



INSTITUTE FOR DEFENSE ANALYSES

**Army Science and Technology
Master Plan (ASTMP) Annex E
Global Science and Technology Watch**

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PREFACE

This document presents the result of the process of nominating, analyzing and validating the international cooperative opportunities for International Technology Watch. When work was initiated on this project it was under the rubric of the Army Science and Technology Master Plan (ASTMP), Annex E, International Cooperative Opportunities. During production and revision, the Technology Watch concept was adopted within Defense Department Research and Engineering as an outgrowth of the ASTMP Annex E. It became the umbrella for capturing technology opportunities for the Army and for other DoD entities.

As in prior years, development of these technology opportunities required a meeting of the Army international points of contact. This meeting consolidated technologies nominated by using commands and validated by technical experts working at the Institute for Defense Analyses. Unlike prior years, augmenting opportunities were requested from Canadian sources through the U.S. Army Standardization Group, Canada. Canadian defense officials provided information on technology opportunities across a wide segment of Canadian industry. These technologies were also analyzed for applicability to the requirements of the Army.

It is anticipated that the basic processes that created this document will continue. These include canvas for opportunities, nominate selected opportunities, validate the technical improvements possible in DoD application, and provide program offices with a broad selection of possibilities for their use. However, these opportunities must also be applied within a context that includes Service policies, prior history, and near-term initiatives for international cooperation.

ANNEX

E

GLOBAL SCIENCE AND TECHNOLOGY WATCH

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ANNEX

E

GLOBAL SCIENCE AND TECHNOLOGY WATCH

This annex plays a supporting role to the Army's capstone science and technology planning document by providing:

- A snapshot assessment of global technology developments.
- An index of international organizations and related resources by technology category.
- A tool for exploiting the explosion of international S&T programs by acting as an information resource in technologies of interest to the Army.

Given the widespread and increasing proliferation of militarily relevant technologies, it is important that the Army's approach to international collaboration is both focused and productive.

A STRATEGIC OVERVIEW

The globalization of science and technology is an irreversible process that is radically changing the environment in which the Army trains, operates, and develops new systems and strategies. This globalization of S&T affects the Army's ability to pursue enabling technologies in support of Future Combat Systems (FCS) for the Objective Force. The Army's International Technology Leveraging strategy (described in Volume I), which has become an increasingly important facet of technology development strategies, given limited resources and new international threats and partners.

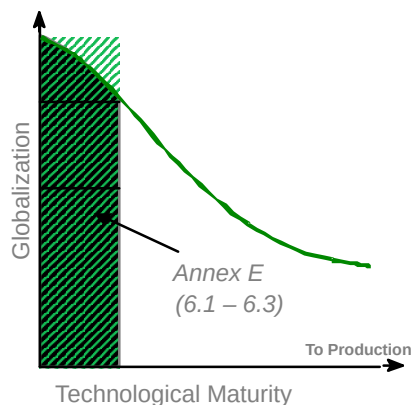


FIGURE E-1. FOCUS OF TECHNOLOGICAL COVERAGE

Globalization has also been viewed as a vulnerability for the United States, in that it can accelerate technology development for potential adversaries and increase U.S. dependence on international technology sources (Figure E-1). By increasing U.S. influence with foreign nations and providing access to technological strengths residing outside the United States, however, globalization also provides many new possibilities to enhance U.S. policy options and defense capabilities. This annex provides a tool for exploiting the phenomenon by acting as an information resource to access international areas of expertise in technologies of interest to the Army. The need for this kind of "technology watch" of global capabilities has been supported at all levels of the Department of Defense, including both the Office of the Deputy Under Secretary of Defense for Science and Technology and the Defense Science Board.

1 Vision

International military–industrial–academic partnerships contribute to the warfighting capabilities of our soldiers and our allies by maintaining truly world-class technology and industrial bases built on a global-minded workforce and the best available industrial capabilities and services. As shown in Figure E–2, our International Armaments Cooperative Strategy (IACS) is a comprehensive effort to focus our diverse goals to:

- Maintain a global awareness of the best technological developments, and develop appropriate leveraging strategies.
- Arrange data and personnel exchanges, and participate in selected international forums to optimize the benefit to the U.S. Army.
- Develop senior-level guidance based on well-thought-out leveraging strategies.

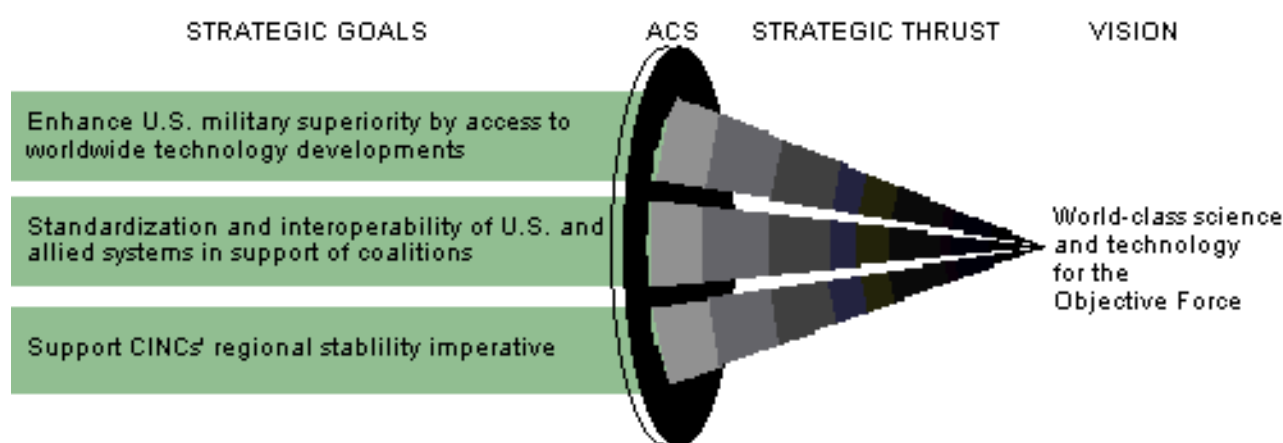


FIGURE E–2. THE INTERNATIONAL ARMAMENTS COOPERATIVE STRATEGY FOCUS

2 Role of Annex in International Programs

Effective international cooperation demands both the development of sound, long-term partnerships and the ability to respond opportunistically when the occasion arises. This annex is designed to accomplish both these objectives. First, this annex provides insights into the broad capabilities of other countries that can be used to allocate resources to develop and cultivate cooperative programs with partners that are most likely to provide reliable long-term benefits. At the same time, identification of specific niches of excellence in research and application provides a basis for responding quickly to the changing political–military landscape while managing potential benefit to the Army science and technology community. The annex also supports the development of international technology cooperation programs that promote interoperability among coalition partners and support peacetime engagement among allies.

