the top layer of a material to light begins a new "clock" from which to measure the time of exposure. Such a mechanism could then be used to ensure that secured but unguarded areas remain untouched or if touched give time indications for the traffic.

Findings and Recommendation. The project on rare-earth chelates is distinguished by having novel aspects and possible future application to Marine Corps needs in area denial. The project is notable for its creative application of new materials and chemical properties.

Recommendation. Code 353 should continue the fluorescent rare-earth chelates project as planned and is encouraged to seek out other similar creative and interesting marking system research opportunities.

Atomic Force Microscopy Determination of Radiation Exposure

The atomic force microscopy project explores the effects of radiation on materials in order to enable the use of everyday materials for dosimetry. Individual gamma rays contain enough energy to produce microscopic craters on the surfaces of nearby materials. This project aims to employ atomic force microscopy to measure the surface density of these craters and thus the total radiation dose to which the material has been subjected.

Findings and Recommendations. The atomic force microscopy project is intriguing in its use of a relatively new technique as a versatile radiation sensor. While the specific method, atomic force microscopy, may or may not ultimately be employed, the ability to use a diverse set of materials as radiation detectors would improve the ability of the Marine Corps to monitor and track nuclear materials.

Recommendation. Code 353 should continue the atomic force microscopy radiation detection project through completion, as planned.

Recommendation. Code 353 should initiate studies that search for radiation detection systems that can be more easily transported to and deployed in the field.

Recommendation. Code 353 should work closely with DOE laboratories in the development of novel radiation sensing techniques.

Surface Enhanced Raman Spectroscopy for Chemical Marker Detection

The surface enhanced Raman spectroscopy project is an initial step toward determining the feasibility of using surface enhanced Raman spectroscopy to detect chemical markers. It focuses on finding classes of molecules that could be used in sensors as marker materials to be detected by surface enhanced Raman spectroscopy.

Findings and Recommendation. A useful system for chemical sensing requires two components, the chemical to be detected and a method for detecting it. This project is an interesting approach to developing a potentially very sensitive detection method to add to the current inventory of methods. Since this project is a new start, no results are yet available.

Recommendation. Code 353 should continue the surface enhanced Raman spectroscopy or chemical marker detection project through completion, as planned.

Microgels for Optical Tagging

The microgels for optical tagging project focuses on developing and understanding a materials preparation method for synthesizing micrometer-sized photonic crystals and then depositing them to form bar-code-style optically active tags. One of the goals is to devise a fast and inexpensive method of producing such photonic materials, which would greatly improve their potential utility.

Findings and Recommendation. Use of photonic crystal-based optical tags is an interesting and novel approach to the generation of tag materials. The proposed extension of the research to the fabrication of infrared active crystals would also improve the utility of the tags since they could be hidden more easily from normal vision. This project is a new start, and no results are yet available.

Recommendation. Code 353 should continue the microgels for optical tagging project through completion, as planned.

Human Sensory Enhancement

Technology has the potential to increase human awareness and sensitivity to the environment. Research on human sensory enhancement focuses on increasing the warfighter's awareness in a stimulus-rich environment, such as an urban setting. Even small improvements in a marine's ability to respond to sensory inputs and react just a few seconds sooner could make a significant difference to a marine's ability to function and survive.

Human Perception of Natural Scenes

The human perception of natural scenes project is investigating the effects of spatial orientation biases on human perception in the context of realistic visual clutter. Recent work has indicated that the effects on human visual perception of the spatial orientation of dominant image background structure, in the presence of realistic clutter, are very different from what they were thought to be on the basis of previous studies.

Findings and Recommendation. The human perception of natural scenes project appears to be studying the response of the human visual system under the influence of a large amount of uniaxial visual clutter (as, for instance, in a forest, where the tree trunks are predominantly aligned in the vertical direction). Understanding the response of the human visual system to uniaxial clutter can be an asset to operational scenario planning, including planning for urban or jungle warfare. It was unclear to the committee, however, how the results of this project would improve the warfighter's capabilities.

Recommendation. Code 353 should clarify the design goals of the human perception of natural scenes project in regard to its support of the warfighter.

Transition Speech Waveform Features to Enhance Speech Recognition in Noisy Environments

The work on transition speech waveform features to enhance speech recognition in noisy environments aims to enhance the efficiency of RF voice communications in a noisy background by isolating

and enhancing transitions between speech sounds. It has been found that the transitions between phonemes, rather than the quasi-steady-state phonemes themselves, contain most of the intelligible content of speech.

Findings and Recommendation. The last four decades have led to a wide array of speech enhancement algorithms, particularly for noisy or bandwidth-limited voice communications systems. This project appears to be appropriately integrated with other academic research in this field and would add to this body of knowledge.

Recommendation. Code 353 should examine existing approaches to enhancing speech recognition (under development by other Service laboratories as well as by industry) and test them within the context of the proposed operational scenario before making a significant financial investment in this research on transition speech waveform features.

Land Mine Detection

Research on land mine detection explores diverse methods of detecting and, possibly, categorizing land mines. Reliable and (especially) rapid detection of mines has proved elusive, and mines have become a major problem both in military combat and for civilians worldwide. In military applications, time is of the essence. Once it has been located, a minefield eventually can be eliminated or a path through it established. However, because of the time it takes to accomplish this, minefields can be effective in keeping military forces from advancing, thereby entrapping forces or, at a minimum, slowing down their advance.

