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THE NATIONAL ACADEMIES

National Academy of Sciences
National Academy of Engineering
Institute of Medicine
National Research Council

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

Editorial



Science, Technology, and Military Experimentation

Maintaining a military advantage based on superior technology has been and will continue to be a keystone of U.S. military strategy. For that reason, the U.S. Department of Defense (DOD) funds a science and technology (S&T) program. For decades, entirely new military capabilities have arisen from discoveries of new knowledge and new technology. Stealth aircraft, satellite imaging, unpiloted air vehicles, and night vision were all *revolutionary*—initially in terms of new scientific knowledge and technology and later in terms of the military tactics and strategies devised to exploit them. Sustained investment in S&T is driven by, and is justified by, results.

From the point of view of the military, a technology is of value only if a useful military capability can be built from it. Therefore, *experimentation* is a critical part of the development of a new technology. Experiments test candidate technologies alone and as components in new systems. Experiments facilitate the transition of a device from operation in the laboratory to operation as a component or system in the field. But most important, experiments challenge the military to find new ways of using technologies, in effect to create new military capabilities. Experimentation is quite different from the engineering testing that DOD already performs very well.

Experimentation has proven to be difficult, however, for several reasons. First, militarily realistic experimentation is expensive because it involves building

multiple copies of risky new devices that embody unproven technologies. Second, proper experimentation is time consuming because it requires that devices be used over a period of time and with different tactics or procedures to determine how they work best. Therefore, experimentation requires a substantial budget. Current S&T budgets fund some experimentation but not enough, and funds for experimentation, especially high-risk experimentation, are hard to find elsewhere in the services' budgets. Appropriate people are even more difficult to find. Creating innovative new concepts for "fighting a system" requires thoughtful military personnel who are willing to invest substantial time in an activity that may or may not be successful. In the current climate, this is not considered helpful to a military career.

Third, because we fight jointly, experiments should be conducted jointly, and current "joint budgets" for experimentation are miniscule. DOD budgets are allocated predominantly to one military department or another. In addition, DOD acquisition processes, which are designed to freeze all attributes of the system being developed as early as possible, cannot accommodate the kind of experimentation I've described. In fact, they actually preclude early experimentation. In addition, the services fear they may lose congressional budget support if experiments fail.

One challenge to the new administration will be to establish adequate budgets and the will to support meaningful experimentation. Experimentation should become "mainstream," part of routine service/DOD processes. The Army's program called Digitization of the Battlefield is an admirable step in the right direction, but joint experimentation must be well funded and encouraged.

Two of the papers in this issue focus on new military capabilities that will be enabled by technology: a ballistic missile defense system and alternatives to antipersonnel landmines that would avoid killing or maiming noncombatants. Neither would rely on a single technology. Both would combine environmental sensing and sophisticated identification and tracking algorithms to determine precisely when and where military action should be taken. Both would also require new weapons.

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Both military capabilities would require the integration of multiple technologies to create complex systems. They illustrate the kind of situation in which military experimentation, ideally joint experimentation, should be conducted. Experimentation would involve the construction of early versions of system components without locking in requirements that would freeze component attributes for the future. Thoughtful, innovative military personnel would define and perform a series of experiments to evaluate the military value of candidate systems using alternative tactics and procedures. In the process, the technical and human-use attributes of the new components would

most likely be altered. In addition, new doctrine would be crisply and clearly defined much earlier than it is now. I would also expect that joint experimentation would reveal incompatibilities among the systems fielded by different services much earlier and that they could be made interoperable at a more reasonable cost. In short, the benefits of routine, robust, joint experimentation would far exceed its cost.



Anita K. Jones

The Quest to Replace Antipersonnel Landmines



George Bugliarello



Larry G. Lehowicz



Margaret N. Novack

**George Bugliarello, Larry G. Lehowicz,
and Margaret N. Novack**

The U.S. military is looking for munitions and other devices that can minimize the risk of injury or death to noncombatants.

In many areas around the world, fields that once produced crops lie fallow, children are cautioned not to leave the road on their way to school, and farmers caring for their herds dread bringing them in from the pasture, and a casual walk through a peaceful village reveals an unusual number of amputees. These seemingly unrelated circumstances have something in common—antipersonnel landmines, small, unobtrusive, inexpensive weapons that can remain active for a long time after hostilities have ended. In other places, such as the demilitarized zone between North and South Korea, where U.S. military forces are on constant alert in anticipation of an incursion by a numerically superior enemy, these same antipersonnel landmines enhance their security. Although the minefields would not stop an attack, they might buy enough time for defenders to prepare to fight back.

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Ideal weapons provide friendly forces with maximum flexibility and inflict maximum damage on the enemy—all without injuring innocent noncombatants. Antipersonnel landmines have these military benefits, but also have dire residual effects. The most obvious positive effect of landmines is that they kill or disable enemy personnel and damage their equipment. Antipersonnel landmines also serve several other, less obvious, functions. Minefields place an enemy in a vulnerable position that can be exploited by friendly forces. They can force an enemy to divide his forces, making him more vulnerable, and can interfere with command and control functions. Minefields can optimize the capabilities of other weapon systems, such as air-delivered precision weapons, by delaying enemy forces in an area where these systems can be used most effectively. Finally, landmines can protect friendly forces from enemy infiltration or attack, as they do in Korea. They provide significant economies of force in places where few troops or support weapons are available to defend an area. They protect small units of soldiers, alert defenders of enemy attack, control enemy movements, and prevent the enemy from disabling larger, more visible antitank mines, while inflicting casualties on enemy troops.

Current landmines cannot distinguish between friends, foes, and noncombatants.

U.S. military doctrine requires that minefields be mapped, marked, and eventually cleared. Many people in the military, however, remain ambivalent about using antipersonnel landmines because, despite these precautions, they have several disadvantages. The principal drawback, of course, is that they cannot discriminate between friends, foes, and noncombatants. In addition, they occasionally kill friendly personnel, especially in hastily marked minefields. Finally, if the tide of battle changes rapidly, mines emplaced during defensive missions can become an obstacle to the execution of rapid offensive maneuvers.

In recent years, concerted efforts have been made to

minimize the effects of all weapons on noncombatants—so-called collateral damage. Over time, landmines used by the United States and other countries with advanced military forces have become more complex, more effective, and easier to use. Advances in the 1970s led to the development of mines capable of destroying or deactivating themselves after a given time. Today, all antipersonnel landmines in U.S. stocks, with the exception of those intended for the defense of Korea, are self-destructing and/or self-deactivating. Other nations and nonstate forces, unfortunately, still use less technologically advanced landmines, which are inexpensive, easily obtainable, and highly effective. Most of these simple, nonself-destructing mines have been deployed with no thought to keeping track of their locations. As a result, millions of them strewn across old battlefields have killed or maimed thousands of innocent civilians in the last 25 years and impeded the resumption of normal activities after conflicts have ended.

Humanitarian groups, international organizations, and many governments around the world have increasingly identified these residual hazards as a threat to innocents and demanded that all antipersonnel landmines be eliminated. The civilian casualties that occur every year are a major international concern that has been taken up by many nongovernmental groups. In 1997, the international outcry led to the Ottawa Convention, which was signed or agreed to by 139 nations, but thus far not by China, Israel, Russia, Turkey, the United States, and several other countries. The convention bans the use of all antipersonnel landmines, which are defined as mines that explode “by the presence, proximity, or contact of a person.”

The U.S. government has taken a number of steps to mitigate the adverse effects of antipersonnel landmines but has not signed the Ottawa Convention. In addition to using self-destructing/self-deactivating mines, the United States has destroyed a large number of “dumb,” nonself-destructing/self-deactivating mines and banned their export. The United States also assists in demining efforts and provides aid to victims of antipersonnel landmines. Most significantly, the U.S. government has established an aggressive program to identify technologies that could serve the same functions as antipersonnel landmines but would not have their negative residual effects.

Antipersonnel landmines used by the United States,

with the exception of those now warehoused for use in Korea, do not have long-term residual effects because they are self-destructing and/or self-deactivating. Nevertheless, they still are not Ottawa-compliant because they explode on contact with a person and do not discriminate between friend and foe. The Clinton administration indicated that the United States would be willing to sign the Ottawa Convention in 2006 if alternatives could be fielded to soldiers by that time. He instructed the U.S. Department of Defense (DOD) to begin developing alternatives that would serve similar functions, which are considered essential to U.S. combat capabilities. DOD responded by initiating a series of projects and studies—referred to as tracks—to identify alternatives. Track I, led by the U.S. Army, has investigated alternatives to the nonself-destructing mines used in Korea and proposed the production of a Remote Area-Denial Artillery Munition, or RADAM (a weapon that combines two existing mine systems into one munition). Track II, led by the Defense Advanced Research Projects Agency (DARPA), is focused on long-term alternatives that would prevent enemy access to an area. Track III, which overlaps Tracks I and II, is led directly by the staff of the Secretary of Defense. The focus of Track III is on new or existing technologies that would provide capabilities equivalent to those of antipersonnel landmines when used alone or in mixed systems with antitank mines. As part of Track III, in response to a mandate from Congress, DOD asked the National Research Council (NRC) to empanel a committee to identify potential alternative technologies, tactics, and operations that could be available by 2006, the date the United States could sign the Ottawa Convention.

Although the Ottawa Convention was a prime context for the NRC study, the study was limited to technological and operational issues and was not expected to comment on the need for, or the morality of, antipersonnel landmines or whether the United States should accede to the Convention. The NRC committee soon realized, however, that the overarching issues are enormously complex, beginning with the question of what makes a weapon more or less humanitarian. Eliminating antipersonnel landmines may not always lead to more “humanitarian” battlefields. Unexploded ammunition, more powerful ammunition with a larger lethal radius than antipersonnel landmines, more airborne precision munitions, and other kinds

of weapons used to compensate for the loss of antipersonnel landmines can also cause civilian casualties. There is also a possibility that the search for alternatives could lead to an arms race in a category of weapons that has, up to now, received little attention in terms of technological sophistication. The consequences of escalating costs, as well as of the temptation of some belligerents under the stress of conflict to resort to the use of “dumb” antipersonnel landmines, are hard to assess.

The study was conducted at an interesting historical juncture. The United States is at peace, and, at the same time, the number of new technologies with military possibilities is unprecedented. The so-called “revolution in military affairs” now envisioned could propel the U.S. military into an information-age capability on the battlefield. The convergence of these factors presents U.S. armed forces with a unique window of opportunity to develop new conceptions and new systems in a time of peace.

U.S. forces have a unique window of opportunity to develop new systems in a time of peace.

The central conclusion of the NRC study is that new systems that incorporate sophisticated sensing and communications technology could eventually be developed that would enhance the capability of U.S. forces. These new weapon systems would respond to humanitarian concerns by leaving the decision of whether or not to explode a munition to a person (a “man-in-the-loop”) who could first determine whether or not an intruder in a minefield, or any designated area, was an enemy combatant. The deterrent function of antipersonnel landmines could be provided by other kinds of devices, thus eliminating the danger created by mines left in the field after a military action. However, many advances in technology will be necessary for the development of alternatives, especially in the areas of munitions, information technology, and

communications. The following examples suggest where these technologies might take us:

- **Sensors.** Imaging systems have clearly demonstrated their value on the battlefield. Affordable, cooled and uncooled staring focal-plane arrays and associated components can operate in the midwave infrared and long-wave infrared bands. Advances in other sensor technologies, such as video cameras and motion, acoustic, odor, and other detectors, could significantly reduce the costs of operations and provide warfighters with better performing, smaller, lighter systems.

Many advances in technology will be necessary for the development of alternatives to antipersonnel landmines.

- **Miniaturization.** Microelectromechanical systems (MEMS) are a revolutionary enabling technology. Embedded into weapon systems, MEMS will provide new levels of situational awareness, information, precision strike capabilities, and new weapons. MEMS will provide integrated electromagnetic systems with many advantages—small size, low power, low mass, low cost, and high functionality. The primary goal of the DARPA MEMS program is to develop technology that merges sensing, actuating, and computing into systems that increase the perception and performance of weapon systems and the control of battlefield environments.
- **Platforms.** Advances in the development of unmanned ground and air vehicles might enable a platoon pinned down by enemy fire to use sensors to look over the horizon, behind buildings, and beyond the range of average eyesight. These unmanned systems might be able to operate for hours, while feeding continuous video images back to ground stations that could use the information to coordinate ground attacks and air strikes.

- **Connectivity.** The U.S. Army's multifunctional, on-the-move, secure, adaptive, integrated communication (MOSAIC) project will be an energy-efficient, wireless, mobile communications system that provides reach-back and secure, networked sensor integration. Its open systems architecture will increase its survivability and enhance military communications.

From a military standpoint, these new systems would all improve the situational awareness of U.S. forces, but they might not be deployed by the 2006 deadline, partly because funding for research has been sporadic at best. In addition to reviewing existing antipersonnel landmines systems and potential alternatives being researched or developed at some level through DOD's three-track program, the committee solicited ideas from independent scientists and nongovernmental organizations, as well as from committee members themselves.

The methodology developed by the committee for assessing the alternative systems considered several factors: when a potential alternative would be available; how effective it would be militarily; how well it would address humanitarian concerns, based on both the Ottawa Convention and the Convention on Certain Conventional Weapons (the other major international agreement governing antipersonnel landmines); cost; overall technical risk; and whether a change in tactics or doctrine would be required. Based on those qualitative assessments, the committee reached several specific conclusions and recommendations.

The emergence of new technologies will create opportunities after 2006 for the development of systems that could outperform today's antipersonnel landmines and would be compliant with the Ottawa Convention. The development of sensor-net technology, an extensive interwoven network of technologically advanced sensors, should be pursued aggressively, and advances in the commercial sector and by other agencies should be applied.

A nonself-destructing landmine alternative, or NSD-A, is currently being developed under the U.S. Army Track I for use against foot soldiers. This hand-emplaced system would allow a soldier or operator, looking at a hand-held display through which sensors would signal that an intruder had entered the protected area, to decide whether to detonate the explosive or

let the person pass safely. Unlike antipersonnel landmines that explode on contact, the decision for detonation of an NSD-A would be in human hands.

A highly contentious issue is whether the NSD-A should be equipped with a battlefield override switch, a software feature that could switch the NSD-A mines to explode automatically in cases of emergency. For example, if a soldier's position were about to be overrun, rather than sacrifice the soldier or abandon the position and leave it undefended, the weapon could be put on "automatic." Indecision about the override switch has stopped production of the NSD-A because its presence would render the weapon non-Ottawa compliant. To allow production of this otherwise Ottawa-compliant mine to commence, two suites of weapon software, one with the switch and one without, could be developed simultaneously in preparation for a presidential decision concerning the Ottawa Convention. In any case, Ottawa-compliant variations to the battlefield override switch should be explored to provide U.S. forces with greater flexibility and to improve a soldier's ability to discriminate among friends, enemies, and noncombatants.