As discussed in Annex F, identification of an opportunity for partnering in this annex establishes the existence of an acceptable technological quid pro quo. Within the guidelines of identified technologies and countries, this annex provides an authoritative basis for the initiation of international agreements, as shown in Figure E–3. However, the proponent organization must make the final determination that the specific quid pro quo exists for concluding cooperative agreements. This annex offers an annually updated snapshot in time, and new and rapidly

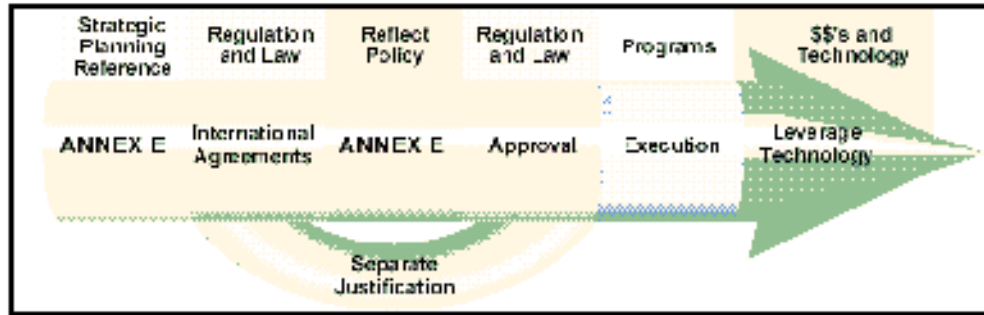


FIGURE E-3. ROLE OF ANNEX E IN INTERNATIONAL PROGRAMS

emerging S&T development may not be reflected. Because this document is publicly released, sensitive or classified information is not included.

The ASTMP is the Army's capstone S&T strategy planning document. This annex plays a supporting role in several of the Army plan's mission areas. As a planning and reference tool, this annex provides senior Army management with a roadmap for initiating discussions with partnering countries on technology cooperation.

3 Country Capabilities and Trends Analysis

Understanding trends is key to an effective strategy. Science and technology is advancing rapidly, and some opportunities may be time sensitive. This analysis of technology and research capabilities spans the entire globe. In all areas, both commercial and government capabilities and programs are assessed. More than in previous years, multinational programs are identified as targets for U.S. cooperation in the various disciplines.

The criteria for determining country capabilities and associated trends were the following:

- *Comparative demonstrated technical performance*—countries were examined for materials, components, or systems produced indigenously, relative to best U.S. practice.
- *Indicators of recognized quality*—the market share of commercial and defense products based on the research and technology areas in each nation was considered as part of the capability assessment.
- *Strength and balance of supporting infrastructure*—the number of R&D organizations, diversity of participation (industry, academia, and government), and level of investment were considered.
- *Expert consensus*—U.S. Army subject matter experts reviewed the analyses.

Technology and research areas addressed are described in detail in Chapters IV and V. These areas span Army interests from research to advanced development (Figure E-1). They have been identified as enabling the Army to upgrade currently fielded systems and to investigate new high-risk areas having significant potential enabling capabilities need for the Objective Force.

4 Global Technology and Research Capability Overview

Leadership in applied technology with identified military relevance is shared among relatively few countries—the United States and its NATO allies France, Germany, and the United Kingdom, and major non-NATO ally Japan. Other countries identified as having significant capabilities include Israel, Canada, China, Russia, Italy, Sweden, Australia, and the Netherlands. In a number of countries, the trend is toward the development of more advanced capabilities. In most areas, capability is widely disseminated, with three or more countries sharing world lead-

ership. Even in those areas where the United States holds a unilateral lead, other countries provide significant technology leveraging opportunities in specific areas.

The number and geographic distribution of countries having significant S&T capabilities is large and can be expected to increase. In the global economy, reliable sources of electronics, computers, sensors, and new materials are becoming more widely available as advances spread rapidly throughout global markets. Computers and electronics are simply commodities—basic tools for studying the scientific areas that these countries have chosen, such as life sciences, biology, chemistry, and behavioral and medical sciences.

Figure E-4 provides a rank ordering of country capabilities based on the total number of high-quality leveraging opportunities that are identified in this annex. The capabilities highlighted correlate to the areas where countries are shown in the individual subsection tables as having world-class capabilities and a level of activity that is expected to enhance or at least maintain their relative position.

LEVERAGING OPPORTUNITIES	BASIC RESEARCH	APPLIED RESEARCH
IN A MAJORITY OF ARMY S&T AREAS	Germany France UK Japan Russia	France UK Germany Japan
IN MANY ARMY S&T AREAS	Israel Canada China Sweden Netherlands	Israel Russia Canada Sweden Netherlands Italy
IN ONE OR MORE ARMY S&T AREAS	Australia Switzerland Italy Korea India Finland Poland Taiwan South Africa Austria Denmark Indonesia Brazil Czech Republic Spain Slovakia Singapore Belgium Cuba Hungary Turkey Argentina	Switzerland Korea China Australia Austria Singapore Poland India New Zealand South Africa Denmark Brazil Czech Republic Thailand Belgium Malaysia Kenya Norway

This rank ordering is based on the number of world-class leveraging opportunities across all research and technology areas of interest to the Army, as identified in Annex E, Volume II.