As discussed in the 2001 report *Naval Mine Warfare*[4] and indicated in briefings on the MCM thrust,[5] the Navy has responsibility for MCM up to the high-water mark, and the Marine Corps is responsible for clearing the beach from the water line to the beach exit points and beyond. The *Naval Mine Warfare* report also noted that there is no joint Navy/Marine Corps concept of operations that involves Navy and Marine Corps mine-clearing systems in a continuous operation. It was not clear from the presentations to the committee how the 6.2/6.3 MCM core thrust (Chapter 3) is integrated with the 6.1 land mine detection research effort.

Consistent with this operational division of mine-clearing responsibilities, the Basic Research projects presented for review all focus on detection challenges associated with buried land mines. There is no application of S&T to MCM as an end-to-end problem (i.e., from the sea to inland) that spans the four Services.

Recommendation. Code 353 should construct an overview table that compares all the different methods for mine detection—from dog sniffing to nuclear resonance—and should then extend the table to evaluate combinations of techniques.

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[4]Naval Studies Board, National Research Council. 2001. *Naval Mine Warfare: Operational and Technical Challenges for Naval Forces*, National Academy Press, Washington, D.C., p. 101.

[5]David C. Heberlein, Institute for Defense Analyses, Technical Advisor, Expeditionary Warfare Operations Technology Division, Office of Naval Research, "ONR Code 353 Naval Science Board Review, Mine Countermeasures (MCM) Thrust," slide 3, presentation to the committee on May 14, 2003.

Recommendation. Code 353 should coordinate mine countermeasures research strongly with Army land mine detection efforts.

Recommendation. Code 353 should support and leverage Navy mine countermeasures programs that show promise for use in the shallow water and surf zone environment.

Recommendation. Code 353 should establish 6.1 companion projects to the Core Thrust MCM projects to include algorithm development not only for new sensors but also for fused combinations of sensors (co-located or remote) in order to increase detection capability (mainly signal-to-clutter) over a broad range of environmental and operational conditions. This very serious problem needs good ideas more than it needs money.

The five seismic and acoustic mine detection projects listed below include an innovative combination of two technologies for mechanical excitation of buried mine vibration—seismic and acoustic—with RF detection of the effects at the ground surface of the mine's vibration. As the waves from the buried vibration propagate to the surface, ground height changes (ripples) are measured by RF methods. Any underground obstruction leads to wave scattering and/or interference. Like purely RF methods (e.g., ground-penetrating radar), this technique could involve high false alarm rates due to buried objects like rocks, holes, subsurface water, or other underground clutter. The general approach common to all seismic, acoustic, and RF methods is to determine the signature of particular mines and eliminate all other signatures. It appears to the committee that this is a very precarious method of separating a mine (and only a particular mine) from clutter.

Environmental Issues in Seismic Mine Detection

The environmental issues studied in connection with seismic mine detection are related to the propagation of ground surface waves in a full spectrum of representative soil types and conditions for detecting buried objects. Field testing is nearly complete, and there are no stated plans to continue the effort.

Findings and Recommendation. The environmental issues in seismic mine detection project was characterized as essentially complete, with the project having met its objective of providing a theoretical basis for modeling the resonant response of mines in a wide variety of soil types. There were no transition roadmaps or discussion of any follow-on activity to use the results.

Recommendation. Code 353 should terminate the environmental issues in seismic mine detection project as scheduled and use the results to investigate the potential of seismic methods in the saturated environment near the surf zone.

False Indicators in Acoustic/Seismic Land Mine Detection

The project on false indicators in acoustic/seismic land mine detection is a new start. It is being established with the objective of understanding the mechanisms responsible for false alarms in acoustic and seismic land mine detection. It will investigate the effects of soil properties and of nonlinear coupling as a function of excitation frequency and spatial resolution.

Findings and Recommendations. The project on false indicators is currently focused on buried land mines in the beach zone above the high water mark and beyond.

Recommendation. Code 353 should continue with initiation of the false indicators in acoustic/seismic land mine detection project and should ensure that it is closely coordinated with the seismic and the acoustic buried land mine detection projects.

Recommendation. Code 353 should consider broadening the false indicators in acoustic/seismic land mine detection to include the craft landing zone, the surf zone, and very shallow water environments.

Seismic Detection of Buried Land Mines

This project is a new start to investigate the interaction between the soil and mine seismic energy situations where the acoustic wave is tuned to generate a resonant vibration mode within the buried mine. The seismic surface wave is generated at some horizontal distance from the buried mine on the ground surface. The project will investigate the projection of mine vibration modes up to the ground surface, where they can be detected by an acoustic or electromagnetic (including optical) sensor above the buried mine.

Findings and Recommendation. Seismic detection of buried land mines is an extremely challenging research topic, and the committee is concerned that soil packing density and mine orientation could lead to significant underreporting of mines. This project currently focuses on buried land mines in the beach zone above the high-water mark and beyond. There is a potential for leverage with the project described below, which is investigating the acoustic detection of buried mines.

Recommendation. Code 353 should ensure that the seismic detection of buried land mines project collaborates closely with the acoustic detection of land mines project, since the two projects involve similar mine and soil issues.

Acoustic Detection of Buried Land Mines

This project is a new start that aims to quantify key parameters and performance thresholds for the resonant acoustic detection of buried land mines. It will investigate energy propagation and resonance measurements (with and without an air gap between the acoustic source and the receiver vertically above the buried mine) to quantify the upper frequency limits to resonant acoustic land mine detection.

Findings and Recommendation. Acoustic detection of buried land mines is an extremely challenging research topic, and the committee is concerned that soil packing density and mine orientation could lead to significant underreporting of mines. This project is currently focused on land mines buried in the beach zone above the high-water mark and beyond. There is a potential for leverage with the project investigating the seismic detection of buried mines.