One alternative that would eliminate the override switch would be to augment the NSD-A with more sensors. Numerous advanced sensors placed in depth on the battlefield could enable the operator to discriminate sooner and better among friends, foes, and noncombatants. The sensors would improve the operator's situational awareness and supply sufficient information for him/her to call in timely intervention by other weapon systems. In addition, the system would be Ottawa-compliant because it would not require an override switch.

A second alternative to eliminate the switch would be internet-worked digital displays and decision procedures among several NSD-A operators. In this system, control of the mines would be transferred instantaneously from an operator at risk to an operator in a less dangerous location, and so forth. This Ottawa-compliant system would have a man-in-the-loop to make decisions to detonate munitions based on NSD-A digital input and direct observation and would provide great flexibility, including the option of turning off all mines to enable friendly forces to move through their own NSD-A fields. The operator could command munitions to explode when the enemy was within the NSD-A area and decide not to detonate

the munitions when confirmed noncombatants or friendly forces were moving back through the area into friendly defenses.

Indecision about the override switch has halted production of the NSD-A.

A third alternative would be an override-type switch that would cause rapid, random detonation of NSD-A munitions over a brief period of time upon a command from the operator in an attempt to slow an advancing enemy and to buy time for an NSD-A operator to take appropriate action. After a few minutes, once all munitions had been detonated, friendly forces could go forward safely or otherwise maneuver unimpeded by their own NSD-As. This type of override switch would be Ottawa-compliant because the munitions would explode randomly and not by the contact or proximity of a person.

In certain military operations, such as peacekeeping, which is typically carried out in the midst of civilian populations, nonlethal alternatives to antipersonnel landmines are highly desirable. Nonlethal weapons by themselves could not fully replace the mines because they would not inspire the fear associated with the life-threatening munitions. Nevertheless, they would be useful deterrents in peacekeeping operations.

New technologies after 2006 that could change the battlefield of the future would require modernizing existing, remotely delivered (by artillery or air) pure-antitank landmine systems by incorporating other technologies, some of them being developed for other purposes, such as sensors, precision locators, and anti-tank mines with much larger lethal radii. DARPA's proposed self-healing minefield is a network of anti-tank mines that could detect when a mine had been disabled and automatically fill in the gap, thus eliminating the need for antipersonnel landmines to protect the minefield. Perhaps the greatest payoff would result from the development of vast networks of sensors, communications links, and nonmine combat systems that would provide human operators with real-time information enabling them to discriminate

between friend, foe, and noncombatant. All appropriate lethal and/or nonlethal weapons systems in range could then be called in.

The self-destructing/self-deactivating capability of current U.S. antipersonnel landmines should be extended to all nonrecoverable, explosive munitions. In one of his last acts as secretary of defense, William Cohen directed that the percentage of munitions that fail to explode be reduced to 1 percent or less. Although this is not a substitute for self-destruction or self-deactivation, it is an important step in the right direction.

In summary, future technologies could enable U.S. forces to retain most of the military advantages of current antipersonnel landmines and simultaneously sub-

stantially reduce the risk of unintended casualties. Because the country is at peace with no apparent peer competition and because the military forces are seeking to transform themselves, this is an opportune time for the United States to pursue these new technologies. The U.S. example may also encourage other countries to consider alternative technologies that would not cause the extraordinary damage to innocent civilians caused by nonself-destructing antipersonnel landmines.

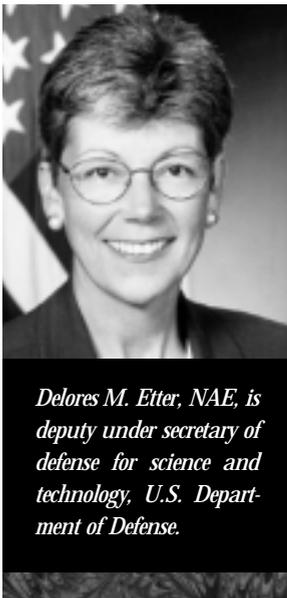
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A Glimpse into the DOD S&T Program

Delores M. Etter

Leveraging advances in commercial technologies and maintaining a well-balanced, adequately funded S&T program will be necessary to retaining our technological edge.



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As the U.S. Department of Defense (DOD) moves into the twenty-first century, its science and technology (S&T) program faces significant challenges from several sources. In a changing world environment, asymmetric threats to our military and our country include chemical and biological warfare, nuclear proliferation, and information warfare (cyberwarfare). New technologies are available globally, and we must expect that our adversaries will have access to many of them. Unrestricted access encourages a “run faster” strategy to try to maintain our technological edge. At the same time, economic realities require that DOD maintain a robust range of capabilities and use commercial systems and processes whenever possible.

In this article, priorities for DOD’s research investments are suggested, a case is presented for strong stable investment in DOD’s S&T, and the role of DOD’s partners in S&T is discussed. The opinions presented do not represent an official position. They are the opinions of an academic who has had a wonderful opportunity to interact with DOD for the last

Box 1 Strategic Cooperative Initiatives in S&T

Hard Problems

- Countermeasures to asymmetrical threats (e.g., deterrence, information operations, behavioral shaping/disuasion)
- Time-critical, stand-off, and concealed-target defeat (e.g., high-speed, precision-strike capability, moving-target tracking, finding and destroying deeply buried targets)
- Chemical-biological (CB) defense modeling and stand-off detection (e.g., CB agent-dispersion models, stand-off detection, near-real-time updating of models)
- Cruise and ballistic missile defense (e.g., enhanced lethality, early detection)
- Military operations in urban terrain (e.g., situational awareness, dynamic training, robotic systems)

Revolutionary Warfighting Concepts

- Networkcentric warfare (e.g., robust connectivity/interoperability, information assurance, human-centric adaptation)

- More complete dominance of space (e.g., affordable launch vehicles, space control, space surveillance/reconnaissance, miniaturized space systems)
- Unmanned land, air, space, sea, and underwater systems (e.g., autonomous, cooperative interaction, swarm behavior, combat capabilities)

Militarily Significant Research Areas

- Nanoscience and advanced materials (e.g., biology-based materials, miniature systems, new energetics, advanced electronics)
- Directed energy (e.g., high-energy lasers, high-power microwaves, pulsed power, more complete understanding of lethality issues)
- Advanced power (e.g., batteries, energy storage, generation and handling of electric power)
- Human dimension and psychological factors (e.g., decision-making under stress, modified cognition, motivation, and dissuasion)

10 years—first as an advisor to various groups and boards and recently as the deputy under secretary of defense for science and technology.

Investment in the Future

The mission of DOD's S&T program is to develop superior, affordable technology with a focus on revolutionary capabilities. History has proven that investments in S&T have significant benefits. Past investments have led to revolutionary capabilities, such as the global positioning system (GPS), night vision, stealth weapons, phased-array radars, and adaptive optics for laser systems, to name but a few. DOD's responsibility today is to ensure that investments in S&T continue so that soldiers 10 to 15 years from now will also have new military capabilities.

There are never enough dollars for all of the research the services and defense agencies want, and identifying the most important problems that should be addressed by DOD's S&T program is a challenge in itself. In areas where industry is the leader, DOD should leverage those efforts, not compete with them. In addition, the services and defense agencies should collaborate on really difficult problems. S&T executives from the services and defense agencies recently

participated in an exercise to develop strategic cooperative initiatives in S&T (Box 1).

S&T priorities for basic research of interest to many of the services and defense agencies are defined in another program, the Multidisciplinary University Research Initiatives (MURI) Program. MURI supports multidisciplinary teams, typically composed of researchers from several universities, to conduct research on topics proposed and managed by the services and defense agencies (Box 2). The items in Boxes 1 and 2 that support the directions outlined by the new secretary of defense should represent the new administration's highest priorities.

Funding for Research

Research is always related to funding, so we now turn to a discussion of some of the fundamentals of DOD funding. Figures 1–5 illustrate the distribution of DOD's investment in S&T for fiscal year 2001 (FY01). Figure 1 shows the allocation by Congress for research, development, testing, and evaluation (RDT&E). The overall total is \$41.3 billion, with \$9 billion of that going to S&T, which is broken into three components: basic research (called 6.1 research), applied research (6.2), and advanced technology development (6.3). Once a

Box 2 Multidisciplinary University Research Initiatives

Theme 1: Control for Adaptive Cooperative Systems

- Adaptive, coordinated control in the multiagent three-dimensional dynamic battlefield
- Control for adaptive and cooperative systems
- Enabling technologies for optical clocks
- Complex, adaptive networks for cooperative control

Theme 2: Interoperable, Adaptive, Scalable Networks

- Adaptive system interoperability
- Scalability of networked systems

Theme 3: Energetics

- Energetic materials designed to improve performance/lower life-cycle cost
- Renewable logistic fuels for fuel-cell power sources
- Biosynthetic methodologies for energetic ingredients and other high-nitrogen-containing compounds

Theme 4: Multifunctional Materials

- Modular design of cost-effective, multifunctional designer materials
- Adaptive materials for energy-absorbing structures
- Design of multifunctional materials

Theme 5: Synergistic Sensing

- Real-time, explosive-specific chemical sensors
- The science of land target spectral signatures
- Biomolecular, subcellular, radio-frequency sensing
- Detection, classification algorithms for multimodal inverse problems

Theme 6: High-Energy Lasers

- High-average-power ultra-short-pulse free-electron lasers
- Affordable high-energy laser systems
- Atmospheric propagation and compensation of high-energy lasers
- High-power, lightweight optics
- High-energy, closed-cycle chemical lasers
- High-average-power diode-pumped solid-state lasers

Theme 7: Nanotechnology

- Flexible membranes exploiting selective, active transport
- Integrated nanosensors
- Multidimensional sensing and spectroscopy

technology goes into prototype (6.4), it is no longer part of S&T. The distribution of the \$9 billion for S&T for FY01 is shown in Figure 2. The first three bars represent the three services. The Defense Advanced Research Projects Agency (DARPA), whose primary focus is on high-risk/high-payoff research, has the largest allocation, nearly \$2 billion. The programs in the Office of the Secretary of Defense (OSD) allocation are primarily corporate programs or DOD-wide programs. The final bar is a combination of dollars for the Ballistic Missile Defense Organization, the Defense Threat Reduction Agency, and the Defense Logistics Agency. The dollars are quickly passed from the services and defense agencies to those who actually perform the research (Figure 3). As expected, the key performers of basic research (6.1) are universities; applied research (6.2) is split between service laboratories and industry; and the key performer of advanced technology development (6.3) is industry.

We can also analyze the contributions of S&T for each service by separating their funding into three categories: (1) dollars for today's forces, which ensure

readiness through operations and maintenance; (2) dollars for tomorrow's forces, which go toward modernizing systems; and (3) dollars invested in the future through S&T. Figure 4 shows the distribution of these dollars for the services by percentage of their total obligation authority. As this figure shows, from an overall perspective the investment in S&T is really very small. S&T funding in actual dollars for the last decade is shown in Figure 5. Note that the Air Force, which was by far the largest investor in FY89, is the smallest investor in FY01. The decrease, an Air Force decision, has caused significant concerns among DOD research offices, the Air Force Scientific Advisory Board, and others that the Air Force is short-changing its future to solve near-term problems. This is not an issue of "good guys" vs. "bad guys"; the Air Force has had to make difficult trade-offs between very real short-term needs (readiness and modernization) and long-term commitments to future needs (S&T). Recently, the Air Force has been considering increasing its commitment to S&T. The next few years will show if this discussion translates into resolve towards that goal.

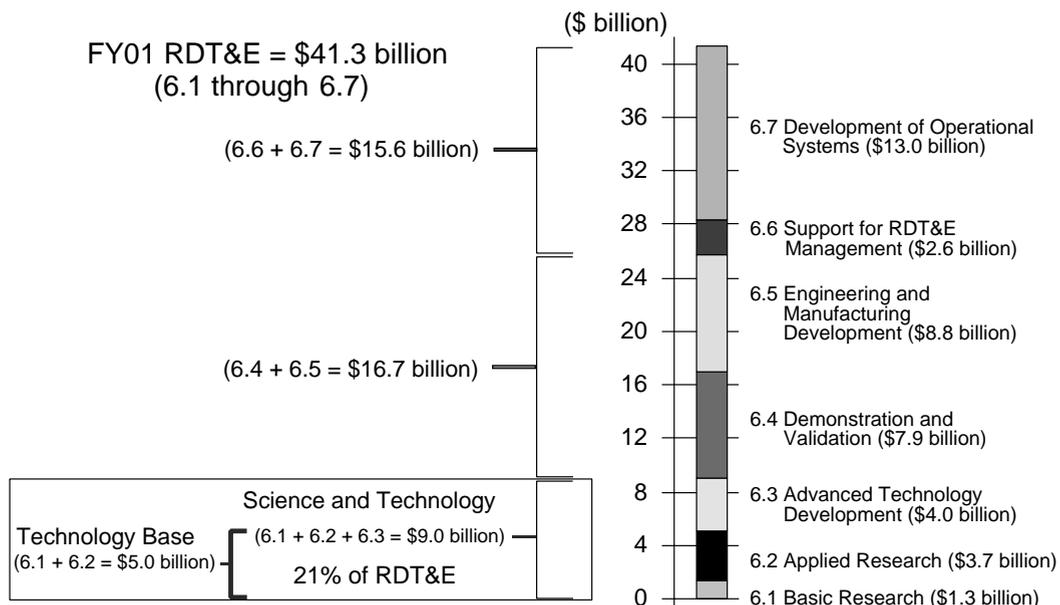


FIGURE 1 Allocations by Congress in FY01.

Partnerships in S&T

The success of many past DOD investments in S&T are directly attributable to the unique contributions of the partners in DOD programs. Universities have pushed the limits of new knowledge and developed a pool of scientists and engineers to work in industry,

government, and academia. DARPA, with its high-risk/high-payoff mission, continues to identify and develop technologies that lead to new capabilities, such as stealth weapons and the Internet. The service laboratories, the links to operational forces, provide a path for the transition of new technologies to fielded systems.