FIGURE E-4. RANK ORDERING OF COUNTRY CAPABILITIES

5 The Future

Although scientific and technological capabilities are important determiners of future capabilities, global economic forces will also play an important role. These forces will inevitably change the distribution of wealth, and with that shift, the future potential for technological and scientific leadership. The position of the United States as the largest economy and market in the world is changing. There is an evolution towards at least three major economies and markets—Europe, Asia-Pacific, and North America. As each market develops, other countries will emerge with increasing economic and technological strength. Accordingly, U.S. Army R&D elements based in these nations are being asked to assume a larger role in the building of this annex. The FY01 document was enhanced through the participation of the Army Research, Development, and Standardization Group–Canada. Cooperation of this type will expand in the future.

Also of increased importance is the role of industry to the Army. DoD has indicated that there will be a renewed emphasis on the developments being made in the private sector, both foreign and domestic. It appears likely that the focus of Army basic and applied R&D will be toward increasing cooperation with the private sector.

For the near term, the United States and our traditional allies will probably maintain a commanding dominance in the physical sciences and in electronics and computer hardware. This will perpetuate a worldwide abundance of devices, systems, and instruments, including sophisticated weapons. In other areas, however, an increasing number of countries will have world-class capabilities. In areas that do not require a large infrastructure, investment, or a well-educated population, many countries will contribute effectively to the global market. Software, for instance, is an area in which good mathematical skills and education are the primary ingredients, especially because powerful computers are becoming widely available. The life sciences, biology, chemistry, medicine, and behavioral science are other areas in which many countries have the requisite skills to compete effectively.

This annex provides the basis for building a strategic approach to international S&T cooperation. With the growing emphasis on coalition warfare, as seen in the past year, it is important not only to leverage global technology, but to keep the channels of communication open and viable. Given the widespread and increasing number of opportunities for technology leveraging—along with decreasing resources—it is important that the Army's approach to cooperation be both focused and productive.

6 Annex E Overview

Sections B and C provide brief overviews of the international opportunities in technology development and basic research, respectively. The technological capabilities identified have the potential to contribute to the objectives and milestones identified in each area addressed in Volume I, Chapters IV¹ and V. Within each S&T area, opportunities to address specific needs are also identified. Each specific opportunity includes a brief description and justification highlighting potential benefits of leveraging the international capability. Examples of foreign facilities and multinational programs with world-class efforts in areas of interest to the Army are also identified. Army Material Command (AMC) points of contact (POCs) and AMC major subordinate commands' international POCs (IPOCs) or project officers for each of the technologies and agreements are cited within the appropriate sections. More complete contact information for

¹The technology areas in this annex do not precisely match those of Chapter IV.

U.S. POCs is provided on the last page of this annex.

A summary, or trend, chart that reflects a general assessment of country capabilities is presented for each technology area. Although the ratings shown in these tables (see box) can never be precise, they do provide a general indication of the level of capability and therefore the relative priority of the opportunity in the technology or research areas. Countries with a four-diamond rating have capabilities generally on par with the United States. This implies that the country is a major contributor to global commercial device or system production, as well as databases and scientific literature. For example, in biomedicine, the pharmaceutical industry, medical diagnostics, food processing, and cosmetics industries represent the result of extensive economic investment by a nation. It is the combination of these capabilities, along with the demonstrated application of the technology and research toward areas of interest to the U.S. Army, that are reflected in a four-diamond rating. A single facility in a nation, be it developing or Third World, is not sufficient to identify the capability with four diamonds unless the facility is the site of world-class production or research in an area directly related to Army interests.

The other diamond ratings reflect increasingly lower capabilities. A three-diamond rating implies that a substantial breadth of capabilities may exist, but the defense goals or commercial production in the area are not present. These nations may have a number of small facilities working across the area, but not at the scale of world leaders. A two-diamond rating indicates that the country has strong niche capabilities in the area. Often this rating indicates the presence of a small research group doing world-leading work in a nation where other capabilities in the area are limited. The one-diamond rating applies to a fledgling attempt by a nation to develop indigenous capabilities without any clear near-term commercial or military impact.

These tables are examples and are not intended to be all inclusive. The lack of an entry does not necessarily indicate the absence of cooperative opportunities; instead, it may be an indication of a lack of available data. Like S&T development, however, the data available to build this annex are dynamic and are updated annually.

◆◆◆◆	The country has strong and broad capabilities in most aspects of the major technology or research area. The country is considered to have world-class capabilities in the identified major area.
◆◆◆	The country has significant capabilities in some aspects of the major technology or research area. However, the country does not have the breadth or depth or capability to challenge world leaders in the area.
◆◆	The country has capabilities in a few niche aspects of the major technology or research area, but does not have broad capabilities. However, the niche capabilities could beneficially contribute to U.S. Army S&T activities.
◆	The country has limited capability in the major technology or research area.
<i>Note: Major technology or research areas are subgroups of one of the primary technology or research areas (e.g., Mathematical Sciences is a primary scientific research area and Applied Analysis is a major research area).</i>	
+	Capability of country is increasing relative to global progress.
–	Capability of country is decreasing relative to global progress.
<i>Note: Trends are indicated only in cases where a significant capability change has been identified in a particular country.</i>	

B INTERNATIONAL COOPERATIVE OPPORTUNITIES IN TECHNOLOGY DEVELOPMENT

1 Aviation

Rotorcraft are of particular interest to the Army. Because of their ability to take off and land vertically and to operate efficiently and effectively at or below treetop level for nap-of-the-Earth missions, they offer a practical solution to many of the Army's operational needs. The operational flexibility afforded by vertical takeoff and landing (VTOL) capabilities has created growing civil and military markets, particularly in Third World nations. As a result, the helicopter industry has become highly internationalized and interdependent. Mergers and joint ventures have been, and will continue to be, in vogue. The West continues to dominate the rotorcraft industry. In addition to the capabilities in the U.S.—Canadian industrial base (Canada is closely aligned with the U.S. helicopter industry and therefore has similar capabilities), Germany, France, the U.K., Russia, and Italy are all capable of designing and producing state-of-the-art military rotorcraft. Additionally, helicopter programs are in place in other countries throughout the world (Japan, Malaysia, India, South Africa).