Recommendation. Code 353 should ensure that the acoustic detection of buried land mines project collaborates closely with the seismic detection of buried land mines project, since the two projects involve similar mine and soil issues.

Impulse or Ultrawideband Radar Research

The objective of the impulse or ultrawideband radar research project is to examine buried-target scattering of UWB electromagnetic radiation (as in impulse radar) by computer analysis (signal processing techniques) to identify the target (a buried mine).

Findings and Recommendation. Research on ultrawideband radar for mine detection is a collaborative effort among ONR, ARL, and the Swedish Defence Research Agency (FOI). Variations on this technology are also being investigated by the Army NVESD for application in its Ground Standoff Mine Detection System program, which is scheduled to transition to a system development and demonstration program in 2004 and may already be addressing Marine Corps land-based countermine problems.

Recommendation. Code 353 should establish a relationship with NVESD to leverage information on both phenomenology and implementation for ultrawideband radar systems applicable to mine detection.

Laser Eye Protection

While such weapons are outlawed by international convention, the possibility exists for countries or terrorist groups to develop laser weapons intended to blind attacking troops. Such weapons would pose a particular threat to the Marine Corps because of its mission as a first-responder force, so that Marine Corps units would likely be among the first to encounter such a new and asymmetric threat. For this reason a small project has been started to develop eye protection systems that would defeat weapons meant to blind. Like mine detection, laser eye protection has been studied for decades, is technically extremely challenging, and is in need of good ideas more than it needs money. This project appears to be a good idea.

Nanostructured Optical Limiters

Organic polymer multilayers in nanometer thicknesses are being prepared that could counter antipersonnel lasers and future frequency-agile versions of these threats. Dielectric multilayers with alternating high and low refractive indexes act as interference filters; the wavelength filtered is determined by the thickness of the layers, and the maximum attenuation is a function of the number of layers.

Findings and Recommendations. Nonlinear optical properties and novel materials preparation methods are being used to create nanostructured multilayered materials for further study. This is a novel approach that promises great design flexibility.

In general, a uniform multilayer structure will only work against a particular laser frequency. A major problem is to achieve a multilayer filter that will function against two or more wavelengths or be tunable against a broad range of laser wavelengths. The approach being studied is described as enabling fabrication of up to ~10,000 layers, presumably with controllable thicknesses, which suggests the potential for creating graded or multiply-tuned and broadband structures.

The committee is aware of similar work once supported by the Army NVESD but does not know where this work stands now.

The work on nanostructured optical limiters is well motivated both scientifically and for its potential implications for the Marine Corps. The methods and techniques being developed have a number of other possible applications. This research is a good example of basic science with a clear practical objective.

Recommendation. Code 353 should proceed with the nanostructured optical limiters project through completion, as planned.

Recommendation. Code 353 should ensure that further efforts in laser eye protection build on similar Army efforts.

Energetic Materials

Two projects involving energetic materials were active in FY03. Existing concerns about lethality-to-weight ratio and safety, both of which call for energetic materials with higher energy density and reduced sensitivity, are magnified by the demands of sea basing and expeditionary warfare. The two projects described address (1) gaining a fundamental understanding of sensitization and initiation and (2) understanding how to develop new binders for explosives and propellants.

Understanding and Predicting Explosive Response of Metal-Metal and Metal-Oxidizer Compositions Subjected to Shock or Impact

Theoretical and atomic force microscopy studies of metal-metal and metal-oxidizer energetics from the Indian Head Division of the Naval Surface Warfare Center were described to the committee. This research seeks to understand the processes responsible for initiation of chemical reactions as a result of shock or impact loading and to use this fundamental understanding to develop both safer and ultimately more lethal explosives. It has succeeded in identifying shear bands as likely sources of initiation following shock or impact and suggests common features for initiation due to impact or shock in different forms of crystalline explosives.

Recognizing that explosive sensitivity to mechanical or thermal abuse is well characterized, the research focuses on understanding plastic deformation and energy dissipation at the atomic level. The long-term goal is to predict the initiation behavior of representative metal-metal or metal-oxidizer compositions, to compare the predictions with experimental data, and ultimately to predict and optimize the behavior of new explosive compositions.

Findings and Recommendations. The study of blast initiation in the context of safety has clear connections to the logistical challenges of sea basing and EMW. This project on understanding explosive response has produced initial results of interest and has identified areas for further study. The good balance of theoretical/modeling work and small-scale experimentation positions this effort well for further evaluation and application. The program is well focused, productive, and of unique long-term interest to the Marine Corps.

The committee recognizes the challenges posed by the need to coordinate further development activities with other organizations that play leading roles in the development and delivery of ammunition for the joint Services.

Recommendation. Code 353 should proceed with the work on predicting explosive response through completion, as planned.

Recommendation. Code 353 should ensure that energetic materials research remains part of the MCS&T program's Basic Research effort.

Synthesis of 1,2,3,-Triazoles via 1,3-Dipolar Cycloaddition of Organic Azides with Activated Acetylenes

New energetic ingredients being studied for higher-performance explosives and propellants can be incompatible with the cure reaction of the urethanes now used as binder materials. This project addresses designs for a new propellant and binder system based on the 1,3-dipolar cycloaddition reactions of acetylenes and azides to form triazole rings. The goal is binders that are cure-compatible with higher-energy ingredients, facilitating lighter-weight warheads. The approach involves modeling, establishment of structure-property relationships, and fabrication and characterization of small propellant systems.