Industry continues to drive much of the innovation and transition of technologies to the commercial world as well as to the military. Interactions with other agencies, such as the National Science Foundation, the National Aeronautics and Space Administration, and the U.S. Department of Energy, have enabled DOD to leverage their investments. And, finally, DOD is developing collaborative research teams with international allies to leverage our respective strengths,

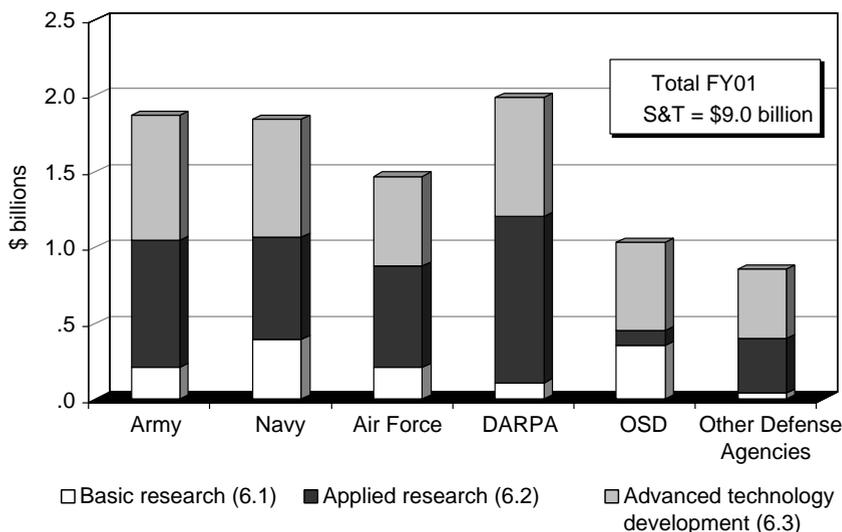


FIGURE 2 DOD S&T investment for FY01.

encourage the interoperability of systems, and provide a foundation for mutually beneficial relationships.

Nontechnical Challenges

Developing S&T is important, but the results must be translated into fielded systems to make a difference. Therefore, the issue of technology transition must have a high priority. There are no silver bullets for transitioning a new technology. Serious efforts must be made to match capabilities with needs early on. The earlier the two are matched, the greater the likelihood of a successful transition. DOD's Advanced Concept and Technology Demonstration (ACTD) Program has successfully taken mature technologies into the field in prototype systems. Recent successes include the Predator, Global Hawk, and new unmanned air vehicles.

Another nontechnical challenge is enhancing and maintaining the S&T workforce. The average age of a laboratory technologist is 45 years and rising, and more than half of DOD's S&T workforce will be eligible for retirement in the next five years. DOD must find creative ways to rebuild the strength of the workforce before critical capabilities are lost. With the help

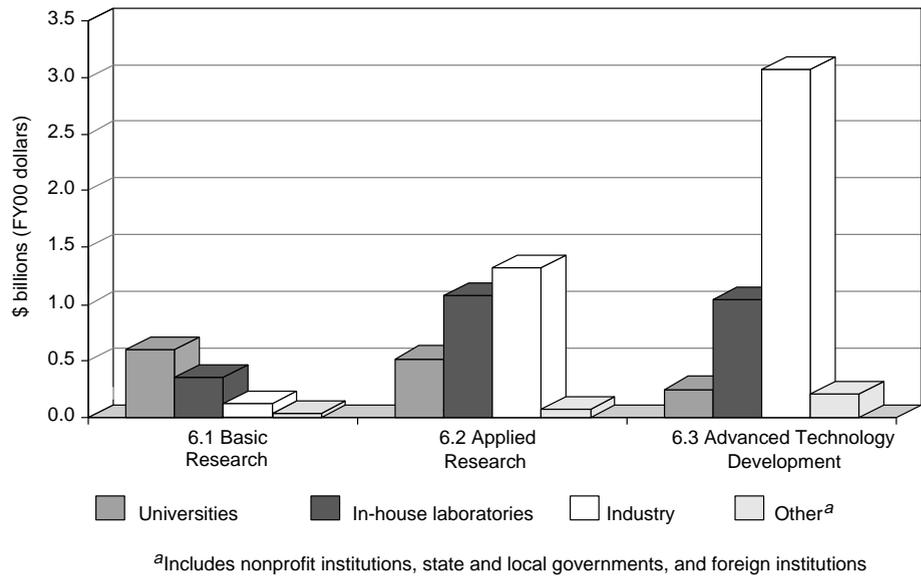


FIGURE 3 Recipients of DOD S&T funds. Source: National Science Foundation, 2000.

of Congress, efforts are under way to give laboratory directors authorities similar to those of commercial laboratory directors, such as the authority to hire outstanding candidates on the spot, the authority to reward employees who make critical contributions to important programs, and the authority to offer competitive salaries. Other avenues are also being explored, such as providing opportunities for commercial scientists and engineers to work temporarily in DOD laboratories and for DOD employees to spend time working in industry; this is a winning situation for everyone.

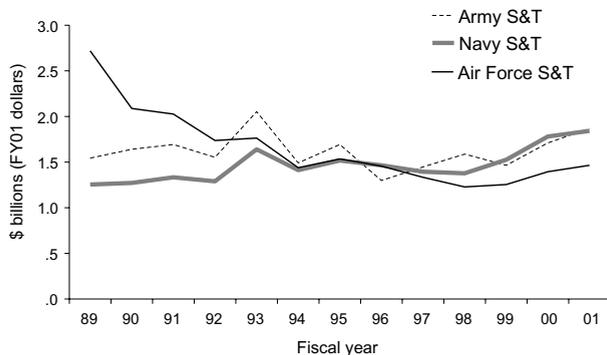


FIGURE 4 Distribution by percentage of total obligation authority.

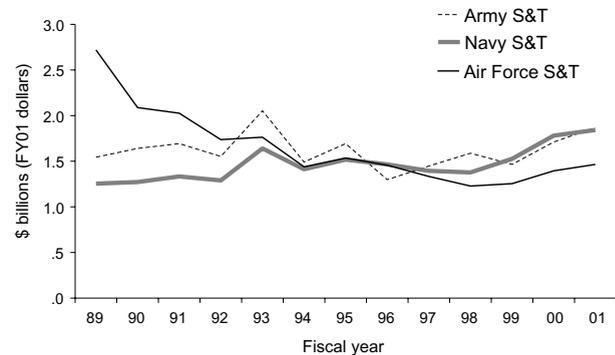


FIGURE 5 S&T funding for the last decade (6.1, 6.2, and 6.3).

Focus on the Future

DOD's S&T program must be focused on the future. The challenges to maintaining a strong program are real, but so are the benefits. There is no doubt that technical superiority is critical to our national defense:

In times of peace, technical superiority provides deterrence. In times of crisis, it provides options. In times of war, it provides an edge.

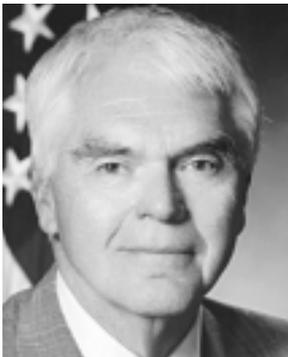
Reference

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A White Paper on the Defense Against Ballistic Missiles

Hans Mark

The United States needs a strong, effective missile defense system to meet the threats and uncertainties that lie ahead.



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Introduction

In the past three years, very significant progress has been made on the development of defenses against ballistic missiles. A number of systems have been tested successfully, and it has been established that “hit-to-kill” technology is feasible. By this I mean that we have shown it is possible to intercept an incoming warhead with a kill vehicle carried by an antiballistic missile (ABM). This has been achieved with several different systems employing, in some cases, different technologies. We have also demonstrated for the first time that a high-power laser is capable of shooting down tactical ballistic missiles. My purpose in writing this paper is to step back and take an overall look at the Ballistic Missile Defense Organization (BMDO), starting with the threats and then turning to military considerations. Finally, I will comment on the programmatic situation. The BMDO is seriously underfunded. My hope is that the recommendations in this paper will be useful in persuading the political leadership to provide the support necessary to a working system that can be deployed in the coming years.

Threats

I have divided the military threats into three categories: near-term threats (the next 10 to 15 years); far-term threats (the next 15 to 30 years); and other threats (less likely threats that still should be considered). The threats are listed in no particular order of priority.

Tests have shown that “hit-to-kill” technology is feasible.

Near-Term Threats (10 to 15 years)

North Korea could pose a threat to South Korea, Japan, Taiwan, and other territories in the neighborhood with short- and intermediate-range ballistic missiles that have been tested. The North Koreans have also probably developed nuclear, chemical, and biological warheads that can be carried by these missiles. To the best of my knowledge, these have not been tested.

China could pose a threat to Taiwan, Japan, South Korea and other territories in the neighborhood with short- and intermediate-range ballistic missiles that have been tested. China has also tested nuclear weapons that can be carried by these missiles and probably has chemical and biological weapons. The Chinese could also pose a threat to Russia, India, Pakistan, and the Middle East with these weapons. Finally, the Chinese have tested a long-range missile that could eventually threaten the United States. However, in my judgment, threats from China are politically less likely than from some of the others listed in this section.

The Middle East. **Israel** has nuclear weapons and probably also chemical and biological weapons. Israel also has the means to deliver the weapons over the ranges compatible with the distances of likely enemies (up to 1,000 miles). **Iraq** has some ballistic missiles acquired from the Soviets and modified to increase their range. Iraq used ballistic missiles in combat in 1991 against both Israel and Saudi Arabia. Iraq’s program to develop nuclear weapons was probably within 18 months of producing enough weapons-grade uranium-235 to manufacture a few nuclear weapons when the facilities were destroyed following the Gulf

War. Iraq also used chemical weapons in combat against Iran and probably has the capability of manufacturing biological weapons. In short, Iraq remains the most dangerous threat to other countries in the Middle East as well as the countries of Eastern and Central Europe. **Iran** has short- and intermediate-range ballistic missiles acquired from China and probably nuclear-weapons-grade fuels and nuclear weapons components acquired from the states of the former Soviet Union. In my judgment, Iran is the most likely nation to test nuclear weapons in the next 10 to 15 years. Iranian weapons and delivery systems could pose a threat to Israel and Eastern Europe in the near term. Over the years, **Syria** and **Libya** have both harbored ambitions of acquiring nuclear, chemical, and biological weapons and their delivery systems. Both were client states of the Soviet Union, but neither has the indigenous capability of manufacturing or maintaining advanced, complex weapons systems. Both countries have exhibited aggressive intentions in the past, but probably neither is capable of implementing them now. **Algeria**, although not strictly in the Middle East, is a large and capable country that could become a threat if a radical Moslem fundamentalist government is installed. **Egypt** could also become a threat if the successor to President Hosni Mubarak changes the policy of peace with Israel. In my judgment, this is not likely, and Egypt will continue to be a stabilizing influence in the Middle East.

India and Pakistan. Both of these nations have tested nuclear explosives, and both are capable of weaponizing them—in fact, they may already have done so. Both also probably have the ability to manufacture chemical and biological weapons. Both nations have ballistic missiles that can deliver these weapons over a range of 2,000 to 3,000 miles. Pakistan’s missiles were obtained from China or North Korea; India has the indigenous capability of developing and manufacturing long-range ballistic missiles. India and Pakistan have developed these weapons because they fear each other. At the present time, neither nation seems to be a threat to other nations in the neighborhood. An open question is what would happen if India and Pakistan used nuclear weapons against each other. Would the United States have to intervene to stop further nuclear exchanges? Would the potential deployment of ABM weapons by the United States neutralize the threat of nuclear weapons

being used by other nations against each other in the near term? Even though neither of these nations constitutes an immediate threat to the United States or its allies, we must think about that possibility.

Far-Term Threats (15 to 30 years)

Russia. Russia remains the most serious threat to the United States because it is still the only nation in the world that can destroy the United States with a surprise nuclear strike. I have listed Russia as a long-term threat because, for the foreseeable future (10 to 15 years), Russia's political priorities will probably be focused on internal development.

China. China presently has the capability of delivering single-warhead nuclear weapons over intercontinental distances. In all probability, China will not be a near-term threat to the United States for various political reasons. However, in the long term, China must be considered an increasing nuclear threat to the United States.

Other Threats

A number of other nations around the world have the technical capability of developing nuclear explosives and the ballistic missiles to deliver them but have not done so for various reasons. Among these are Japan, Germany, Italy, Sweden, Spain, Brazil, and possibly a few others. In the next 15 to 30 years, alliances and politics could shift, however, and a complete reversal is at least possible. Thus, the possibility of weapons proliferation to these nations should be considered. All of the nations listed above, as well as many others, also have the capability of developing chemical and biological weapons. Thus, in the long term, we must consider the proliferation of these weapons around the world. Hence the development of appropriate defenses becomes even more important.

Other Means of Delivery

Many people believe that there are easier and less expensive ways of delivering nuclear, chemical, and biological weapons than ballistic missiles. Aircraft, trucks, ships, and even trains are all possible means of delivery. So-called "suitcase" bombs can "easily" be hand carried. Similar means of delivery are even more effective for chemical and biological weapons. My first answer has always been that, if it is indeed easier to deliver these weapons by other means, why do all

nations—even smaller nations such as Iraq, Iran, North Korea, and Pakistan—that are developing or trying to develop a nuclear weapons capability also acquire ballistic missiles in one way or another. To my mind, the answer has always been very clear: A ballistic missile is the only means of delivery against which there is no workable defense. Once a missile is properly launched, the laws of physics guarantee that it will get close enough to its target to inflict serious damage. In the case of a very expensive and probably scarce weapon, such as a nuclear bomb, the certainty that the weapon will get to its target must be a major factor in the mind of any military commander.

A ballistic missile is the only means of delivery against which there is no workable defense.

All other delivery systems are less certain. Airplanes would be next on the list of priorities for delivery systems. But most nations have some kind of air defense system, which might create uncertainty in the mind of someone with a small number of weapons to expend. In my judgment, the U.S. air defense system is not as good as it should be. In fact, for a long time I have advocated improving our defenses against intrusions into our air space by unauthorized aircraft to discourage a rogue state or a terrorist group from expending a very valuable weapon. A comprehensive air defense system could be designed in a way that would also improve our air traffic control system.

Delivery of nuclear weapons by ship or by truck is possible, of course, but could be substantially hindered by careful inspection of incoming cargoes, which would create uncertainty in the minds of the people attempting to "import" weapons into the country. Finally, suitcase bombs are very hard to produce—only a very sophisticated design would be small enough to carry the bomb. A suitcase bomb would also be quite radioactive, so it would be relatively easy to detect.

Chemical and biological weapons would obviously be easier to smuggle into the country. However, in

light of past experience, their effects would probably be much less devastating than the detonation of a nuclear explosive.