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Hindustan Aeronautics Ltd. in India has experienced continuing delays and uncertainties surrounding its Advanced Light Helicopter project. Technical problems with engine-to-frame mismatch have delayed the program. In Russia, MIL Helicopter is facing bankruptcy. If this happens, it could affect the joint venture, Euromil, of MIL and Eurocopter S.A.

Eurocopter [<http://www.eurocopter.com>], a Franco-German company, claims to be the world's largest helicopter company and holds a 40 percent share of the world's civil market. The company is also active in the military market and gave the go-ahead to produce the Tiger, an attack escort helicopter, at the Paris Air Show in June 1999.

Although rotary-wing production through 2003 is forecast to be essentially level, militaries worldwide are cutting back on the number of new helicopters they buy. Two trends are emerging: consolidation of helicopter assets and emphasis on multimission helicopters. Purchases of mission-specific helicopters will be severely limited by cost factors.

Competition for international military sales is intense, and marketing rights and export prospects have affected development decisions, particularly in international programs. Such market forces continue to push worldwide developments. Helicopter emphasis will be on initial and operating cost reduction. Table E-1 summarizes potential air platform opportunities for international cooperation.

a *Aeromechanics*

Aeromechanics technology includes multidisciplinary efforts in acoustics, aerodynamics, rotor loads, vibration, maneuverability, and aeroelastic stability. A number of efforts are focused on reducing noise and vibration. The main source of external noise is blade vortex interaction (BVI), which occurs when a blade hits the vortex shed by the preceding blade. Current efforts to reduce BVI include developing low-noise flight profiles. Modifications to the helicopter are farther out. Scientists are focusing on three areas to reduce noise: tail rotor, main rotor, and cabin.

TABLE E-1. TECHNOLOGY DEVELOPMENT—AVIATION

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
AEROMECHANICS						
◆◆◆◆ Rotorcraft design	◆◆◆◆ Rotorcraft CFD Bearingless rotor hub	◆◆◆◆ Rotorcraft Bearingless rotor hub	Japan ◆◆◆ Rotorcraft CFD BVI	◆◆◆◆ Rotorcraft design	◆◆◆◆ Rotorcraft design	Italy, Israel ◆◆◆ Aeromechanical design
FLIGHT CONTROL						
◆◆◆◆ Fly-by-wire M&S Active control	◆◆◆◆ Adaptive controls Fly-by-light	◆◆◆◆ Fly-by-light	India ◆◆ Adaptive controls	◆◆◆◆	◆◆◆ Fly-by-wire	Sweden ◆◆◆ Adaptive controls Netherlands ◆◆◆◆
STRUCTURES						
◆◆◆◆ Composites Smart structures	◆◆◆◆ + C-C matrix ceramic Crash survivability ◆◆◆◆ Smart structures High temperature structures	◆◆◆◆ Smart structures Fatigue & fracture analysis	Japan ◆◆◆◆ + Ceramics Composite materials & structures Korea ◆◆◆ Smart materials & structures India ◆◆ Composites	◆◆◆ Ti & steel alloy struc- tures	◆◆◆ Smart structures Fracture/fatigue analysis	Italy, Switzerland ◆◆ Smart materials & structures
SUBSYSTEMS						
◆◆◆◆ FADEC Direct voice input	◆◆◆◆ FADEC Advanced light- weight armor	◆◆◆◆ Advanced cockpit systems & integra- tion	Japan ◆◆◆ Avionics	◆◆◆◆ Cargo handling Ceramic armor	◆◆◆◆ FADEC	Israel ◆◆◆ Advanced cockpit systems Lightweight armor
ROTORCRAFT PROPULSION/DRIVES						
◆◆◆◆ High performance transmission Advanced turbine design	◆◆◆◆ High-temperature structures Rotorcraft propulsion	◆◆◆◆ Composite & high- strength alloy shafting High-temperature gas turbines Rotorcraft propulsion	Japan ◆◆ Ceramics	◆◆◆◆ Small gas turbines High-temperature structures	◆◆◆◆ + Wind tunnel test facilities	Israel ◆◆ Small gas turbines
FUELS & LUBRICANTS						
◆◆◆ Coatings, hydraulic fluids & seals	◆◆◆ High-temperature lubricants, coolants & seals	◆◆◆ High-temperature lubricants, seals & coatings	Japan ◆◆◆ Seals & coatings			

Note: See page E-6 for legend.

Most of the effort is being concentrated in the main rotor, with individual blade control gaining more favor than higher harmonic control.

The French research organization, Office National d'Études et de Recherches Aéropatiales (ONERA) [<http://www.onera.fr/english.html>] and German Deutsche Zentrum für Luft- und Raumfahrt e.V. (DLR) (Aerospace Research Establishment) [<http://www.dlr.de/>] are working on noise and vibration reduction, enhanced operating performance, and day/night, all-weather operations.

By adopting special features for the tail rotor, such as unequally spaced blades, advanced airfoils, modified blade taper, blade tip shapes, and blade tip speeds within the context of a “Fenestron” fan-in-fan design, noise from the source has been considerably reduced; the EC-135 employs these enhanced features. Engineers are now looking at additional Fenestron noise reductions. Eurocopter, with the Technical University of Aachen [http://www.rwth-aachen.de/zentral/aguide_english_default.htm] in Germany, has devised a network of Helmholtz resonator passive-noise absorbers that they believe can resolve the problem.

The British Defence Evaluation and Research Agency (DERA) possesses a full range of rotor and control system modeling, simulation, and test and experimental facilities in the complex field of helicopter aeromechanics [<http://www.dra.hmg.gb>].

The National Aerospace Laboratory (NAL) in Japan [<http://www.nal.go.jp>] has performed work on the calculation of rotor BVI noise using parallel supercomputers.

Eurocopter is working on an advanced technology rotor with better aerodynamics, simpler blade attachments, and new materials. The use of a new fiber/matrix system with R-glass for the spar and cost-efficient 6K carbon fiber for the blade planking is thought to offer shorter production times and curing cycles, as well as better material characteristics.

b Flight Control

Flight-control technology defines the aircraft’s flying qualities and the pilot interface. Helicopters are inherently unstable, nonlinear, and highly cross coupled. Advances in smaller, more powerful computers hold tremendous promise for realizing the full potential of the rotorcraft’s performance envelope and maintaining performance even in poor weather and at night. Integrating flight control with weapons control to permit improved pointing accuracy and the use of lower cost, unguided rockets as precision munitions are of great interest. Other goals include improved external load handling at night and increased exploitable agility and maneuverability.