The project addresses the basic questions of manufacturing incompatibility that have prevented the introduction of higher-density explosives. Results to date show that the triazole cure works well, evolves no water or gaseous by-products, and proceeds in the presence of energetic compounds. The problems facing continued development of this technology center on a clear understanding of the structure-property relationships and on the cross-linking polymerization chemistry.

Findings and Recommendations. The development of energetic materials with an improved lethality-to-weight ratio has a clear connection to the logistical challenges of sea basing and EMW. This project has produced initial results of interest and has identified areas for further study. The good balance of theoretical/modeling work and small-scale experimentation positions this effort well for further evaluation and application.

Recommendation. Code 353 should proceed with the novel binder project through completion, as planned.

Recommendation. Code 353 should ensure that energetic materials research remains part of its Basic Research effort.

Appendixes

A

Committee and Staff Biographies

Frank A. Horrigan (*Chair*) is retired from the Technical Development Staff for Sensors and Electronic Systems at Raytheon Systems Company. He has broad general knowledge of all technologies relevant to military systems. Dr. Horrigan, a theoretical physicist, has more than 40 years' experience in advanced electronics, electro-optics, radar and sensor technologies, and advanced information systems. In addition, he has extensive experience in planning and managing information R&D investments and in projecting future technology growth directions. Dr. Horrigan once served as a NATO fellow at the Saclay Nuclear Research Center in France. Today he serves on numerous scientific boards and advisory committees, including the NRC's Army Research Laboratory Technical Assessment Board and the Naval Studies Board. He recently chaired the NRC's Committee for the Review of the Office of Naval Research's Uninhabited Combat Air Vehicles Program.

Alan Berman is a part-time employee at the Applied Research Laboratory of Pennsylvania State University (ARL/PSU) and at the Center for Naval Analyses (CNA). At ARL/PSU, Dr. Berman provides general management support and program appraisal. At CNA, he assists with analyses of Navy R&D investments, space operation capabilities, information operations, and C4ISR programs. In addition, Dr. Berman is a member of the Free Electron Laser oversight board that advises the Department of Energy Jefferson National Laboratory. At one time, he was dean of the Rosenstiel School of Marine and Atmospheric Sciences at the University of Miami, responsible for the graduate programs in physical oceanography, marine biology, geology, geophysics, applied ocean science, and underwater acoustics. He was also director of research at the Naval Research Laboratory (NRL), where he administered broad programs in basic and applied research. The NRL programs included electronic warfare, radar, communications, space systems, space sciences, material sciences, plasma physics, antisubmarine warfare, underwater acoustics, oceanography, electronic devices, and space-based time standards for the GPS. He has been a member of numerous government advisory boards and panels and is currently a special advisor to the NSB.

Charles F. Bolden, Jr., is senior vice president of TechTrans International, Inc., having retired recently at the rank of Major General after 34 years of service to the U.S. Marine Corps. General Bolden, as a naval aviator, flew more than 100 sorties into North and South Vietnam, Laos, and Cambodia. He

became an astronaut in 1981 and later flew the space shuttle on four flights. General Bolden was assistant deputy administrator for NASA in 1992 and 1993 and then served 1 year as Deputy Commandant of the U.S. Naval Academy. General Bolden's command positions include Deputy Commanding General, First Marine Expeditionary Force (1 MEF); Commanding General, 1 MEF (FWD) in support of Operation Desert Thunder in Kuwait; Deputy Commander, U.S Forces, Japan; and, finally, Commanding General of the 3rd Marine Aircraft Wing. He received a B.S. in electrical science from the U.S. Naval Academy and an M.S. in systems management from the University of Southern California.

Michael S. Bridgman is program manager of Acquisition Logistics for the Logistics Management Institute (LMI), where he leads study teams and performs analyses on supportability and cost drivers, alternative support concepts, system reliability, operational availability, test and evaluation of weapon system suitability, and relationships between design and logistics support. Dr. Bridgman's areas of application include weapon systems, electronics, transportation equipment, and space systems. Prior to joining LMI, Dr. Bridgman served at the Battelle Memorial Institute as a research fellow and projects manager for logistics studies. Dr. Bridgman holds a Ph.D. from the Ohio State University in industrial and system engineering and is a senior member of the International Society of Logistics.

John D. Casko is the director of airborne mine countermeasures programs at Northrop-Grumman's airborne ground surveillance and battle management systems business area. Mr. Casko has a background in systems engineering, radar, lidar, and other sensors. He is responsible for transitioning remote-sensing technology into DOD and non-DOD applications, including land and sea mine countermeasures. Mr. Casko earned a B.S. in aerospace engineering from the University of Kansas, an M.S. in aerospace engineering from the Naval Postgraduate School, and an M.S. in physical science from the University of West Florida. Mr. Casko is a retired naval officer and Navy pilot.

Nancy M. Haegel is a member of the physics faculty at the Naval Postgraduate School in Monterey, California. Dr. Haegel's research interests are in the area of semiconductor materials, with an emphasis on the electrical and optical behavior of high-resistivity semiconductors and materials for far-infrared detection. She is involved in the development and modeling of extrinsic photoconductors for use in infrared detectors on satellites. Dr. Haegel's prior positions include professor of physics at Fairfield University in Fairfield, Connecticut; research scientist at the Siemens Research Laboratories in Erlangen, Germany; and associate professor of materials science at the University of California, Los Angeles. Dr. Haegel holds a B.S. in materials science and metallurgical engineering from the University of Notre Dame, summa cum laude, and an M.S. and Ph.D. in materials science from the University of California, Berkeley. Dr. Haegel was a member of the Defense Science Study Group in 1992 and 1993.