Response to the Threats

I have spent considerable time and space discussing threats because an ABM program must be structured to deal with them. The general principles that govern our thinking about the program should combine what we think we know about the threats and the technical means available to deal with them. Here are the three most important principles:

- The protection of troops in the field and warships at sea should have first priority. During the Gulf War in 1991, U.S. forces in the field were attacked by ballistic missiles carrying weapons. In fact, the majority of U.S. casualties in that conflict were caused by an Iraqi SCUD warhead that struck an American barracks building in Saudi Arabia.

The most effective time to destroy a ballistic missile is in the boost phase.

- The most effective time to destroy a ballistic missile is in the boost phase, or ascent, of the trajectory. At that point, the missile is easy to detect because of its large infrared and visible light signal caused by the rocket plume. In other words, in the initial phase of the trajectory, a missile is much “softer” (i.e., easier to destroy) than a warhead entering the atmosphere. Furthermore, if ballistic missiles can be reached in the boost phase, ABM systems designed to shoot down incoming warheads may not be necessary at individual targets around the world. In other words, shooting down ballistic missiles as they are being launched would maximize the defended area.
- For a number of reasons, the platforms on which ballistic missile defense systems are mounted should be easy to move. First, we cannot know ahead of time where troops will have to be deployed. Moveable

defensive systems could be brought in along with the troops or ships to be defended. Second, mobility may be critical to placing ABMs where they could intercept threatening missiles in the boost phase. Finally, mobile ABM systems would provide a significant diplomatic advantage for the United States because they might be used to defend our friends and allies around the world against ballistic missile attacks.

Programmatic Considerations

In this section, I assess the technical status and the potential military value of various programs against the threats I outlined above. I will also discuss three programs, the Tactical High-Energy Laser (THEL), the Airborne Laser (ABL), and the Space-Based Infrared Satellite (SBIRS-High and SBIRS-Low), that are closely related to the development of a defense against ballistic missiles but are not included in the budget of the BMDO.

Tactical Systems

Tactical systems are primarily designed to defend troops in the field and ships at sea against short-range ballistic missiles. The highest priority systems should be Patriot Advanced Capability-3 (PAC-3) and Minimum Extended Air Defense System (MEADS), the Navy Area Defense, and the ABL.

PAC-3 and the related **MEADS** systems are the ground-based antiballistic missiles systems nearest to deployment. Two tests of the PAC-3 missile with the K-band active seeker radar and a unique, rapid-reaction divert system have been successful. In addition, in 1994 and 1995, there were three successful “hit-to-kill” intercepts by Extended-Range Interceptor missiles (ERINT), the immediate predecessor of the PAC-3 system. MEADS is a ground-based defensive system designed to work against short-range ballistic missiles and cruise missiles. A joint program with several NATO nations, MEADS will use a PAC-3 missile and a European radar system on the ground. The PAC-3 system has been successful technically and should be fully funded and deployed at the earliest possible time. The related MEADS system should also be fully funded.

Navy Area Defense is a system based on the Navy’s Aegis fleet of defense cruisers and destroyers. The cruisers are equipped with 122 missile launchers, the destroyers with 90. All of the ships are equipped with

S-band radar to perform detection and fire control functions called SPY-1. The missile used for the intercepts, the Standard Missile-2 (SM-2), has undergone a number of upgrades and "block" changes over the years. The SM-2 is equipped with active radar and an infrared seeker called the SM-2 Block IVA. The Aegis system has been tested numerous times as a defense against aircraft and short-range Terrier missiles. The warhead has a small explosive charge to perform a shrapnel kill. A successful hit-to-kill intercept using the SM-2 Block IVA missile was conducted at White Sands Missile Range (WSMR) in January 1997. Several other successful tests at WSMR were conducted in 2000. Because of the positive legacy of the Aegis program, there is good reason to believe that this program will be successful and that it will be an important addition to the nation's ballistic missile defense capability. It should be fully funded and deployed with the fleet as rapidly as possible.

The **ABL** originated in 1972 with the initiation of the Airborne Laser Laboratory (ALL), a proof-of-concept experiment that involved putting a large carbon dioxide laser on a KC-135 aircraft and conducting a number of flight experiments. The ALL demonstrated, among other things, that a large gas-dynamic laser could be operated successfully on an airplane, that the laser beam could be successfully transmitted through the boundary layer that surrounds the aircraft, that it could be pointed in all directions without undue distortion, and that an optical system could be built to provide fire control and fire direction. The ALL program was successfully completed when the KC-135 equipped with the laser disabled five Sidewinder missiles using a closed-loop fire control system.

In the 1980s, a more capable laser became available, the Chemical Oxygen Iodine Laser (COIL), which operates at a wavelength of 1.3 microns rather than the 10.4 microns for carbon dioxide lasers. Thus, atmospheric transmission would not be a limiting factor. The Air Force, which initiated the ABL program in 1994, planned to put a large COIL laser on a Boeing 747-400 cargo airplane that could be deployed in areas where our forces were engaged in combat and threatened by theatre ballistic missiles. The mission of the ABL aircraft would be to shoot down theatre ballistic missiles during the boost phase of their flight. The estimated range of COIL is sufficient to accomplish

this objective in most circumstances. The aircraft would constitute part of the defense system of the warfighting forces against ballistic missiles.

A jitter in the optical system caused by vibration and the spreading of the beam caused by atmospheric turbulence has been addressed by a series of experiments and by extensive calculations. In addition, a number of countermeasures have been considered, such as special construction materials and coatings for the missile. Analysis shows that it would be hard to defeat the ABL by such passive means at militarily interesting ranges. The system performed successfully in closed-loop fire control experiments at the Oscura Peak Laser Test Facility in New Mexico over a path length of more than 50km.

There is every reason to believe the ABL will work as predicted.

Based on these results, there is every reason to believe that the ABL will work as predicted. Recently, the Air Force drastically reduced funding for the ABL program to cover shortfalls in other programs the Air Force believes should have a higher priority. Some of these reductions have been restored by Congress, and a missile shoot-down is scheduled for 2004. The ABL is the only long-range ABM weapon based on genuinely new technology that has an excellent chance of working as advertised. The ABL program should be fully funded and transferred to the BMDO so that it can be evaluated against other weapons designed to counter tactical-ballistic missiles.

The **Tactical High-Energy Laser (THEL)** is not part of the BMDO program. For some years, the U.S. Army's Missile Defense Command, in collaboration with the Israeli Air Force, has been developing a laser designed to shoot down Katyusha artillery rockets, Russian-designed guided ballistic missiles with a range of tens of kilometers. The Katyusha is cheap and is available in large quantities from a number of sources around the world. It has been used by Arab forces based in southern Lebanon against targets in northern Israel, hence the Israeli interest.

THEL is a hydrogen-deuterium fluoride (HF-DF) chemical laser that can produce a beam with a wave length of 3.4 microns and a continuous wave beam energy in the megawatt range. Against Katyusha rockets, the THEL has an effective range of a few kilometers. In June 2000, the first THEL (Fire Unit One) was

The THAAD system is the most advanced of the theatre-wide ABM defense systems.

tested at the WSMR Laser Test Facility. The laser promptly shot down a Katyusha in flight by heating the case of the missile sufficiently in one to two seconds to detonate the missile's explosive charge. A few weeks later, the THEL shot down two Katyushas fired within a second or two of each other. This test demonstrated that the acquisition, pointing, and tracking system of the THEL worked well enough to bring down Katyushas fired in a salvo. By September 2000, the THEL had engaged and destroyed 13 Katyusha missiles in flight. Even though the THEL Fire Unit One is not yet a deployable weapon, these tests demonstrate that a mobile THEL would be of great military value. The THEL would be the first practical directed-energy weapon.

Theatre-wide Defense Systems

Theatre-wide defense systems are designed to deal with threats that cover an entire theatre of operations rather than a single tactical situation. These missiles would have ranges of 500 to 3,500 miles, rather than the 300 to 800 miles characteristic of the tactical missiles we have considered so far. Longer range missiles have trajectories that reach altitudes of 500 miles or more, in contrast to short-range missiles that stay mostly within the atmosphere. Thus, ABM systems designed to shoot down missiles that pose theatre-wide threats must be capable of exoatmospheric, as well as endoatmospheric intercepts. The tactical systems discussed in the previous section are intended to perform

only endoatmospheric intercepts. For this reason, tactical ABM systems are usually referred to as lower-tier systems, and theatre-wide systems are called upper-tier systems. Two upper-tier systems are discussed in this section, the Army's Theatre High-Altitude Air Defense (THAAD) system and the Navy Theatre-wide (NTW) System.

The **THAAD** system, the most advanced and the most sophisticated in the BMDO inventory, consists of a very capable X-band radar for fire control and an interceptor missile capable of exoatmospheric and some endoatmospheric intercepts. In addition, THAAD has a good ground-based control computer. THAAD has had a troubled history, however. Eight of the first nine test shots failed. Only in late 1998 and early 1999 were two successful hit-to-kill intercepts conducted at the WSMR. The early failures were caused primarily by poor quality control in the manufacture of the missiles, but a number of design flaws in various missile components also became apparent. Therefore, the test program using the old test missiles was terminated in the summer of 1999, an engineering development phase of the program was initiated during which the missile will be redesigned, and other components of the system will be improved. The THAAD system is a ground-based system that can be moved from place to place, but not easily. The PAC-3 defense system is genuinely mobile; in contrast, THAAD is movable. The THAAD system is the most advanced of the theatre-wide ABM defense systems. The first units will probably be fielded in 2007 or 2008. The program is now properly funded to achieve its objectives.

The **NTW** is an outgrowth of the Navy Area Defense System described above. The essential difference between the area-defense and the theatre-wide defense systems is a new and more powerful missile called the Standard Missile-3 (SM-3) Block I, which is capable of reaching a final velocity of about 3.5 km/sec and is designed to execute exoatmospheric intercepts. The missile is a three-stage solid-fueled vehicle with a unique solid-state third stage with two combustion chambers that permit a high degree of thrust control. The radar system is based on the SPY-I S-band radar with some upgrades. The high-range resolution radar system will make it possible, using phase-control techniques, to use the SPY-I radar to discriminate between warheads and decoys, in spite of the relatively long wavelengths at which the system operates.

Like the Navy Area Defense system, the NTW missiles and radar are carried by Aegis cruisers and destroyers. The great advantage of the NTW is its mobility. The Aegis ships can be moved easily and can provide defensive cover for any region in the world within a few hundred miles of the sea. Thus, the NTW could become an important diplomatic lever in terms of enabling the United States to defend friends and allies around the world.

Some debate has arisen about the concept of operations for sea-based systems. The Aegis ships were originally intended to defend valuable ships in naval task forces in the open ocean against attacks by relatively short-range air-to-air and surface-to-air missiles. After the end of the Cold War in 1991, the Soviet navy—at least the surface units—were no longer a threat. Thus, the idea that the Aegis cruisers could be modified to add an ABM defense capability became more attractive. Originally, the capability was considered an add-on, but in the past year, the Navy has been considering dedicating some ships in the Aegis fleet to the ABM defense mission rather than combining them. This would simplify software development and probably avoid delays in fielding the first missile-defense-capable ships.

A series of tests of the NTW system, originally planned for a hit-to-kill intercept in 2000 as part of the so-called Aegis Leap Intercept (ALI) test series being carried out in the Pacific to test both the SM-2 Block IVA missile of the Navy Area Defense System and the SM-3 Block I missile intended for NTW, had to be postponed because of technical problems with the solid divert and attitude control system (SDACS), a solid-fueled unit that is the fourth stage of the SM-3 Block I missile. The fourth stage, which contains both the SDACS and the seeker, constitutes the missile's kill vehicle. The SDACS unit has a unique design that is, unfortunately, very difficult to implement. In the past year, several ground-based tests of the SDACS system have been either partial or complete failures.

In an encouraging test conducted on January 25, 2001, the *U.S.S. Lake Erie* fired a complete SM-3 Block I missile against a target launched from the Barking Sands Missile Range on the island of Kauai. The missile came within a few hundred feet of the target. However, the SDACS was not activated because of the problems I have mentioned, so no hit-to-kill was attempted. Nevertheless, it was a successful test of the missile

system and the SPY-1 guidance radar. On February 4, 2001, there was a successful ground test of the SDACS unit. Based on this test, a sea-based hit-to-kill attempt might be made later this year.

One limitation of the NTW missile defense system is that it is capable only of exoatmospheric intercepts. Thus, the differences in trajectories between the warhead and decoys in the upper atmosphere cannot be used to discriminate between them. To assist both THAAD and NTW in exoatmospheric intercepts, a space-based infrared satellite (SBIRS) system is being developed that can detect temperature differences between the warhead and the decoys above the atmosphere.

The **SBIRS** system consists of two satellite constellations, one in Molnya orbits, which are highly elliptical with the apogee (and thus, the long residence time) above the northern hemisphere, and the other in a roughly circular orbit at an altitude of about 500 miles. The satellites in the Molnya orbits are called SBIRS-High, and those in the circular orbits are called SBIRS-Low. The SBIRS-High system uses an existing constellation of satellites in Molnya orbits to carry the infrared radiation detectors. The primary purpose of SBIRS-High is to detect missile launches. SBIRS-Low satellites can also detect launches, but their more important mission is to discriminate between warheads and decoys by pointing the infrared detector at a point above the horizon through which the warhead and the accompanying decoys will pass. The data gathered in this way is then passed to the interceptor in real time.

The NTW missile defense system is only capable of exoatmospheric intercepts.

The SBIRS program is currently managed by the Air Force. SBIRS-High is expected to be deployed in the near future and is more or less on track. The history of the SBIRS-Low system has been troubled, however, and there have been delays partly because of technical problems but mostly because of the relatively low priority assigned to the development of the system by the Air Force. Based on a number of test flights in the past

few years of satellites that have successfully demonstrated the capability of very sensitive infrared detectors mounted on satellites (MISTI-3 and MSX, both satellites flown in 1996 and 1997), there is not much doubt that an operational system that can improve exoatmospheric discrimination can be developed. Because of the importance of exoatmospheric discrimination to the theatre-wide defense systems managed by the BMDO, the SBIRS-Low project should be transferred from the Air Force to the BMDO.

The ABM treaty would have to be renegotiated for the United States to deploy a national missile defense system.

National Missile Defense

Besides the technical problems posed by defending large areas against an attack by intercontinental missiles, the most difficult problem considered in this paper, a national missile defense system must be governed by the ABM Treaty that was concluded with the Soviet Union in 1972. No discussion of a national missile defense system would be complete without considering how it might be affected by the treaty.