DLR (Germany), the German Ministry of Defense, Eurocopter [<http://www.eurocopter.com>] Deutschland, and Liebherr Aerospace Lindberg [<http://www.liebherr.com>] have designed a flying EC-135 testbed that incorporates advanced rotor and fly-by-light control technologies (along with state-of-the-art avionics concepts). They also have finalized the design of the combined active control technology (ACT) demonstrator/flying helicopter simulator. ACT is the enabling technology for improved performance and flying qualities of aircraft. Ongoing ACT research at DERA (U.K.) is identifying improvements in performance and reductions in attrition in future military helicopters.

To improve simulation modeling and control law design, DERA conducts high-fidelity experiments in flight using ground-based simulation, supplemented by in-depth theoretical studies. In addition, two facilities are operated for research into flying qualities and control: Aeromechanics Lynx Control and Agility Research Testbed (ALYCAT), and the Advanced Flight Simulator—a high-fidelity, ground-based simulator.

c Structures

Structures programs aim at improving aircraft structural performance while reducing both acquisition and operating costs. Virtual prototyping to optimize structural design for efficiency and performance is of particular interest as a means to remove a large portion of the risk involved in exploring new concepts and moving rapidly from concept to production. An inte-

grated product and process development approach will be used. Other areas of interest include reducing both dynamically loaded structural stress prediction inaccuracy and the production labor hours per pound for composite structures. Breakthroughs in these and other areas will lead to improvements in maintenance and production costs, as well as reduction of the empty weight fraction of the airframe, while increasing durability, performance, and ride comfort.

Advanced composite structures and fly-by-wire/-light are becoming common in international aircraft. Technologies for military systems reside primarily in the few countries that produce military helicopters. Predominant among these are France, Germany, the U.K., and Italy. Britain has strong capabilities in composites and smart structures; crash survivability is an area of special interest. France's expertise is generally on par with the United States in this area. Survivability depends on a number of factors, including equipment performance, which may be enhanced by more efficient design and testing of aircraft structures. Of particular interest is the testing of advanced structural concepts and manufacturing processes for composite and thermoplastic materials for primary helicopter airframe structures. Canada has strong capabilities in fracture/fatigue analysis, Russia in titanium (Ti) and steel alloy structures, and Japan in ceramics and composite materials.

DERA does significant research and experimentation in rotorcraft technology [<http://www.dra.hmg.gb>] that covers all aspects of aerodynamics and aeroelastic research into composite blade structures for optimum performance. The research addresses the structural design of blades, model performance trials and evaluation, validation of the theory and analysis of external noise research, and structural acoustics, including noise path identification and advanced statistical energy analysis. Scale rotor experiments are undertaken at a major hover test facility, where DERA also assesses rotor blade icing and the overall operational performance of rotorcraft. MSC.Nastran and MSC.Dytran finite-element-analysis software, various pre- and post-processors, and Structural Analysis and Redesign System structural design optimization packages are available.

DERA is at the forefront of research into lightweight material technologies. This research aims to reduce the observability and weight of airborne structures while providing high strength. High-temperature operation is also important, especially for future high-performance engines.

Virtually all countries with any level of industrial development have national nondestructive evaluation (NDE) organizations and some level of university research. The following highlight some of the more relevant capabilities identified:

- *Germany*—The helicopter manufacturer Messerschmitt-Boelkow-Blohm (MBB) is an active participant in a number of Basic Research for Industrial Technologies in Europe—European Advanced Materials (BRITE/EURAM) initiatives related to NDE for composite structures.
- *Italy*—Particularly relevant effort is directed toward NDE for composite materials and toward rotorcraft applications. Among the key players in government and academia are the Italian Center for Aerospace Research and the University of Rome. In the private sector, Ispra appears to be heavily engaged in a wide range of research activities, including laser ultrasonic techniques and the use of combined acoustic emission and thermographic techniques. Italy is also a partner in BRITE/EURAM projects in which the Italian helicopter manufacturer Agusta has the lead. (As noted, other participants in these programs include MBB (Germany) and Westland (U.K.). Fiat Aviazione is also reported to be working in composite material NDE.)
- *United Kingdom*—Extensive research is conducted in areas of NDE relating to aerospace applications. The British Institute for Nondestructive Testing and a number of government and university centers of research are very involved. Work at the University of Strathclyde, Glasgow, Ultra-

sonics Research Group is often cited as world class by other researchers. In the private sector, the U.K. helicopter manufacturing firm Westland is actively involved with BRITE/EURAM activities, principally in cooperation with Agusta (Italy) and MBB (Germany).

- *France*—ONERA and Aerospatiale have active research in composite materials and NDE, and work in impact damage to polymer-based composite at Aerospatiale may provide access to empirical data. French organizations do not appear to be as well represented in the BRITE/EURAM programs or as extensively referenced by researchers in other countries.
- *Japan*—Much of the NDE-related work in Japan is focused on microelectromechanical systems (MEMS) and on composite materials with novel electronic or optical sensing properties. These areas directly related to rotorcraft NDE include (1) eddy current and electrical potential measurement inspection techniques for detecting delamination defects in carbon fiber reinforced plastics and graphite-epoxy structures, (2) sensor techniques for monitoring of airframe repair patches, and (3) research in applications of optical fibers for structural monitoring and fault detection.
- *Canada*—Work at the Institute for Aerospace Research (IAR) under the Canadian National Research Council is developing NDE techniques, including what is described as a “highly portable” ultrasonic scanning system capable of real-time evaluation of an area of 0.45×0.45 meter. There may be operational advantages to areal measurements (as opposed to testing at specific points), particularly if the size can be extended to several meters to permit inspection of large portions of an airframe.
- *Korea*—Although specific expertise in NDE has not been identified, much of the Korean academic research in smart materials and structures is directed toward technologies for rotorcraft applications. These may provide useful information for characterizing airframe response and for design of embedded actuators and sensors to support more advanced NDE capabilities in the future.