R. Bowen Loftin joined Old Dominion University (ODU) in Norfolk, Virginia, in 2000 as professor of electrical and computer engineering and professor of computer science. In addition, Dr. Loftin is executive director of the Virginia Modeling, Analysis and Simulation Center and the university's director of simulation programs, with responsibility for the university's graduate programs in modeling and simulation. Before coming to ODU, Dr. Loftin was a professor in and chair of the Department of Computer Science and the director of the NASA Virtual Environments Research Institute at the University of Houston. Since 1983 Dr. Loftin, his students, and coworkers have been exploring the application of advanced software technologies, such as artificial intelligence and interactive, three-dimensional computer graphics, to the development of training and visualization systems. He is a frequent consultant to both industry and government in the area of advanced training technologies and scientific and engineering data visualization. Dr. Loftin serves on advisory committees and panels sponsored by numerous government and professional organizations. Awards received by Dr. Loftin include the University of Houston-Downtown Awards for Excellence in Teaching and Service, the American Association of Artificial Intelligence Award for an innovative application of artificial intelligence, NASA's

Space Act Award, the NASA Public Service Medal, and the 1995 NASA Invention of the Year Award. He is the author or coauthor of more than a hundred technical publications.

Geoffrey C. Orsak currently serves as associate dean for research and development and professor of electrical engineering in the School of Engineering at Southern Methodist University (SMU). Dr. Orsak is also executive director of the Institute for Engineering Education at SMU and chief architect and director of the Infinity Project, the nation's leading high-tech K-12 engineering education program. Dr. Orsak's research focuses on the development of advanced technologies for high-speed wireless communications and novel techniques for signal interception and intelligence. In addition to his research, Dr. Orsak speaks and writes widely on issues associated with K-16 engineering and technology education. Dr. Orsak received his B.S.E.E., M.E.E., and Ph.D. degrees in electrical and computer engineering from Rice University.

Irene C. Peden is professor emerita of electrical engineering at the University of Washington, Seattle, where she has also served as associate dean of the College of Engineering and as associate chair of the Department of Electrical Engineering. Her research interests are in geophysical subsurface remote sensing, radio science, and electromagnetic wave scattering and propagation. Dr. Peden has also served as director of the Division of Electrical and Communications Systems at the National Science Foundation. Dr. Peden was the first woman principal investigator to do field work in the Antarctic interior (1970). She has been a member of several government and military boards, including the Army Science Board, the Naval Research Advisory Committee, and the Joint Senior Advisory Group to the Assistant Secretary of Defense (C3I). Dr. Peden holds a B.S. degree from the University of Colorado at Boulder, and M.S. and Ph.D. degrees from Stanford University, all in electrical engineering. Dr. Peden is a member of the National Academy of Engineering and a fellow of the IEEE.

Frederick W. Riedel is the assistant supervisor of the Weapons Branch and chief engineer of the Strike Warfare Business Area at the Johns Hopkins University Applied Physics Laboratory (JHU/APL). Mr. Riedel has extensive experience in the mathematical modeling of physical systems. His work on missile systems includes analyzing missile terrain following, rolling airframes, and bank-to-turn airframes, as well as measuring the accuracy of land attack cruise missiles. His other technical work includes developing a spectral model of the ocean surface, modeling the reflection of light from that surface, and determining requirements for autonomous ship classification. More recently, Mr. Riedel has applied systems engineering practices to land attack cruise missile weapon systems and defense suppression weapons. He supervised the Guidance, Navigation and Targeting Systems Group at JHU/APL, which is responsible for guidance and navigation analyses and designs, in particular as applied to power projection weapons and for the development of mission planning performance prediction algorithms and methods for cruise missiles. Mr. Riedel has a B.S. in mechanical engineering from Carnegie Mellon University, an M.S. in mechanical engineering from Syracuse University, and an M.S. in electrical engineering from the Johns Hopkins University.

James K. Stedman is currently a consultant for DARPA and other government agencies on electrical power generation research and development. Mr. Stedman has over 35 years of industry and government experience in the design, development, management, and marketing of aerospace and terrestrial fuel cell technology. Mr. Stedman spent most of his professional career at United Technologies Corporation (UTC), where he retired as program manager of UTC's fuel cell power system development and production division. During his tenure, Mr. Stedman conceived design concepts and implemented strategies for DOD and NASA aerospace power system programs, including analysis and design of advanced fuel cell systems and acting as senior engineer responsible for initial design and performance analysis of the Apollo and space shuttle fuel cell power systems. He chaired a NASA select committee investigating the fuel cell anomaly on space shuttle flight STS-83. Mr. Stedman received a B.S. in

mechanical engineering from Rensselaer Polytechnic Institute and worked initially with Boeing Aerospace Company before joining UTC. He holds eight fuel cell patents.

H. Gregory Tornatore recently retired as special assistant to the department head for business development information and as manager of special security at JHU/APL. Prior to his retirement he also served in a number of managerial positions, including program area manager for defense communications systems. His areas of expertise include strategic and tactical command, control, and communications (C3), over-the-horizon targeting systems, wide-area surveillance and reconnaissance, C3 systems vulnerability assessment, test and evaluation of major communications systems, satellite communications systems and architectures, command and control (C2) information processing, information operations, and communications networks. Other specialties include radio physics phenomenology, atmospheric and galactic RF noise, radio wave propagation, HF radar signatures and clutter, electronic countermeasures, trajectory estimation and tracking algorithms, and antenna systems. Mr. Tornatore was employed at JHU/APL for 26 years and was a member of the principal professional staff for 23 years. Before that, Mr. Tornatore was responsible for HF propagation and radar studies and field experiments at the ITT Electro-Physics Laboratory. He was also a graduate research assistant in ionospheric physics at the Pennsylvania State University and an instructor in physics at St. Francis University in Loretto, Pennsylvania.