The ABM Treaty limits the deployment of defenses against ballistic missile attacks intended to inflict heavy casualties on the civilian population, part of the doctrine of Mutually Assured Destruction that governed the deployment of nuclear weapons by the United States and the Soviet Union during the Cold War. The theory was that neither side would attack the other if unacceptable casualties would be inflicted on the aggressor. Some have argued that the ABM Treaty was concluded at a time when it was not technically feasible to shoot down ballistic missiles, and, thus, neither side gave anything really important away. As Winston Churchill said in a speech to the Parliament in 1955: "We are entering an era in which terror will be the sturdy handmaiden of peace."

The writers of the treaty, however, realized that technology would not stand still and that someday means might be found to build a successful defensive system. Thus, the ABM Treaty not only limits deployments but also forbids conducting certain experiments necessary to the development of antimissile technologies. In other words, the ABM Treaty would have to be renegotiated for the United States to deploy a national missile defense system. In fact, President Clinton initiated a process to negotiate changes in the ABM Treaty. Given the history of these negotiations, success is likely to depend on the kind of system proposed.

The ABM Treaty as originally written permitted the deployment of one ABM system with no more than 100 missiles in the continental United States. The treaty also limited radar systems, space-based fire control systems, and how they could be deployed. The Clinton administration's plan to deploy a ground-based ABM defense system in Alaska with a worldwide network of radars and space-based infrared detectors to detect and track incoming missiles would have required that the ABM Treaty be modified. The Russians and some of our European friends and allies have already expressed serious concerns about the Alaska-based system. In addition, a number of U.S. senators have objected to renegotiating the ABM Treaty. Partly because of these considerations and partly because of technical failures (two successive intercept attempts by a kill vehicle failed in 2000), President Clinton cancelled the proposed deployment late last year.

In my opinion, negotiations with the Russians to modify the ABM Treaty to make the deployment of a national ABM defense system possible should be initiated as soon as possible. President Clinton clearly understood this when he raised the matter with Russian President Vladimir Putin at a meeting in June 2000. As expected, President Putin's reaction was negative. Even if the likelihood of reaching an agreement with the Russians is small now, it is vitally important that we do whatever is necessary to find out their current thinking on this subject. In addition, I believe it is very important that we look for an alternative to a land-based system that might be militarily more effective and that might also be more acceptable to the Russians because it would not threaten its land-based strategic deterrent rocket forces.

An attractive alternative to the land-based system based in Alaska might be a modification to the NTW

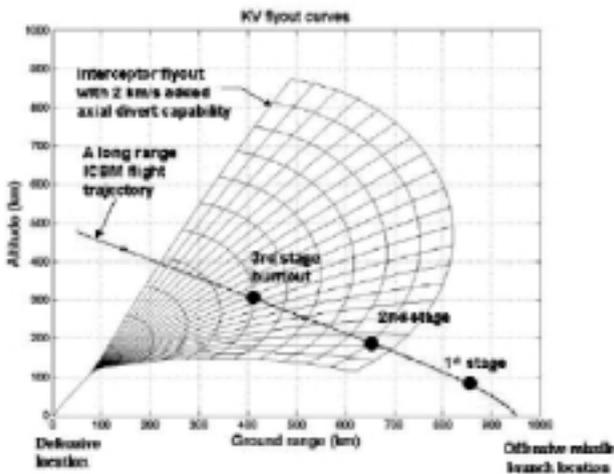


FIGURE 1 This diagram shows intercept trajectories for missiles with a burnout velocity of 5.5 km/sec fired by a ship located at the origin of the coordinate system. A boost-phase intercept (forward intercept) of a missile launched a little less than 1,000 km (600 miles) from the ship is shown. The intercept occurs at an altitude of about 300 km three minutes after the missile is launched from the ship. Also shown is a terminal intercept of a long-range ballistic missile five minutes after the ship has launched the intercept missile. Courtesy of Drs. G. Edward English and Arno Ledebuhr, Lawrence Livermore National Laboratory.

proposed by a group at the Lawrence Livermore National Laboratory. The modification would provide the NTW system with a limited capability of shooting down intercontinental ballistic missiles in the boost phase, or ascent, of their trajectories by adding a fourth stage to the SM-3 Block I missile that would raise the burnout velocity of the missile from about 3.5 km/sec to about 5.5 km/sec. The total velocity increment of about 2.0 km/sec would leave 0.5 km/sec for maneuvering during the end game of the intercept. The fourth stage would be a small, pressurized, hydrogen peroxide rocket or one that would use a hypergolic mixture for propulsion. An important feature of the fourth stage is that it would fit into the same shroud on the missile that houses the current seeker and kill vehicle. The fourth stage would also weigh about the same as the currently existing kill vehicle. Thus, and this is the important point, the proposed upgrade could be made without any other significant changes to the missile. Figure 1 shows the trajectory diagram for an interceptor with a burnout velocity of 5.5 km/sec. An Aegis ship-based SM-3 Block I missile with the proposed liquid-fueled fourth stage would be capable of performing ascent and boost-phase intercepts of missiles launched as far away from the ship as

1,000 km (600 miles). With a space-based sensor providing the missile launch cue, the SPY-1 radar could provide guidance to the intercept point. No discrimination capability would be necessary if the intercepts were performed while the missile was in the boost or ascent phase.

Ship-based ABM systems designed to protect large territories and population concentrations are also prohibited by the ABM Treaty. However, the Russians might be persuaded to accept a sea-based system rather than the Alaska-based system because a sea-based system with an SM-3 Block I missile with a burnout velocity of 5.5 km/sec could not possibly seriously threaten Russian or Chinese strategic land-based nuclear missile forces. Those missiles would be launched from silos beyond the range of the sea-based SM-3 Block I missiles. Aegis ships equipped with SM-3 Block I missiles plus the liquid-fueled fourth stage could deal with threats from North Korea and the Middle East because all of the conceivable launch sites would be close enough to the sea. Figure 2 shows the region an Aegis cruiser would have to occupy to shoot down a Taepo Dong missile launched at the United States from Pyongyang. The area increases as a function of the burnout velocity of the interceptor missile.

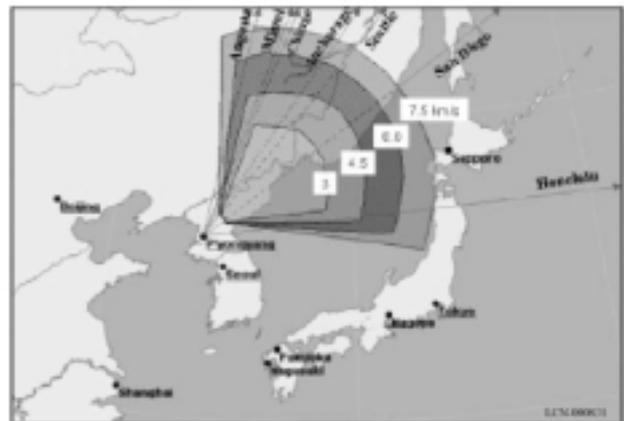


FIGURE 2 This diagram shows the areas from which an Aegis ship could intercept a Taepo Dong missile in the boost phase launched from Pyongyang as a function of the burnout velocity of the interceptor missiles. An interceptor missile with a burnout velocity of 3.5 km/sec would force the ship to stand in close to shore and would be unable to shoot down missiles launched from certain areas of North Korea. If the burnout velocity were 5.5 km/sec, the ship could stand offshore and shoot down a Taepo Dong launched from anywhere in North Korea. Courtesy of Ambassador Henry F. Cooper and Admiral James D. Williams, U.S. Navy retired. Prepared by Lawrence Livermore National Laboratory.

The Aegis ships could not defend against a Chinese or Russian threat because the launch areas would be too far inland. To hit missiles launched from these sites, new ships with larger launch tubes would have to be developed. This argument would probably make more sense to the Russians, and eventually to the Chinese, than a guarantee on our part not to expand a land-based system.

The proposed fourth stage of the SM-3 Block I missile is a relatively small item that would probably require between \$200 and \$300 million for the development of hardware and tests necessary to make sure it works. The BMDO has allocated a small fund to study the possibility of developing the liquid-fueled fourth stage for the SM-3 Block I missile.

The arguments in favor of a sea-based ABM defense system are compelling. Unlike land-based defenses, ships are mobile and can, therefore, be moved easily. In addition, for the most likely threats (from North Korea and the Middle East), the ships could be placed so ascent and boost-phase intercepts would be possible. The alternative I have outlined should be seriously considered and carefully analyzed before a commitment to a purely land-based system is made. I believe very capable land-based high-frequency radars and sea-based missile launchers would be the best combination for an ABM defense system.

Summary and Recommendations

Earlier in this paper, I listed three principles that should govern the development of the architecture for the national ABM defense system: (1) the defense of troops in the field (an operational consideration); (2) intercepts in the ascent or boost phase of the missile trajectory (an organizational military and technical consideration); and (3) mobile launch platforms (an operational and diplomatic consideration).

At the beginning of this paper, I pointed out that all of the current BMDO programs have funding problems that could lead to serious compromises in U.S.

capability. The PAC-3 system does not have enough missiles, and deployment delays have occurred with THAAD and the Navy's Area Defense system. Deployment of the NTW is not funded at all after fiscal year 2002. Finally, the ABL and the SBIRS, which are critical to the architecture of the ABM defense system, are included in the Air Force budget but are not properly funded. All of these funding problems could be solved by reallocating the funds currently allocated to the cancelled Alaska-based system. In order of priority, I recommend that the funds from the cancellation of the Alaska-based system be used for the following purposes:

- We should fully fund the PAC-3 program by funding the number of missiles originally planned and also the missiles allocated to MEADS. We should also help the European partners of the MEADS system with the development of the radar and fire-control systems.
- We should fully fund the ABL and THEL. These weapons, the first fielded directed-energy weapons, promise to be important tactical assets and would be a unique addition to our arsenal. These weapons are based on genuinely new physical principles.
- We should make the decision now to fund the NTW fully. The allocation of these funds should be determined by the results of the ALI tests that will be conducted later this year. Fully funding the NTW would include accelerating the development of SBIRS-Low and the fourth stage of the NTW to defend the United States against attacks by a limited number of intercontinental ballistic missiles launched from the most likely threat areas.
- We must immediately revive negotiations with the Russians to modify the ABM Treaty. If, after a reasonable period of time, these negotiations fail, the United States should seriously consider unilaterally abrogating the ABM Treaty.

Renewal of the Military-Service Laboratories

Walter E. Morrow, Jr.

Changes in personnel policies will be key to ensuring the high quality of military-service laboratories in the future.



Walter E. Morrow, Jr., NAE, is director emeritus of the MIT Lincoln Laboratory.

As the new Bush administration formulates its national security policies, it would do well to review the state of the military-service laboratories, which have declined to the point that their ability to provide future military technologies to U.S. forces is no longer assured. During World War I, World War II, and the Cold War, military-service laboratories made important contributions to advances in military technology, including the initial development of radar, night-vision systems, carrier aviation, and computer-based flight control systems. A few military-service laboratories achieved worldwide recognition and even produced several Nobel Prize winners. However, in recent years, the capabilities of these laboratories have been severely diminished.

Some people mistakenly assume that tremendous technology advances in the civil sector can more than make up for the decreasing capabilities of military-service laboratories. However, a number of critical military

technologies are not being addressed by developments in civil-sector technology. In addition, most civil-sector technological developments have a relatively short-term focus on evolutionary improvements and do not address potential quantum jumps in technology that could be vital to the country's future national security. Strengthening the military-service laboratory system is vital to the national security of the United States. In the discussion that follows, the problems besetting the current system are discussed, and suggestions for overcoming them are offered.

The capabilities of military-service laboratories have been severely diminished.

The military-service laboratory system, which is derived from organizations and facilities that were set up over the past century, now numbers approximately 100 separate facilities spread geographically over the entire country. Guidance on the overall operation and focus of this large laboratory system is provided by the Office of the Director of Defense Research and Engineering (DDR&E), which is part of the Office of the Secretary of Defense (OSD). The laboratories are administrated, however, by separate military services with three different management systems. In recent years, the services have tended to unify their physically separate laboratories under single names, such as the Army Research Laboratory or the Air Force Research Laboratory. For the most part, however, they continue to operate in their original locations and with their original technical focus. The exception is the Navy, which has maintained the Naval Research Laboratory as a separate entity but has incorporated the rest of its research organizations into its acquisition centers, which are responsible for procuring systems.

The overall population of the military-service laboratories reached a peak of about 23,000 during the 1980s Cold War buildup. Since then, as a result of cutbacks in personnel, the number has dropped to about 14,400, a decline of about 35 percent (DSBTF, 2000c). In the process, support personnel were reduced in

greater numbers than the professional staff.

The civil service personnel system has greatly compounded the problem. Because of civil service seniority regulations, the forced reductions in personnel have been focused mostly on younger staff. At the same time, an uncompetitive civil service salary structure has made it next to impossible to hire recent graduates with advanced degrees in important new technologies. The result has been a steady increase in the average age of the professional staff. As older staff members retire, the laboratories are likely to face significant difficulties in filling their positions. In addition, civil service system regulations make it extremely difficult to remove unproductive professional staff.

While these laboratories have shrunk in size, funding has decreased dramatically (although some funds have been restored in the last few years). Only a modest fraction of this funding supports research and technology development inside the military-service laboratories. The larger portion supports research carried out by industry and university laboratories. The supervision of a great deal of this extramural research and development is the responsibility of the military-service laboratory staff. Thus, the managerial burden on the staff has increased at the same time that its numbers have decreased.

The combination of staff reductions, civil service personnel system regulations, and increased contracting responsibilities has had a serious adverse impact. Although the laboratories continue to produce important new military technologies, recent output, as measured by the development of breakthrough capabilities for U.S. military forces, the publication of technical papers, recognition by professional societies, and appointments to the National Academy of Engineering, has been significantly reduced compared to the output of industry and university research organizations (DSBTF, 1998, 2000c). The concern now is to restore the capabilities of the military-service laboratory system.

The success of any laboratory system requires a clear focus on meeting the goals of the organization. In that sense, military-service laboratories are no different from industry laboratories. Military-service laboratories are, of course, primarily focused on meeting the needs of today's, and especially tomorrow's, military forces. Because of the large size (roughly three times the size of the largest industrial organizations) and

complicated structure of the U.S. military, the developers and users of military technologies are widely separated, which makes it difficult for the users to communicate their needs to the research and development organizations. By contrast, in most successful private-sector companies, marketing, research, product development, testing, and production organizations are closely involved, both physically and organizationally. This close physical proximity encourages feedback on development and production problems to research professionals and facilitates the transfer of research findings into new products and systems.