An area of specific interest to the Army is the application of smart materials and structures to rotorcraft.

- *Germany*—Germany is one of the European Union (EU) leaders in smart materials and structures and an active participant in EU-sponsored programs. German academic and research work generally recognized in the field includes (1) University of Saarlandes and the Technische Hochschule at Darmstadt, both of which participate in the University of Patras program in generic smart surfaces for vibration and acoustic control; and (2) Fraunhofer Institute for Ceramic Technologies and Sintered Materials [<http://www.ikts.fhg.de>] in Dresden conducts an extensive program of research in piezoelectric ceramics and new applications of such materials in various technical areas.
- *United Kingdom*—Both academia and private industry participate in smart materials and structures programs. Participation in the BRITE/EURAM-sponsored activities pertinent to smart structures provides an insight into the breadth and depth of U.K. capability. The EU has funded development of advanced electrorheological fluids and devices at the University of Hull. Hull is a participant in the BRITE/EURAM-sponsored work in the optimization of smart structural connections for vibration and noise control. Work in applications of electrorheological fluids for vibration control and isolation is also reported in the U.K. at the University of Manchester and Gordon University.
- *Italy*—Substantial research in sensing and smart structures is centered throughout government, academic, and private industry participants. Much of the work in materials and sensors is directed toward NDE. However, much of the underlying technology, such as the BRITE/EURAM III initiative in magnetostrictive actuators for damage analysis and vibration control at the University of Naples, is directly applicable to smart structures. This work is of interest because it may develop alternatives to the piezoelectric and other electroactive ceramic techniques being stressed by other centers, particularly in applications requiring high authority over a wide frequency range. The Italian Center for Aerospace Research is a participant in the BRITE/EURAM III project in active vibration control of surfaces headed by the University of Patras (Greece).
- *France*—Research programs in vibration control and NDE are conducted by government institutes, academic institutes, and private industry, all of which participate actively in European

research initiatives relating to smart materials and structures. At this juncture, they do not appear to be applying the technology as aggressively as the U.K., Germany, and Italy.

- *Canada*—The Canadian National Research Council conducts and coordinates a wide range of programs in basic materials (including rheological studies and piezoelectrics), as well as related work in vibration analysis and control applicable to characterization of smart structures. The Center for Research in Earth and Space Technology reports an effort in smart adaptive structures focused on potential applications to aircraft, bridges, space structures, and pressure tanks. The development of fiber-optic sensors that are integrated with a host structure are a precursor to the broader development of smart adaptive structures.
- *Japan*—Cited as being on par with the United States as a world leader in smart materials and structures, Japanese research areas of interest include smart polymeric composites with applications to infrastructures and ground and aerospace vehicles; shape memory alloy (SMA) materials and their composites; smart materials based on the coupling behavior between physical and mechanical phenomena; piezoelectric, piezoresistive, magnetostrictive, and their composite materials and structures where the stress and strain are key driving or resulting parameters; and novel electronic and optical composite materials with unique sensing capabilities. Much of Japan's most advanced capability is directed toward MEMS and electronic sensor applications.
- *Switzerland*—The work at the University of Lausanne covers a wide range of topics of interest, including work in the bismuth titanate family of piezoceramic materials (which are of interest for high-temperature applications) and in lead zirconate titanate for high-frequency use. In addition to basic materials, other research includes fabrication technology (for piezoelectric and ferroelectric microtubes), application of thick-film screen printing techniques to fabricate zirconate titanate sensors and actuators, and development of smart structures. Here, Swiss researchers report better than 20-dB active vibration damping in composite metal-ceramic structures. The Ecole Polytechnique Federale de Lausanne is also cited as a contributor to the BRITE/EURAM-sponsored British Aerospace, Plc., investigation of MEMS for boundary layer control in airfoils.
- *Greece*—One of the more interesting and relevant of the BRITE/EURAM efforts is investigation, headed by the University of Patras, of generic approaches to active vibration control of smart surfaces. This work is directed at the use of artificial neural networks (ANNs) and genetic algorithms for smart structure controls for a variety of aerospace and industrial applications.
- *Korea*—Both the Pohang University of Science and Technology (POSTECH) in Pohang, South Korea [<http://www.postech.ac.kr/e>] and the Seoul National University conduct research programs in smart structures. Topics include the use of electrorheological fluids for damping and integration of feedback control and advanced composite material technologies with the design of high-performance structural systems. The stated objectives of the research are to design and develop structures that are adaptable and responsive to external disturbances, especially for aerospace applications. POSTECH appears to be a center of Korean research in rotorcraft technology.

d Subsystems

Rotary-wing vehicle subsystems encompass a broad range of S&T topics related to support, sustainment, and survivability of aircraft systems and their associated weaponry. Germany, Japan, and Israel all have strong capabilities in advanced cockpit systems, but the German work on cockpit integration is of special interest. The U.K. is doing significant work on full-authority digital engine control (FADEC). Japan has strong capabilities in avionics, based on its significant electronics capability.

Lightweight armor for rotorcraft is an area of particular interest to the Army. Japan, Germany, the U.K., and France have been identified as having the capability for producing advanced armor systems. Russia has been a traditional force in armored systems and in bulk ceramics. The materials are widely available, and other countries—notably the Netherlands, Israel, China, Sweden, and Switzerland—have sufficient experience and resources to develop effective systems. Applications of ceramics or fibers to armor systems can be found in Germany, the U.K.,

France, the Netherlands, China, and Israel. Israel has extensive experience in armor design and testing and has a number of firms actively involved in developing and marketing lightweight armor.