Jud W. Virden is currently deputy director of the Energy Science and Technology Directorate at Pacific Northwest National Laboratory (PNNL). He is engaged in power systems, building systems, energy product development and applications, energy operations and maintenance, industrial technology, advanced manufacturing, advanced materials science, and information systems engineering. Previously, Dr. Virden served as director of transportation programs at PNNL, responsible for development of both public and private programs with automotive customers and the DOE. Prior positions at PNNL included technical group leader of the Materials Department, where he participated in programs to develop fiber composite materials, catalysts, mesoporous materials, and nonthermal plasmas. From 1994 to 1996, he completed a 2-year assignment in Flint, Michigan, working with General Motors, Ford, and Chrysler as part of the U.S. Council of Automotive Research and the Partnership for a New Generation of Vehicles. Prior to joining PNNL, he worked in the Science Research Laboratory at the 3M Company and was part of a team developing ordered, organic thin films for nonlinear optical applications. Dr. Virden holds a Ph.D. in chemical engineering from the University of Washington.

Paul S. Weiss is a professor of chemistry and physics and director of the Center for Molecular Nanofabrication and Devices at the Pennsylvania State University. Dr. Weiss works broadly in the areas of surface chemistry and physics with a focus on self-assembly, molecular electronics, nanometer-scale science and technology, and control of adhesion, uptake, and immune response in biological and model membranes. This work relies on advancing the art and methods of scanning probe technology to push surface science into studies of molecular and biological phenomena. Dr. Weiss is a fellow of the AAAS and the American Physical Society and has served on several Defense Science Board review panels. Dr. Weiss holds an S.B. and S.M. in chemistry from the Massachusetts Institute of Technology and a Ph.D. in chemistry from the University of California, Berkeley.

Leo Young was director for research in the Office of the Under Secretary for Defense Research and Engineering (ODDR&E) in the Office of the Secretary of Defense from 1981 to 1994 and consulted for ODDR&E through 2002. Before joining ODDR&E Dr. Young served as associate superintendent for the Electronics Division at the Naval Research Laboratory and as staff scientist and laboratory manager at the Stanford Research Institute. In those positions his research focused on microwave filter design. As director for research in ODDR&E, Dr. Young oversaw DOD's Basic Research program, initiated the DOD Small Business Innovation Research program, chaired the IR&D coordinating committee, exer-

cised oversight of the Defense Technical Information Center, and advised on technology export control. Dr. Young was secretary of the DOD-University Forum, and of the Laboratory Management Task Force, and had responsibility for the congressionally mandated Defense Critical Technologies Plans (starting in 1989). Dr. Young is a fellow of IEEE (he served as president in 1980) and of AAAS, a member of the National Academy of Engineering, and a fellow of the Royal Academy of Engineering (U.K.). He has received numerous awards, including the Microwave Career Award from the IEEE and the Woodrow Wilson Award for Distinguished Government Service from the Johns Hopkins University. He holds B.A. and M.A. degrees in both mathematics and physics from Cambridge University and M.S and D.Eng. degrees in electrical engineering from the Johns Hopkins University.

Staff

Ronald D. Taylor currently is on assignment to the Department of Homeland Security (DHS). In July 2003, Dr. Taylor became director of the Office of Studies and Analysis in the Science and Technology Directorate at DHS. He also serves as the executive secretary for the Homeland Security Science and Technology Advisory Committee. Dr. Taylor has been director of the National Research Council's Naval Studies Board since 1995. In 2002 he assumed collateral duties coordinating National Research Council work with the Intelligence community as well as its work on homeland security. He joined the National Research Council in 1990 as a program officer then senior program officer with the Board on Physics and Astronomy and in 1994 became associate director of the Naval Studies Board. During his tenure at the National Research Council, Dr. Taylor has overseen the initiation and production of more than 40 studies focused on the application of science and technology to problems of national interest. Many of these studies address national security and national defense issues. From 1984 to 1990 Dr. Taylor was a research staff scientist with Berkeley Research Associates working on-site at the Naval Research Laboratory on projects related to the development and application of charged particle beams. Prior to 1984, Dr. Taylor held both teaching and research positions in several academic institutions, including assistant professor of physics at Villanova University, research associate in chemistry at the University of Toronto, and instructor of physics at Embry-Riddle Aeronautical University. Dr. Taylor holds a Ph.D. and an M.S. in physics from the College of William and Mary and a B.A. in physics from Johns Hopkins University. In addition to a specialty in science policy, Dr. Taylor's scientific and technical expertise is in the areas of atomic and molecular collision theory, chemical dynamics, and atomic processes in plasmas. He has authored or co-authored numerous professional scientific journal papers and technical reports. In 2002 Dr. Taylor received the National Academies Individual Distinguished Service Award and Group Distinguished Service Award for his role as study director of the report *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism* (2002). In 2003 he received the Department of the Navy Superior Public Service Award from the Chief of Naval Operations for his service since 1995 as director of the Naval Studies Board.