In both industry and military-service technology development, activities can be divided into two classes: (1) applied research (evolutionary improvements to current capabilities); and (2) basic research (revolutionary technologies with longer time horizons). Because of tight budgets, most military and industry research today is focused on short-term, evolutionary programs. Commercial organizations can obtain nearly continuous feedback on the value of improvements in terms of market share and profits. But success for U.S. military research can only be measured by the outcome of military conflicts.

To remedy this difficult situation, it has been suggested that approximately one-third of military science and technology programs be focused on the development and field testing of revolutionary military technologies; the remainder would be focused on improvements to current equipment and force concepts. The military services should also take maximum advantage of civilian research, which is funded at much higher levels than military research. However, in some areas, such as intelligent systems, robotics, and advanced propulsion systems, the military should be a major research investor, civilian research notwithstanding. To test the effectiveness of futuristic military technologies and operational concepts, the military should make maximum use of realistic computer simulations coupled with experimental field engagements between specialized combat forces equipped with advanced capabilities and realistic opposing forces.

Conceiving, promoting, and managing research on revolutionary military technologies requires unusually strong leaders. Historically, such individuals have been military officers with strong technological backgrounds as well as operational combat experience. However, recent reductions in military forces have

naturally emphasized the retention of officers with combat experience, which has resulted in a substantial decline in the numbers of innovative, technologically trained officers. In the future, more technically qualified officers should be identified and retained.

Funding for military-service laboratories is principally derived from the defense science and technology budget. In the early 1990s, such funding reached a peak of nearly \$10 billion in today's dollars. Funding proposed in budget submissions had decreased to about \$7.4 billion by 1998. A study by the Defense Science Board found that the DOD science and technology budget as a percentage of total DOD funding was much lower than the percentage for typical high-technology industries (DSBTF, 2000c). For this reason, and because of concerns about the future military capabilities of U.S. military forces, Congress has increased the science and technology appropriation levels by more than a billion dollars in the last few years.

Only a modest fraction, perhaps 20 percent, of this funding, however, is used to support the military-service laboratories. The rest flows to industry and university laboratories, as well as to laboratories of other government departments (DSBTF, 2000c). Of the 20 percent, only a portion goes to fund research actually carried out by the military-service laboratories. The rest supports research in other laboratories, principally industry laboratories. Projects outsourced to indus-

The success of military research can only be measured by the outcome of military conflicts.

tries and universities are managed by military-service laboratory staff. Therefore, even though current funding should be more than adequate to support the current, downsized military-service laboratory system, only a fraction of the funding is used for this purpose. Serious concerns have arisen about whether the laboratories still have the skilled technical management,

high-quality professional staff, sufficient technical support personnel, and adequate technical facilities to carry out their own research. These issues are central to the productivity of the military-service laboratories.

DDR&E provides broad guidance on the level and focus of the science and technology program. In the last few decades, management has increasingly devolved from the services to OSD. Approximately one-half of the total science and technology program is under the control of OSD. The Defense Advanced Research Projects Agency (DARPA) administers about half of the OSD-controlled portion.

In the past decade, it has been suggested that the management of the entire defense science and technology program be put under the control of OSD, as it is in the United Kingdom, Canada, and Australia. After careful consideration, the current arrangement has been retained because it allows the individual services to focus on evolutionary improvements in current systems and allows the OSD-managed portion of the program to be focused on exploring potential revolutionary military technologies that could dramatically change the capabilities of future U.S. military forces. However, the current management system has several problems.

Recruiting and retaining capable managers is extremely difficult under the civil service personnel system.

First, recruiting and retaining capable research and development managers for directing both the OSD portion of the program and the military-service programs is extremely difficult under the civil service personnel system. DARPA has overcome this problem to a considerable extent by using private-sector professional staff.

Second, the current management system reinforces the separation between combat forces (the users of new technologies) and the laboratories (the develop-

ers of new technologies). Because of the size and physical location of combat forces, communication with the military-service laboratories is often difficult. In addition, procedures are often lacking to bring together innovative combat officers and innovative scientists and engineers to explore new military capabilities.

Third, funding for transitioning newly demonstrated military technology to an acquisition program is often lacking, sometimes because total acquisition funding is inadequate and sometimes because funds have been shifted to incremental improvements in current military systems. As a result, the transition of a new technology from demonstration to acquisition is often delayed for long periods of time.

Some solutions for overcoming these problems include: using management personnel provided by the private sector; forming military concept-generation teams of personnel with recent combat experience and innovative scientists and engineers; forming project organizations separate from the established acquisition organizations to implement promising new military capabilities. These organizations would include personnel with both operational and technical backgrounds.

During World War II and the early Cold War periods, the urgency of the national security situation attracted many talented professionals to military research. Since the end of the Cold War, however, there have been fewer incentives for scientific and engineering staff to join the military-service laboratories. In addition, the number of openings for new staff has been drastically reduced. Adding to the problem, because of seniority rules of the civil service personnel system, the major reductions have been in younger staff, and the average age of military-service laboratory staffs has steadily increased.

The adverse impact of the civil service personnel system goes much further than simply its seniority rules. Over the past several decades, studies by several dozen committees (e.g., DSBTF, 1998, 2000a,b,c,d) on the effectiveness of military-service laboratories have virtually all concluded that the civil service personnel system has seriously impeded the recruitment and retention of capable professional staff. The problems are summarized below.

First, the salaries offered under the civil service personnel system are significantly lower than salaries in the private sector. For recent graduates, offers by the

government are \$10,000 to \$20,000 per year lower. For experienced professionals, the difference is much greater—as much as \$200,000 per year for directors of large laboratories. Obviously, very few of the best and brightest scientists and engineers are willing to consider taking positions at military-service laboratories.

Second, delays between interviews and offers of a position in a military-service laboratory can extend to months while extensive bureaucratic competitive processes are being completed. Very few prospective employees are willing to wait that long, especially if they receive offers of higher salaries from the private sector in the interim.

Third, promotional opportunities, and the higher salaries that go with them, are extremely limited because of fixed ceilings on the number of higher level grades and positions. As a result, younger staff educated in the most recent technologies are strongly motivated to leave for private-sector employment after a few years.

To address these serious problems in the civil service personnel system, Congress has authorized experiments in personnel policy over the past two decades. These experiments have generally taken the form of broader bands for salary levels, salary increases related to realistic performance appraisals, and rapid offers made at the laboratory level. These changes have been helpful at the margin, but they have never been universally applied, and in the end, they have done little to solve the basic problem. Meaningful reform of the civil service personnel system would require the adoption of salary levels, staff appraisal and promotion processes, and dismissal processes for unproductive staff comparable to those used by industry and university laboratories. In light of past experience, meaningful change in the civil service personnel system seems an unlikely prospect.

Other government departments have addressed this problem by operating laboratories as government-owned contractor-operated (GOCO) facilities. For example, the U.S. Department of Energy laboratories and production facilities are being run by industry and universities with considerable success. Conversion of the military-service laboratories to GOCO operation has been repeatedly recommended to the military services but has been rejected because of the employment security and pension concerns of government employees (e.g., DSBSS, 1987). Considering past rejections,

this approach is not likely to be accepted, although a GOCO solution is clearly attractive.

Under the circumstances, the only practical way for the military-service laboratories to recruit and retain a competitive professional staff is to draw on personnel provided by the private sector and to use personnel practices of the private sector, thus avoiding the problems of the civil service personnel system. As government employees retire, the proportion of personnel provided by the private sector could be increased. Private-sector staff could even be rotated over time back to their parent organizations to ensure that a continual flow of new talent with fresh ideas and skills would be available. The leadership of the military-service laboratories could remain with government employees who could exercise necessary government functions. In time, the leadership might also be drawn from private-sector organizations.

Meaningful change in the civil service personnel system seems unlikely.

For each technical professional in large industrial and university-associated research laboratories, one or two support personnel are typically provided, either in the form of direct support personnel (e.g., technicians or programmers) or indirect support personnel (e.g., librarians, purchasers, security guards, etc.). At military-service laboratories the situation is very different. Because of recent forced reductions in personnel, these laboratories have focused on retaining professional staff, which has resulted in higher proportional cuts in support staff. The lack of adequate support personnel inevitably undermines the productivity of the professional staff and discourages capable professionals from accepting positions.

Many military-service laboratories are housed in older buildings, some of which date back to World War II or earlier. In addition, in many but not all cases, the technical facilities and equipment are not state of the art. This not only discourages capable professionals from accepting positions but also adversely affects the

productivity of the resident professional staff.

To sum up, advances in U.S. military technology are essential if the United States is to remain a guarantor of world security. The U.S. military-service laboratory system will require major changes to restore its former capabilities as a primary source of new military technology.

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NAE News and Notes

NAE Officers and Councillors Elected



Wm. A. Wulf

In the spring 2001 election by NAE members, **Wm. A. Wulf** was elected to a second six-year term as NAE president. A new treasurer and two councillors were elected, and one councillor was re-elected. In accordance with the NAE bylaws, a new councillor was then elected by the NAE Council. All terms began July 1, 2001.

William L. Friend, chairman of the University of California President's Council on the National Laboratories, was elected NAE's new treasurer for a four-year term. Friend retired in 1998 as executive vice president and director of the Bechtel Group, Inc., after 41 years in the international engineering and construction industry. He succeeds **Paul E. Gray**, professor of electrical engineering and president emeritus, Massachusetts Institute of Technology.

William F. Ballhaus, Jr., president, Aerospace Corporation, Los Angeles, California, and **M. Elisabeth Paté-Cornell**, professor and chair, Department of Management Science and Engineering, Stanford University, Stanford, California, have



William L. Friend



William F. Ballhaus, Jr.



M. Elisabeth Paté-Cornell



Robert M. Nerem



Robert R. Beebe

been elected to three-year terms as councillors. **Robert M. Nerem**, Parker H. Petit Professor and director, Institute for Bioengineering and Bioscience, Georgia Institute of Technology, Atlanta, has been re-elected councillor for a three-year term.

Robert R. Beebe, who retired as senior vice president of Homestake Mining Company in 1991 and is now a consultant, was chosen as a fourth councillor by vote of the NAE Council at its May meeting. He will serve a three-year term. This position is filled subsequent to the members' election of councillors to ensure that the distribution of engineering disciplines on the council is representative of NAE membership.

Betsy Ancker-Johnson, retired vice president, General Motors Corporation, **John A. Armstrong**, retired vice president for science and technology, IBM, and **Chang-Lin Tien**, university professor and NEC Distinguished Professor of Engineering, University of California, Berkeley, ended their terms of service as councillors on June 30, 2001.

NAE Newsmakers

Jan D. Achenbach, McCormick School Professor, Center for Quality Engineering and Failure Prevention, Northwestern University, received the 2001 **William Prager Medal in Solid Mechanics** from the Society of Engineering Science.

Alan C. Brown was admitted to the degree of **Doctor of Science** (honoris causa) at Cranfield University, England, on June 8, 2001.

Stephen H. Davis, McCormick Professor and Walter P. Murphy Professor of Applied Mathematics, Northwestern University, received the 2001 **G.I. Taylor Medal** from the Society of Engineering Science, and **D.Sc.** (honoris causa) from the University of Western Ontario.

Doris Kuhlmann-Wilsdorf, University Professor of Applied Science, University of Virginia, was named the **Christopher J. Henderson 2001 Inventor of the Year** by the University of Virginia Patent Foundation. She was recognized for her research and six patented inventions relating to electrical brushes, simple but critically important parts of most motors and generators that establish internal electrical connections between the fixed and rotating parts of machinery.

Raymond C. Kurzweil, chairman and CEO, Kurzweil Technologies, Inc., and a pioneer of pattern-recognition technologies, is the recipient of the 2000 **Lemelson-MIT Prize**. Mr. Kurzweil was honored for

his commitment to improving the quality of life for people with disabilities through technology and for the breadth and scope of his innovations, such as the Kurzweil reading machine, which converts print to speech. The prize was awarded on April 25 at a ceremony at the Smithsonian National Museum of Natural History.

Joseph F. Traub, the Edwin Howard Armstrong Professor of Computer Science, Columbia University, received an **Honorary Doctorate of Science** from the University of Central Florida at the commencement on May 4, 2001. The previous day he presented a talk, "Computing: Yesterday, Today, and Tomorrow," to the School of Electrical Engineering and Computer Science.

On May 1, five NAE members were elected members of the National Academy of Sciences. They are **Frederick P. Brooks, Jr.**, Kenan Professor of Computer Science, University of North Carolina, Chapel Hill; **Robert A. Brown**, provost and Warren K. Lewis Professor of Chemical Engineering, Massachusetts Institute of Technology; **Charles B. Duke**, vice president and senior research fellow, Xerox Wilson Center for Research and Technology; **Arthur C. Gossard**, professor of materials, electrical, and computer engineering, University of California, Santa Barbara; and **James N. Gray**, senior researcher, Microsoft Corporation.

Preview of the 2001 Annual Meeting

Two hotels have reserved blocks of rooms at reduced rates until September 14, 2001, or earlier if they become full. So please make your hotel reservation as early as possible. Identify yourself using the hotel "Meeting Code" listed below. Taxes and parking charges are not included.

Deadline for Both Hotels is Friday, September 14, 2001

J.W. MARRIOTT

1331 Pennsylvania Avenue, N.W.

Reservations: 202/393-2000

800/228-9290

Meeting Code: NAE 2001 Annual Meeting

Rates: \$202.00 (single/double)

The J.W. Marriott, located one mile from the National Academies Building, has three restaurants, a health spa, an indoor pool, and valet parking. More information is available at <http://www.marriotthotels.com/WASJW/>.

STATE PLAZA

2117 E Street, N.W.

Reservations: 202/861-8200

800/424-2859

Meeting Code: 6075

Rates: Stateroom Suites
\$129.00 (single/double)
Plaza Suites
\$159.00 (single/double)

The State Plaza, located within walking distance (three blocks) of the National Academies Building, features a restaurant and an exercise room. Parking is limited. More information is available at <http://www.stateplaza.com/sp/index.htm>.