Israeli capabilities represent an example of the type of activity and products occurring in many countries. Rami Ceramic Industries advertises a wide range of armor products, including lightweight ceramic armors for helicopters. They advertise lightweight, impact-resistant ceramic plates capable of meeting stringent military standards (U.S. National Institute of Justice (NIJ) Std 0101.02 and 0108.01 and MilStd.662D).

e Rotorcraft Propulsion/Drives

Propulsion, drive train, and power transfer research is required to lower weight, volume, noise, and increase durability. The U.K. has strong capabilities in high-performance power transmission technologies. DERA has an experimental capability for validating the theoretical methods and exploring the application of advanced technology rotor systems. This capability is provided by a Mach-scaled model rotor rig that, combined with a purpose-built hover facility used with the DERA 24-foot and 5-meter wind tunnels, forms an integrated test capability covering the flight envelope of the helicopter.

France has expertise in bearingless rotor hubs, as does Germany. Germany also has noteworthy capabilities in composite materials and high-strength alloy shafting. The Sadlier VTOL Aircraft Company Pty., Ltd., of Australia is considering a vertical takeoff aircraft that would combine the properties of fixed-wing and rotary-wing aircraft. It has a fan in the wing and a rear fan. It employs a diamond-shaped lift system with a single lift rotor at the center of the fan.

Unmanned aerial vehicles (UAVs) contribute to the military's effectiveness by providing tactical and strategic reconnaissance. The number of countries using UAVs or funding development programs or both has doubled since 1991. There is a mix of large and small industry players, partly because of increasing strategic alliances, industrial cooperation, and teaming arrangements.

- *France*—CAC Systems has teamed with Dragonfly (Italy) to produce the Heliot unmanned helicopter system with a 100-kg pod payload. In addition to cooperative work with the U.S. Air Force Research Laboratory on an unmanned combat air vehicle (UCAV), ONERA is working on exploratory studies for a high-altitude, supersonic, stealthy UAV for reconnaissance and electronic warfare.
- *Germany*—UAVs are used for reconnaissance and for communications jamming at up to 100-km. Schiebel Technology, Inc., has demonstrated its Camcopter airborne optical minefield survey system, which for over 2 years has detected buried landmines 2–6 inches deep with a gimbaled IR camera.
- *United Kingdom*—DERA is developing a remote minefield detection payload for the Phoenix UAV system, which entered service in December 1998. Other payloads envisioned include a miniature synthetic aperture radar, multispectral IR/visual imager, laser designator for attack helicopter targeting, and acoustic/chemical sensors. DERA is also looking at UAVs as potential communications relay platforms.
- *Canada*—Orenda Aerospace and the Department of National Defence are developing an engine-life management system, including structural and thermal models, that is geared to optimizing maintenance and repair schedules for aircraft.

All conventional rotary-wing aircraft have a forward speed at which drag, vibration, and loss of lift reach unacceptable levels, limiting any further increase. One approach to dealing with this

problem is to tilt the rotors through a right angle so that for vertical takeoff they are horizontal until sufficient height is attained. Transition to forward flight is achieved by tilting the rotors to the horizontal. In forward flight, the fixed wing provides lift. To enable increased loads to be carried, the rotors may be set at a midway position, clearing the ground, so they provide both thrust and lift, while the fixed wing also provides lift. Thus configured, a very short takeoff run is needed to appreciably increase lifting power.

A significant advantage of the tilt-rotor layout over the helicopter is that, whereas the rotor blades of a “pure” helicopter must have relatively little twist (the difference between root and tip angles-of-incidence)—say, about 12 degrees—the blades of a tilt-rotor aircraft may have as much as 40 degrees twist. Thus, these blades are very efficient whether generating lift for vertical flight or hovering or thrust for forward flight.

The proof of the efficacy of the tilt-rotor configuration is that, of all the design layouts tested with prototypes, only the helicopter, vectored-thrust fighter, and tilt-rotor have entered production. In late 1987, the European Eurofar tilt-rotor project was launched as a preliminary plan by Eurocopter (France and Germany), Aerospatiale (France), Agusta and Alenia (Italy), Westland in England, and CASA in Spain. The specification was for a 30-passenger commercial aircraft with a range of 664 nmi (1,230 km) at a cruising speed of 335 knots (620 km/hr). The project was backed by extensive wind-tunnel aerodynamic and aeroelastic testing, simulated flight control, and a full-scale, pressurized fuselage cabin section.

Matching U.S. plans, a Eurofar civil tilt-rotor aircraft—smaller than a derivative of the Osprey—could be flying within 12 years. This would require the Eurofar demonstrator to fly in 2004 and the ground-test article (Iron Bird) to begin spin-up tests 2 years earlier.

f *Fuels and Lubricants*

The Army’s main interest in the fuels and lubricants subarea is the development and validation of new analytical technologies. Of particular interest are techniques for rapid assessment of petroleum quality using spectroscopic and chromatographic methods. New analytical methods will enable a significant reduction in operational requirements for petroleum field tests. This includes less manpower, test time, and test hardware. Technical challenges relate to compressing testing time, developing improved detection systems, correlating testing results, and developing computer-based expert systems. In this subarea, France and Germany are the only countries found to have special capabilities, both in the area of high-temperature lubricants.

All countries engaged in the operation of military weapons and systems use fuel and lubricant technologies to some degree or another. To a great extent, civil sector products can be used successfully in military systems but not at the outer bounds of their operational envelopes. Much of the work involved in development and production of these materials depends on a sophisticated chemical industry. Thus, all industrialized nations, and many developing ones as well, have capabilities in special functional materials. Particularly noteworthy are France in engine coolants, lubricants, and seals; Germany in seals and coatings; the U.K. in coatings, hydraulic fluids, and seals; and Japan in seals and coatings. These countries can approach or duplicate U.S. technology in these areas.

g Example Research Facilities

The following facilities have demonstrated expertise in aviation technology development:

- Japan—National Aerospace Laboratory [<http://www.nal.go.jp>]
- France—The French Aeronautics and Space Research Center, ONERA [<http://www.onera.fr/english.html>]
- Canada—Institute for Aerospace Research [<http://www.nrc.ca/iar>]
- Europe—Eurocopter [<http://www.eurocopter.com/>]

2 Command, Control, Communications, and Computers

Several approaches are being considered for Information Systems, each of which (if ultimately realized) is likely to offer advantages for different applications. High-performance computing (HPC) and scalable parallel systems are of particular importance. For example, optical processing techniques combine elements of both and are being pursued as a means of increasing inherent parallelism and computational throughput. Further, software advances are seen as a way to allow aggregation of very large numbers of computing elements. Both of these approaches lend themselves to solving complex deterministic problems (i.e., problems for which a sequence of calculations to reach a specific solution can be defined). Contrast this to neural networks, which provide a better way of attacking less determinate problems.