Charles F. Draper is acting director at the National Research Council's Naval Studies Board. He joined the National Research Council in 1997 as a program officer then senior program officer with the Naval Studies Board and in 2003 became associate director. During his tenure with the Naval Studies Board, Dr. Draper has served as the responsible staff officer for studies on a wide-range of topics aimed at helping the Department of the Navy with its scientific, technical, and strategic planning; his recent efforts include topics on network-centric operations, theater missile defense, mine warfare, and nonlethal weapons. Prior to joining the Naval Studies Board, he was the lead mechanical engineer at Sensytech, Incorporated (formerly S.T. Research Corporation), where he provided technical and program management support for satellite Earth station and small satellite design. He received his Ph.D. in

mechanical engineering from Vanderbilt University in 1995; his doctoral research was conducted at the Naval Research Laboratory (NRL), where he used an atomic force microscope to measure the nano-mechanical properties of thin film materials. In parallel with his graduate student duties, Dr. Draper was a mechanical engineer with Geo-Centers, Incorporated, working on-site at NRL on the development of an underwater x-ray backscattering tomography system used for the nondestructive evaluation of U.S. Navy sonar domes on surface ships.

Michael L. Wilson has been a program officer of the Naval Studies Board of the National Research Council since 2002. From 1998 to 2002, Dr. Wilson was an assistant professor of physics at the University of Tulsa where his research focused on granular dynamics under microgravity. Dr. Wilson was a visiting assistant professor of physics at Clemson University from 1996 to 1998, where he helped establish a laboratory to study novel thermoelectric materials. Prior to working at Clemson, Dr. Wilson was a National Research Council associate at the Naval Research Laboratory, where he worked on ceramic magnetic materials synthesis and characterization as well as studies of superconductivity in thin metal films. He holds a Ph.D. in physics from Michigan State University and a B.A. in physics from Grinnell College.

B

Agenda for the Committee's Meeting

KECK CENTER OF THE NATIONAL ACADEMIES
WASHINGTON, DC 20001

Tuesday, May 13, 2003

Closed Session: Committee Members and NRC Staff Only

0800 CONVENE—Welcome, Introductions, Study Plans and Schedules
Frank A. Horrigan, Committee Chair
Ronald D. Taylor, Director, Naval Studies Board (NSB)
Michael L. Wilson, Program Officer, NSB

Data-Gathering Meeting Not Open to the Public: Classified Discussion (Secret)

0930 ONR CODE 353 WELCOME
John Beadling, Firepower Science and Technology Program Support, Expeditionary Warfare Operations Technology Division

0930 ONR WELCOME; OVERVIEW OF EXPEDITIONARY WARFARE PROGRAM; AND MARINE CORPS SCIENCE AND TECHNOLOGY PROGRAM SUPPORT OF CHIEF OF NAVAL OPERATIONS' AND COMMANDANT OF THE MARINE CORPS' STRATEGIC OBJECTIVES
Capt Stephen D. Hancock, USN, Department Head, Naval Expeditionary Warfare Department

1000 U.S. MARINE CORPS SCIENCE AND TECHNOLOGY PROGRAM CONTEXT
OVERVIEW OF THE USMC S&T DIVISION
Tom O'Leary, Director, Expeditionary Warfare Operations Technology Division

1200 MCS&T BASIC RESEARCH PROGRAMS (6.1)
Clifford W. Anderson, Thrust Area Manager

1330 MANEUVER THRUST
Jeff Bradel, Thrust Area Manager
1430 HUMAN PERFORMANCE, TRAINING, AND EDUCATION THRUST
George W. Solhan, Thrust Area Manager
1545 MINE COUNTERMEASURES THRUST
David C. Heberlein, Institute for Defense Analyses
1645 LOGISTICS THRUST
Maj Craig Penrose, USMC, Thrust Area Manager

Closed Session: Committee Members and NRC Staff Only

1745 COMMITTEE DISCUSSION
Moderator: Frank A. Horrigan, Committee Chair

Wednesday, May 14, 2003

Closed Session: Committee Members and NRC Staff Only

0800 CONVENE, COMMITTEE DISCUSSION—Welcome, Opening Remarks, Report Discussion
Frank A. Horrigan, Committee Chair
Michael L. Wilson, Program Officer, NSB

Data-Gathering Meeting Not Open to the Public: Classified Discussion (Secret)

0815 ONR CODE 353 WELCOME
John Beadling, Firepower Science and Technology Program Support, Expeditionary Warfare Operations Technology Division
0815 FIREPOWER THRUST
Maj Pat Lavigne, USMC, Thrust Area Manager
0915 COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS, INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE THRUST
John Moniz, Thrust Area Manager
1030 LITTORAL COMBAT FUTURE NAVAL CAPABILITY PROGRAM
Barry Blumenthal, Program Manager, Littoral Combat FNC
1200 EXPEDITIONARY INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE FOR THE AMPHIBIOUS FORCE ENABLING CAPABILITY
Jay Moore, Enabling Capability Manager (Acting)
1300 AMPHIBIOUS FORCE COMMAND AND CONTROL ENABLING CAPABILITY
Ruth Schearer, Enabling Capability Manager
1400 EXPEDITIONARY FIRE SUPPORT FOR THE MAGTF ENABLING CAPABILITY
Vickie Williams, Enabling Capability Manager
1515 MAGTF MANEUVER IN THE LITTORALS ENABLING CAPABILITY
Barry Blumenthal, Enabling Capability Manager (Acting)
1615 USMC S&T PROGRAM SUMMARY
Tom O'Leary, Director, Expeditionary Warfare Operations Technology Division