Agenda

October 5	5:00–9:00	NAE Council Meeting
October 6	8:00–4:00	NAE Council Meeting
	8:00–5:00	NAE 2002 Election Peer Committees
		<i>Special Events for NAE Class of 2001</i>
	12:00–1:00	NAE Council Lunch with Class of 2001

1:00–4:30	Orientation
1:00–2:30	Overview of the National Academies
2:30–3:00	Break
3:00–4:30	Overview of NAE
7:00–9:30	NAE Council Reception/Dinner for Class of 2001 (black tie)

October 7	10:30–11:30	Brunch
	12:00–1:30	Public Program Chair's Remarks President's Address Induction of the Class of 2001
	1:30–2:00	Break (Photo of Class of 2001)
	2:00–3:30	Public Program Awards Program Founders Award Bueche Award Lillian Gilbreth Lectureships
	3:30–4:00	Break
	4:00–5:00	Guest Speaker (TBA)
	5:00–5:30	Musical Interlude (Albert R.C. Westwood and Jeanne Westwood)
	5:30–6:30	Reception
October 8	7:00–8:30	Foreign Secretary Breakfast (by invitation)
	7:00–8:30	Home Secretary Breakfast (by invitation)
	8:30–9:30	Business Session
	9:30–11:00	Section Liaisons to the NRC Informal Meeting
	9:30–12:30	Member Briefings
	12:30–1:30	Lunch
	2:00–5:00	Section Meetings
	7:00–12:00	Reception/Dinner Dance (J.W. Marriott) with entertainment by <i>The Capitol Steps</i>
October 9	9:00–5:00	Technical Symposium

New Volume of *Memorial Tributes* Available

Volume 9 of *Memorial Tributes*, a series that honors deceased members and foreign associates, is now available. Each volume of *Memorial Tributes* is a collection of articles, mostly by friends or business associates of the deceased, highlighting his or her contributions to engineering for the benefit of humankind. NAE members or foreign associates who wish to receive copies of Volume 9 or a previous volume should contact the NAE Membership Office at (202) 334-2198. Copies are available to nonmembers from the National Academy Press, (202) 334-3313.

Tributes to the following individuals are included in Volume 9:

Gianni Astarita
J. Leland Atwood
Philip Barkan
Marcel L.J. Barrère
Robert Bromberg
G. Edwin Burks
Paul F. Chenea

Jerome B. Cohen
Neville G.W. Cook
Wallace H. Coulter
Sidney Darlington
Rolf Eliassen
Richard S. Engelbrecht
Michael Ference, Jr.

Donald G. Fink
John C. Geyer
Martin Goland
James P. Gould
Meredith C. Gourdine
Robert Herman
Eivind Hognestad
Joe E. House
George J. Huebner
Lawrence E. "Larry"
Jenkins
Reynold B. Johnson
Robert T. Jones
Jerry R. Junkins
Robert M. Kenedi
John R. Kiely
Koji Kobayashi
Walter F. Kosonocky
Jai Krishna
Rolf W. Landauer
Clarence E. Larson

Gerald A. Leonards
Fritz Leonhardt
Arthur Lubinski
Robert E. McIntosh
David Packard
Earl R. Parker
Donald W. Pritchard
Wilbur L. Pritchard
Eberhard F.M. Rees
Eric Reissner
Rudolf Schulten
Henry E. Singleton
Richard Skalak
Gregory E. Stillman
James R. Wait
Robert H. Wentorf, Jr.
Harold A. Wheeler
Basil W. Wilson
Carlos C. Wood
Aaron D. Wyner
Konrad Zuse

From the Home Secretary



W. Dale Compton

Dear Colleagues:

I would like to bring all members up to date on three membership activities.

- **2002 Election.** The process of identifying candidates for the 2002 election of members and foreign associates is well under way. Letters of recommendation for new nominations were due in the Membership Office by June 8, 2001. I regret to report that approximately 8 per-

cent fewer new nominations and renominations have been received than were received last year. Fortunately, the quality of the nominations appears to be as high as ever. I urge all of you to participate in the subsequent steps of the election process, including providing member comments on the form mailed to you in early July.

- **Project 2003.** The first step in carrying out Project 2003, in which members of each section were asked to identify emerging single-discipline and interdisciplinary areas, has been completed. Although the

number of suggestions was very large, the number of individuals who participated in this first step was small. As a result, rather than limiting participation in the next step, namely voting to prioritize the areas, to the small number of members who made suggestions, all members will be asked to participate in the voting. The voting will still be conducted on a membership section basis.

- **Electronic Communications.** In response to my message to you in March 2001 encouraging the use of electronic communications, only about 25 percent of the membership has indicated a willingness to use this media. Anyone willing to join the group of electronic users is encouraged to contact the Membership Office (202/334-2198). It is never too late to help us reduce paperwork and the associated costs of printing and postage.

Thank you for your participation in all of these programs.

A handwritten signature in cursive script that reads "W. Dale Compton". The signature is written in dark ink and is positioned above the printed name.

W. Dale Compton
Home Secretary

Baruch Joins NAE as Augustine Senior Scholar



Jordan Baruch

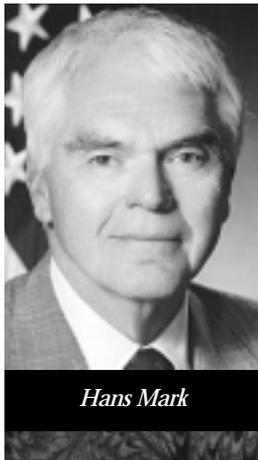
NAE member **Jordan Baruch** joined NAE for an initial one-year term as the Augustine Senior Scholar on May 1, 2001. He has had a long and distinguished career in business, government, and academe. He was a founding partner of Bolt Beranek and Newman, a founding member of Boston Broadcasters, Inc. (licensee for Channel 5 TV in Boston), and general

manager of the MEDINET Department of General Electric. From 1977 to 1981, he was assistant secretary

of commerce for science and technology. He has also taught engineering at Massachusetts Institute of Technology (MIT) and business at Harvard and Dartmouth and has been active on various committees and panels of the National Academies. Dr. Baruch is presently a member of the Board of Directors of the Baupost Group, an investment management firm, and president of Jordan Baruch Associates, consultant to industry and governments on the planning, management, and integration of strategy and technology.

Dr. Baruch received his doctorate in electrical instrumentation from MIT and is a registered professional engineer in Massachusetts, New Hampshire, and Prince Edward Island. In residence at the academy one day a week, Dr. Baruch will address issues related to engineering education.

Mark Joins NAE as Senior Fellow



Hans Mark

NAE member **Hans Mark** joined NAE for an initial one-year term as a senior fellow on May 1, 2001. He is currently professor and John J. McKetta Centennial Chair in Engineering at the University of Texas at Austin, a position to which he returned after nearly three years as the director of defense research and engineering, U.S. Department of Defense. From 1984 to 1992,

Dr. Mark was chancellor of the University of Texas System. Previously, he was director, NASA-Ames Research Center, Moffett Field, California (1969–1977), under secretary (1977–1979) and secretary (1979–1981) of the Air Force, and deputy administrator of the National Aeronautics and Space Administration (1981–1984). In addition to his present academic post, Dr. Mark has taught physics and nuclear engineering at Boston University, Massachusetts Institute of Technology (MIT), and the University of California at Berkeley. He received his Ph.D. in physics from MIT.

Dr. Mark will be in residence at NAE two days a month and will address issues related to defense science and technology policy.

NAE Welcomes New Fellows



Michael Davey

Michael Davey, a specialist in science and technology policy in the Resources, Science and Industry Division at the Congressional Research Service (CRS), has taken a one-year leave of absence from CRS to serve as NAE fellow and study director for the National Research Council Review of the National Nanotechnology Initiative (NNI). Mr. Davey will spend half of his

time developing and launching an NAE workshop series for public policy makers to explore social, ethical, and related policy implications of rapid advances in engineering and technology, including robotics, nanotechnology, software engineering, and bioengineering/biotechnology.

At CRS, Mr. Davey conducted research for Congress on a variety of issues associated with Department of Defense technology programs and laboratories. He has just completed a report on issues related to the President's National Nanotechnology Initiative.

For more than 10 years, Mr. Davey was an adjunct instructor at the University of Maryland, where he taught courses in strategic management. He has also been a visiting instructor at the Brookings Institution, where he taught courses on the federal role in supporting research and development.

Mr. Davey received a B.A. from Illinois Wesleyan University and an M.S. in futures research and policy analysis from the University of Houston. He is also a graduate of the Industrial College of the Armed Forces, where he received the Commandant's Award for Excellence in Research.



Brendan P. Dooher

Brendan P. Dooher, who began a one-year fellowship with the NAE on June 1, 2001, is a systems analyst and risk assessor at Lawrence Livermore National Laboratory (LLNL). He received his Ph.D. in mechanical engineering in 1998 from the University of California at Los Angeles, where he studied probabilistic risk assessment and environmental systems. Dr. Dooher has

worked extensively with California public agencies to assess the threat to public water supplies and resources from leaking underground fuel tanks and methyl tertiary butyl ether (MTBE). He helped create an interactive web site, GeoTracker, for Geographic Information System to help regulators, responsible parties, and the public assess the vulnerability of water supplies cost effectively and develop a "living groundwater model" for California.

During his year with NAE, Dr. Dooher will help develop and execute program initiatives related to engineering, energy, and the environment.



James Phimister

James Phimister is the 2001 J. Herbert Hollomon Fellow at NAE. Dr. Phimister will be involved in the Engineering and Health Care Delivery Systems project, which is based on two recent Institute of Medicine reports, *To Err Is Human*, which estimates that more than 98,000 Americans die annually as a result of medical mistakes, and *Crossing the Quality Chasm*, which recommends an overhaul of national health care and the

adoption of systems-based and quality-based management strategies to ensure patient safety.

With a background in engineering and systems management, Dr. Phimister is well qualified to address this complex issue. He was a fellow at the Wharton School of Business, University of Pennsylvania, where he worked with health, safety, and environment management at Fortune 500 companies to improve system reliability and worker and community safety through employee engagement strategies to identify and resolve situations in which employees are exposed to risk. During his NAE fellowship, Dr. Phimister will retain his connection to the Wharton School, where he is co-leader of the Near-Miss Project, which develops management systems that identify precursors to accidents and remedy them. The Near-Miss Project is

part of a cooperative agreement between the Wharton Risk Center and the Center for Emergency Preparedness and Prevention of the Environmental Protection Agency and is supported by ATOFINA, DuPont, Johnson & Johnson, Rohm and Haas, and Sunoco.

Dr. Phimister completed his Ph.D. in chemical engineering at the University of Pennsylvania; he was awarded a 2000 Merrill Lynch Innovations Grant for his development of the concept of semicontinuous distillation. He also earned an M.S. in chemical engineering from the University of Pennsylvania in 1997, an M.S. in chemical engineering from the University of Edinburgh, Scotland, in 1995, and a B.E. from the University of Edinburgh in 1994.

Carol R. Arenberg New NAE Managing Editor



Carol R. Arenberg is the new managing editor for NAE. She comes to NAE after five years at the NRC, where she was editor for the Commission on Engineering and Technical Systems (CETS, now part of the Division on Engineering and Physical Sciences). Dr. Arenberg was responsible for the editing and publication of 25 to 30 full-length

reports per year, and she received several certificates of appreciation for her work. She is also the author of many articles and book reviews for academic and general publications. Her background includes medical editing, newspaper and magazine editing and writing, and teaching. She earned a B.A. in English and an M.A. in comparative literature from the University of Michigan and a Ph.D. in comparative literature from Washington University in St. Louis.

Lillian M. Gilbreth Lectureships for Young Engineers

At the May meeting, the NAE Council approved the establishment of the Lillian M. Gilbreth Lectureships for Young Engineers as a means of recognizing outstanding young engineers and bringing them to the attention of NAE members through presentations at NAE's annual, national, and regional meetings. For the first two years of the program, speakers will be selected from presenters at NAE's Frontiers of Engineering symposia. The selection process will then be reviewed and may be revised. Two young engineers will present lectures at each Annual Meeting, and when it does not conflict with a symposium honoring an outgoing NAE officer, two or more will make presentations at the National Meeting.

The first lectures will be given at the Annual Meeting in October 2001. Each lecturer will receive a plaque, an honorarium, and travel expenses to the meeting. Funding for the lectureship will be derived from income on an endowment designated for the encouragement of young engineers. If the topic of a regional meeting corresponds with the meeting topic of a past Frontiers meeting, organizers will be encouraged to

include at least one speaker from that meeting.

The Gilbreth Lectureships were created in response to suggestions from NAE members that the academy reach out to younger engineers. The goal of the lectureships is to increase NAE's interactions with rising stars in the profession without creating a special category of junior membership.

The Gilbreth Lectureships are named in honor of Lillian Gilbreth, the first woman elected to the NAE (1965). To address their concerns that capable individuals be given opportunities to perform efficiently and effectively, Lillian and Frank Gilbreth made noteworthy contributions in the field of human factors. After Frank Gilbreth died in 1924, Lillian became the intellectual force and spokesperson for a humanistic approach to management. Lillian, who died in 1972, was also the author of the perennially popular book, *Cheaper by the Dozen*.

For information about the Lillian M. Gilbreth Lectureships, contact Janet Hunziker, Program Officer, at (202) 334-1571.

Convocation of Professional Engineering Societies

The annual Convocation of Professional Engineering Societies, hosted jointly by NAE and the American Association of Engineering Societies (AAES), was held on May 7 and 8, 2001. The convocation brings together the presidents, presidents-elect, and executive directors of major professional engineering societies to discuss issues of importance to the U.S. engineering community. On May 7, at a meeting held in conjunction with the AAES Government Affairs Conference in the Rayburn House Office Building, staffers from the U.S. Congress and senior officials of federal government agencies were invited to share their views on national engineering issues.

The meeting on May 8 at the National Academies Building was called "Public Awareness to Public Understanding: Engineering a Common Message." Speakers included Scott Giles, deputy chief of staff,

House Science Committee, who spoke on "Public Understanding of Engineering: Communicating a Common Message"; Hyman Field, senior program advisor, National Science Foundation, whose topic was "Informal Education: At the Crossroads of Public Relations and Education"; and Professor Ioanis Miaoulis, dean of engineering, Tufts University, whose topic was "Reaching K-12: A Grassroots Approach for Attracting a New Generation." The wrap-up to the convocation, a discussion of "Maximizing Our Impact through Strategic Cooperative Ventures," was intended to encourage engineering societies to work together to promote public awareness of engineering. The discussion was led by NAE **President Wm. A. Wulf** and **Stephen D. Bechtel, Jr.**, chairman emeritus and a director of Bechtel Group, Inc., and former NAE chairman.

Campaign Update

To fulfill NAE's mission and realize the goals outlined in the Strategic Plan will require considerable financial resources. In 1997, NAE, NAS, and IOM launched a joint **Campaign for the National Academies** with the goal of raising \$300 million by December 2004—\$65 million specifically for NAE programs. As of May 31, 2001, the overall campaign had raised \$153 million—51 percent of its goal—in contributions from individuals and philanthropic organizations. NAE's portion has reached the \$27 million mark.

NAE has traditionally relied on corporations and foundations for most of its nongovernmental support. The goals outlined in the Strategic Plan, however, will require long-term, proactive responses. Therefore, we must double our endowment. Our traditional partners will no doubt continue to support our mission, programs, and projects, but our success in building our endowment will also require the collective participation of NAE members.

Five recent gifts from NAE members demonstrate the impact of individual philanthropy on building NAE's endowment and enhancing our capabilities.

- **Bernard M. Gordon**, recently retired chairman and CEO of Analogic Corporation, has given stock valued at \$10 million to establish the **Gordon Prize for Innovation in Engineering and Technology Education**.

- **Norman Augustine**, former NAE chairman, has pledged \$1 million to create the **Augustine Senior Scholar**, an essential part of NAE's agenda for self-initiated projects.
- NAE has received an anonymous pledge of \$1 million for unrestricted support of self-initiated projects.
- In support of the Public Understanding of Engineering Program, the **Elizabeth and Stephen D. Bechtel, Jr., Foundation** has given \$500,000.
- **John A. Armstrong**, retired vice president of IBM and former NAE Council member, has contributed \$650,000 toward an endowment for the encouragement of young engineers, including **Frontiers of Engineering**. A portion of this gift is a challenge grant; an additional gift of at least \$150,000 will be necessary this year to meet the challenge.

All of these gifts—and many more NAE has received—demonstrate the importance of NAE programs to its members and to the larger society. And these gifts are not the only good news: annual member support has risen steadily—from \$76,000 in 1997 to slightly less than \$500,000 in 2000. The upcoming 2001 Annual Fund campaign, beginning in September, will give members another opportunity to provide tangible support for NAE's mission and programs.

Council and Staff Awards Luncheon



Left to Right: Patricia Scales, Barbara Bishop, Wm. A. Wulf, Miriam Glaser Heston, Cynthia McFerson, and Nathan Kahl. Katie Gramling is not pictured.

The National Academy of Engineering (NAE) recently held its annual Council and Staff Awards Luncheon at the Riverview Room of the Swissôtel, The Watergate. **President Wm. A. Wulf** hosted the ceremony.

Five staff members received awards for outstanding performance. **Patricia Scales, Cynthia McFerson, and Miriam Glaser Heston** of the NAE Membership Office were recognized for their dedication and commitment to serving NAE members. **Katie Gramling**, from the NAE Program Office, was recognized for developing the Engineer Girl program and its web site, www.engineergirl.org. **Nathan Kahl**, also from the Program Office, was honored for his work on NAE's diversity program. All five received certificates of appreciation and \$1,000 cash awards. **Barbara Bishop** received a service award for 20 years of service with NAE.

In Memoriam

GEORGE A. FOX, 81, past president and chairman, Grow Tunneling Corporation, died on May 17, 2001. Mr. Fox was elected to the NAE in 1988 for his contributions to the advancement of engineered heavy construction and his service to higher education.

HENRY MICHEL, 76, chairman emeritus, Parsons Brinckerhoff, Inc., died on May 23, 2001. Mr. Michel was elected to the NAE in 1995 for his leadership in applied research technology transfer and the promotion of alternative forms of project execution.

OWEN RICHMOND, 73, former director, Core Technologies, Alco Technical Center, died on April 17, 2001. Dr. Richmond was elected to the NAE in 1997

for developing the scientific basis for the fabrication and processing of engineering materials.

ROBERT H. SCANLAN, 86, professor of civil engineering, Johns Hopkins University, died on May 27, 2001. Dr. Scanlan was elected to the NAE in 1987 for novel, sustained contributions in mechanics applicable to civil, mechanical, and aeronautical engineering, especially in structural dynamics, aeroelasticity, and wind engineering.

ABE SILVERSTEIN, 92, retired director, NASA Lewis Research Center, died on June 1, 2001. Dr. Silverstein was elected to the NAE in 1967 for his work on aeronautical and space systems.

Calendar of Upcoming Meetings and Events

July 13	NAE Congressional Lunch	September 21	NAE Congressional Lunch
July 17	NRC Governing Board Executive Committee	September 25	Charles Stark Draper Prize Committee
July 19	Bernard M. Gordon Prize Committee	October 5	NAE Finance and Budget Committee
July 24–25	Committee on Diversity in the Engineering Workforce	October 5–6	NAE Council NAE Peer Committees
July 25	Journalist Training Institute Curriculum Development Committee	October 7–9	NAE Annual Meeting
July 31	New Council Members Orientation Woods Hole, Massachusetts	October 10	NRC Governing Board Executive Committee
August 1–2	Action Forum on Diversity in the Engineering Workforce NAE Council Woods Hole, Massachusetts	October 11–13	2001 German-American Frontiers of Engineering Symposium Essen, Germany
August 3–4	NRC Governing Board Woods Hole, Massachusetts	October 15–16	IOM Annual Meeting
September 6	NRC Governing Board Executive Committee	October 18	Bernard M. Gordon Prize Committee
September 13–15	7 th Frontiers of Engineering Symposium Irvine, California	October 29–30	Committee on Diversity in the Engineering Workplace Best Practices Workshop

All meetings and events are held in the National Academies Building, Washington, D.C., unless otherwise noted.

National Research Council Update

Realities of 21st Century Warfare



by Michael Clarke, Associate Director, Division of Military Science and Technology

Picture yourself driving an SUV over rough terrain at about 20 miles per hour. The vehicle is pitching and rolling and very difficult to control. Obstacles appear and disappear as you fight the steering wheel. Somehow you manage to avoid hitting anything big and immovable.

Now expand your vision. You are in the same situation, but shells are hitting the ground and exploding in your vicinity, bullets are striking the exterior of your vehicle, and smoke and haze obscure your vision. At the same time, you are attempting to fire back. Multifunctional displays are putting out streams of information on the distribution of enemy forces, the nature of the terrain, the deployment of friendly forces, weapons controls, and more. Sweat runs down your face as you try to maintain control of your vehicle and absorb some of the displayed data. In your ear, your unit commander is telling you where you should be going and reminding you of your mission.

If only you had time to access your secure military Internet connection, you know you could get even more relevant information. But it is becoming more and more difficult to concentrate as your body temperature rises in the chemical protection suit you are forced to wear. Even though none of your chemical or biological sensors has detected an agent or pathogen, you know there have been reports of them. Somehow, you find a reservoir of strength you didn't know you had. After all, you can't let your unit and your country down.

As mental and physical fatigue set in, you begin to lose your ability to think and react quickly. Medical sensors attached to your body sense these changes and

automatically inject drugs to calm your mind and stimulate your body. As your strength returns and your perception clears, a feeling of well-being pervades your system. You fight on renewed.

Just then your luck runs out. A precision guided projectile hits your vehicle. You are still alive, but, although you can't feel it, you know you are gravely wounded. As your senses fade, your medical sensors kick into a higher gear. Tourniquets tighten around badly injured limbs to stop the bleeding. Medicines to fight shock and infection are injected. Electromagnetic emergency information is transmitted from your vehicle to a central medical unit. Within seconds a semiautonomous medical vehicle is heading toward you. Days later you awaken in a military hospital and are told you will survive.

Farfetched? I don't think so. The military is considering all of these things, and many will be fielded in the next two decades. Nevertheless, as this scenario demonstrates, no matter how sophisticated the technology and how capable the machines, success depends on the soldier and his or her ability to use them effectively. Science can provide the wherewithal to accomplish unheard-of feats, but warfare may become so complex that human beings will be left behind. As we reach the limit of our ability to absorb data, make quick decisions, and react to the conditions of modern combat, more extensive use of robotics may become critical to mission success. Our weapons could become so effective, lethal, and impersonal that war as it has been fought in the past will become obsolete or unthinkable. Battles between large, maneuvering ground armies may soon be artifacts of the past. What will the metrics of the new battlefield be? Might the new battlefield be hundreds of miles above us in space? Is war itself, as commonly defined, unlikely to occur except in the form of demonstrations of advanced, accurate, impersonal weaponry, such as in Iraq or Kosovo? And finally, what is the role of the National Academies and the National Research Council (NRC) in all of this?

The NRC Division of Military Science and Technology (DMST) and its two boards, the Board on Army Science and Technology (BAST) and the Air Force Science and Technology Board (AFSTB), have at one time or another discussed these and other complex national defense issues. Committees under the boards are currently working on studies focused on the role of biotechnology in the Army of tomorrow, replacements for antipersonnel landmines, the ability of the aerospace industry to continue to provide quality military products, evolving and obsolescing avionics systems in our aging fleet of military aircraft, and the continuing problem of destroying America's arsenal of chemical weapons. Future reports will address the military uses of nanotechnology, digital experimentation, and semi-autonomous and autonomous vehicles.

All of the services are undergoing massive transformations to deal with threats of tomorrow. For example, the Army's Future Combat System (FCS), which could well realize the scenario hypothesized above, has been discussed extensively by BAST. The FCS will consist of smaller, lighter vehicles embedded in a new systems construct involving aircraft, new weapons, and advanced communications and information management. NRC studies will help pave the road to that future.

At the last several meetings of the AFSTB, military space considerations have been discussed. The military transition to space is under intense consideration, and the board is focusing on issues associated with Air Force worldwide force projection and how the application of science and technology could increase lethality and deployment speed, while reducing costs and logistics support tonnage.

A survey of the Department of Defense science and technology programs confirms that the systems being procured and on the drawing board are becoming increasingly complex, lethal, and impersonal. Any combatant, anywhere, can be attacked without warning, even without knowing an enemy is present. Stand-off, precision, small, smart bombs, individually programmable and reprogrammable in flight and accurate to within a few feet, could be dropped by the hundreds from altitudes and distances that would make the launch platform essentially undetectable. Energy weapons from aircraft or space will soon be capable of attacking aircraft and missiles in flight, as

well as targets on the ground. In short, a force with these capabilities could attack anyone, anywhere, combatant or otherwise. The world is safe right now only because the United States is apparently the only nation with these capabilities.

No nation on earth can stand up to the United States on a symmetrical basis. This circumstance has changed the nature of warfare. Since the end of the Cold War, we have continued to invest heavily in defense (although many would argue that budget reductions and multiple force deployments, such as Iraq, Bosnia, and Kosovo, have weakened America's armed forces to the point of concern). In fact, other nations, including our European allies, have undergone even larger cuts. The military concerns of today are the rise of Chinese military capabilities, the continued deterioration of the Russian military that could lead to weapons proliferation or a nuclear accident, and attacks by rogue nations or extranational terrorist groups. American homeland defense is being increasingly talked about and pondered by all of the services.

Future warfare could be incredibly complex and asymmetrical. Nameless and nationless individuals or groups could strike the United States with conventional or unconventional weapons, not to win victories but to induce terror and unrest and cause us to change our policies. The goals of these enemies could vary widely and could be all but incomprehensible to us. The challenge is how they could be detected and dealt with before they accomplish their mission.

The solution to these and other problems will require continued American vigilance and a strong military science and technology base. The scientific seeds of today will bring forth the technology programs of tomorrow. The NRC military boards are increasingly working in partnership with the services to ensure that our combat forces are the best equipped and most modern in the world. NRC activities are not pro-war; they are pro-deterrence. The stronger we are, the more capable we are of defeating both symmetrical and asymmetrical threats, the less likely our country is to be attacked and the better our citizens can sleep at night. We take our responsibilities seriously.

I have heard it argued that involvement with the Department of Defense and the military services is somehow unbecoming to the National Academies and the NRC. We believe that no activity is closer to the

charter of the institution. We have a continuing opportunity to provide mature, thoughtful, rational, and independent advice to the Department of Defense. We provide information and perspectives not generated

solely from within the department. Shining the light of independent reason and providing an outside perspective on defense activities is, I believe, of the utmost importance to our institution and the nation.

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academy Press (NAP), 2101 Constitution Avenue, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP on-line at <http://www.nap.edu> or by phone at (800) 624-6242. *Note: Prices quoted by NAP are subject to change without notice. On-line orders receive a 20 percent discount. Please add \$4.50 for shipping and handling for the first book and \$0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.*

Aging Avionics in Military Aircraft. This report addresses the issue of aging and obsolescing avionics in military systems. Like all computer-based systems, avionics systems operate on a life cycle of about two to three years. By contrast, the systems in which they are embedded have life cycles as long as several decades. The report provides recommendations for technical solutions to this problem. \$18.00, paper.

Alternative Technologies to Replace Antipersonnel Landmines. New technologies under development could offer tactical advantages similar to or greater than those offered by antipersonnel landmines and reduce the risk to civilians. These technologies could replace some, but not all, of the U.S. military's antipersonnel landmines. With increased funding, an alternative system to nonself-destructing mines could be ready by 2006, the United States' target date for signing an international treaty banning them. The report recommends that the military aggressively pursue technologies that could be used as components of long-term alternatives to antipersonnel landmines. \$40.00, paper.

Disposition of High-Level Waste and Spent Nuclear Fuel. Addressing the challenges posed by the disposal of spent nuclear fuel from reactors and high-level radioactive waste from processing fuel for military or energy purposes will require the focused attention of

world leaders. The biggest challenges to safe and secure storage and permanent waste disposal are not technical but societal. \$32.00, paper.

Frontiers of Engineering: Reports on Leading Edge Engineering from the 2000 NAE Symposium on Frontiers of Engineering. This collection includes summaries of presentations given at the September 2000 symposium. Topics include: system engineering, visual simulation and analysis, engineering challenges and opportunities in the genomic era, and nanoscale science and technology. \$32.00, paper.

Naval Forces' Capability for Theater Missile Defense. This report includes evaluations of present and projected threats to naval forces from ballistic and cruise missiles, the current state of technologies involved in theater missile defense, and current and projected Department of the Navy programs designed to meet the threats. The report prioritizes cruise and ballistic missile defense programs and recommends R&D priorities. \$42.25, paper.

Opportunities in Biotechnology for Future Army Applications. This report examines how biotechnology might be used by the Army to improve the survivability and effectiveness of U.S. soldiers in battle. The report reviews current directions in biotech research and applications and identifies opportunities most relevant to the Army. The major recommendation encourages the Army to develop an in-house cadre of experts knowledgeable in both engineering and biology who can contribute to, interpret, and influence developments. \$27.75, paper.

A Review of the New Initiatives at the NASA Ames Research Center. This volume provides a summary of a workshop reviewing the NASA Ames Research Center's plans to develop a science and technology park. The project will involve cooperative activities with two universities, collaborative research with industries, and efforts to encourage small business development. \$35.50, paper.