Closed Session: Committee Members and NRC Staff Only

1715 COMMITTEE DISCUSSION—Study Plans, Schedules, Report Issues
Moderator: Frank A. Horrigan, Committee Chair
1800 ADJOURN

Thursday, May 15, 2003

Closed Session: Committee Members and NRC Staff Only

0800 CONVENE—Welcome, Opening Remarks, Report Discussion
Frank A. Horrigan, Committee Chair
Michael L. Wilson, Program Officer, NSB
0830 COMMITTEE REPORT WRITING—Prepare Draft Report
Moderator: Frank Horrigan, Committee Chair
0930 TELECONFERENCE CALL WITH BRIGGEN FRANK PANTER, USMC, COMMANDING GENERAL, MARINE CORPS WARFIGHTING LABORATORY
1030 (CONTINUED) COMMITTEE REPORT WRITING—Prepare Draft Report
1700 ADJOURN

C

Acronyms and Abbreviations

AAAV	advanced amphibious assault vehicle
ACTD	advanced concept technology demonstration
AFATDS	Advanced Field Artillery Tactical Data System
ALMDS	Airborne Laser Mine Detection System
AMD	advanced mine detector
AM OLED	active matrix organic light-emitting diode
ARI	Army Research Institute
ARL	Army Research Laboratory
AROSS	Airborne Remote Optical Spotlight System
ASTAMIDS	Airborne Standoff Minefield Detection System
ATD	advanced technology demonstration
BAA	Broad Agency Announcement
BEZ	beach exit zone
BLOS	beyond-line-of-sight
C2	command and control
C3	command, control, and communications
C4	command, control, communications, and computers
C4I	command, control, communications, computers, and intelligence
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CMOS	complementary metal oxide semiconductor
CNO	Chief of Naval Operations
COBRA	Coastal Battlefield Reconnaissance and Analysis
COTS	commercial off-the-shelf
CRB	chemical, radiological, and biological

CROP	common relevant operational picture
CSS	Coastal Systems Station (Panama City, Florida)
DARPA	Defense Advanced Research Projects Agency
D&I	Discovery and Invention
DMT	distributed mission training
DOD	Department of Defense
DOE	Department of Energy
DPD	diver propulsion device
EC	enabling capability
EFSS	Expeditionary Fires Support System
EMW	Expeditionary Maneuver Warfare
EO/IR	electro-optic/infrared
EPLRS	Enhanced Position Location and Reporting System
ExLog	Expeditionary Logistics
FCS	Future Combat System
FDOA	frequency difference of arrival
FLIR	forward-looking infrared
FNC	Future Naval Capability
GPR	ground-penetrating radar
GPS	Global Positioning System
HIMARS	High-Mobility Artillery Rocket System
HMMWV	high-mobility multipurpose wheeled vehicle
HVPC	high-velocity particle consolidation
IDA	Institute for Defense Analyses
IPT	integrated product team
ISR	intelligence, surveillance, and reconnaissance
JCATS	joint conflict and tactical simulation
JTRS	Joint Tactical Radio System
LAN	local area network
LC	Littoral Combat
LIDAR	light detection and ranging
LPD	low probability of detection
LPI	low probability of intercept
MAGTF	Marine Air-Ground Task Force
MCCDC	Marine Corps Combat Development Command
MCM	mine countermeasures
MCS&T	Marine Corps Science and Technology

MCTSSA	Marine Corps Tactical Systems Support Activity
MCWL	Marine Corps Warfighting Laboratory
MEF	Marine Expeditionary Force
MEFFV	MAGTF Expeditionary Family of Fighting Vehicles
MEMS	microelectromechanical systems
MNS	mission needs statement
MOUT	military operations in urban terrain
MRAM	magnetic random access memory
MURI	Multidisciplinary University Research Initiative
NASA	National Aeronautics and Space Administration
NLW	non-lethal weapon
NMD	neuromuscular disruption
NQR	nuclear quadrupole resonance
NRC	National Research Council
NSB	Naval Studies Board
NSFS	naval surface firepower support
NVESD	Night Vision and Electronic Sensors Directorate (Army)
OCSW	objective crew served weapon
OMFTS	Operational Maneuver From the Sea
ONR	Office of Naval Research
P3I	preplanned product improvement
PLI/RI	position location information/range instrumentation
R&D	research and development
RF	radio frequency
ROAR	Rapid Overt Airborne Reconnaissance
RST-V	reconnaissance, surveillance, and targeting vehicle
SATCOM	satellite communications
SINCGARS	Single Channel Ground and Airborne Radio System
S&T	science and technology
STO	science and technology objective
STOM	Ship-to-Objective Maneuver
TBMCS	Theater Battle Management Core System
TDOA	time difference of arrival
TDS	tactical decision simulation
TIG	technology insertion game
TRL	technology readiness level
TTPs	tactics, techniques, and procedures
TUAV	tactical unmanned aerial vehicle
TUGV	tactical unmanned ground vehicle

UAV	unmanned aerial vehicle
USMC	U.S. Marine Corps
UWB	ultrawideband
WAS	wide-area surveillance
WNW	wideband network waveform

D

Technology Readiness Levels

A general description of technology readiness levels is provided in Table D.1.

TABLE D.1 General Description of Technology Readiness Levels

TRL Number	Description
1. Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be imagined. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.
3. Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment.	Basic technological components are integrated to establish that they will work together. This technology is relatively low-fidelity compared with the eventual system. Examples include integration of ad hoc hardware in a laboratory.

TABLE D.1 Continued

TRL Number	Description
5. Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include high-fidelity laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in the technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7. System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and "flight qualified" through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system "flight proven" through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.