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Even though military applications will increasingly rely on COTS products, there remain unique requirements for which technological advances in computing hardware and software will be required. These advances fall into the realm of HPC, the so-called “grand challenge,” which requires trillions of floating point operations per second (teraFLOPS). This section partitions Information Systems into three areas (which are further subdivided): computers and software technology; command, control, and communications; and modeling and simulation.

Integration and demonstration of technology in the field are significant challenges. Widespread mass market availability of low-cost computers of unprecedented power and global connectivity over the Internet has led to rapid expansion and proliferation of information system technologies. COTS software is also readily available throughout the world, some of it being customized to large applications.

HPC is an area of international R&D. In addition to France, which is recognized as a world leader in photonics, Japan and Russia have had strong programs in optical computing. Germany has a growing interest and has strong capabilities in production of photodynamically active bacteriorhodopsin films that may be an enabling technology for future optical/molecular computers. Israel has a small but sound and growing electro-optics infrastructure as well. The growth of the Internet and multimedia are producing growing demand for development and global implementation of very high-speed digital networks. Development of these is an international activity, with cooperation among major telecommunications firms. One example is the Japanese Real-World Computing program, which includes a number of other countries as participants. Table E-2 summarizes international information systems technology capabilities.

TABLE E-2. TECHNOLOGY DEVELOPMENT—COMMAND, CONTROL, COMMUNICATIONS, AND COMPUTERS

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
COMPUTERS & SOFTWARE TECHNOLOGY						
HIGH-PERFORMANCE COMPUTING & SCALABLE SYSTEMS						
◆◆◆◆ MPP	◆◆◆◆ Optical processing	◆◆◆◆ MPP	<i>Japan</i> ◆◆◆◆ <i>China</i> ◆◆+ <i>Taiwan</i> ◆◆	◆◆— Optical processing		
NETWORKING						
◆◆◆◆ Optical switching	◆◆◆◆ Fiber optics	◆◆◆◆ Fiber optics	<i>Japan</i> ◆◆◆◆ Optical switching <i>China</i> ◆◆ Fiber optics		◆◆◆◆ Optical switching	<i>Israel</i> ◆◆ Fiber optics
SOFTWARE ENGINEERING						
◆◆◆◆	◆◆◆	◆◆◆◆ MPP	<i>India</i> ◆◆◆ CASE		◆◆◆◆ CASE	<i>Israel</i> ◆◆◆ CASE
ARTIFICIAL INTELLIGENCE						
◆◆◆◆	◆◆◆◆	◆◆◆◆	<i>Japan</i> ◆◆◆◆	◆◆	◆◆◆	
COMMAND, CONTROL, AND COMMUNICATIONS						
HUMAN-COMPUTER INTERFACE						
◆◆◆◆ Visually coupled systems	◆◆◆◆ Visually coupled systems	◆◆◆◆ Visually coupled systems	<i>Japan</i> ◆◆◆ Visually coupled systems		◆◆◆◆ Visually coupled systems	<i>Italy</i> ◆◆◆ <i>Israel</i> ◆◆◆
SEAMLESS COMMUNICATION						
◆◆◆◆ Battlefield interoperability	◆◆◆◆ Battlefield interoperability	◆◆◆◆ Battlefield interoperability, international interoperability	<i>Japan</i> ◆◆◆◆ Fuzzy logic High-speed communications <i>ROK</i> ◆ Systems interoperability		◆◆◆ Tactical interoperability	
INFORMATION MANAGEMENT ASSURANCE AND DISTRIBUTION						
◆◆◆ Natural language processing	◆◆◆ Machine translation	◆◆◆◆ Natural language processing, machine translation	<i>Japan</i> ◆◆◆◆+ High-speed switching <i>ROK</i> ◆ Data fusion		◆◆◆ Advanced data display	<i>Netherlands</i> ◆◆◆ Natural language processing Database science

TABLE E-2. TECHNOLOGY DEVELOPMENT—COMMAND, CONTROL, COMMUNICATIONS, AND COMPUTERS (CONT'D)

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
DECISIONMAKING						
◆◆◆◆ Mission planning	◆◆◆◆ Mission planning		Japan ◆◆◆◆ Fuzzy logic			Israel ◆◆◆◆ Battle management
MODELING & SIMULATION						
SIMULATION INTERCONNECTION						
◆◆◆◆+ Distributed information systems	◆◆◆◆ Distributed information systems	◆◆◆◆+ Distributed information systems	Japan ◆◆◆◆+ Distributed enterprises			NATO ◆◆◆◆+ Australia, New Zealand ◆◆◆◆
SIMULATION INTERFACES						
◆◆◆◆+ VR	◆◆◆◆+ VR	◆◆◆◆+	Japan ◆◆◆◆+ VR		◆◆◆◆+ VR, 3D	
SIMULATION INFORMATION						
◆◆◆◆+ Dynamic training	◆◆◆◆ Dynamic training	◆◆◆◆+ Battle M&S	Japan ◆◆◆◆+ VR		◆◆◆◆ Battle M&S	Netherlands ◆◆◆◆ Battle M&S
SIMULATION REPRESENTATION						
◆◆◆◆	◆◆◆◆	◆◆◆◆	Japan ◆◆◆◆ Distributed enterprises		◆◆	Netherlands, Switzerland ◆◆

Note: See page E-6 for legend.

a Computers and Software Technology

The United States dominates and is projected to continue to drive the state of the art in HPC; Japan has strong capabilities. The United States has pioneered a variety of technologies for scalable, distributed processing based on U.S. microprocessor designs in which computational power continues to double approximately every 18 months. These configurations now dominate the market. Availability of an affordable HPC capability has also led to a growing level of international interest and work in intelligent systems and human-computer interfaces.

Massively parallel processing (MPP) and neural network programming could be applied to numerous applications covered by ASTMP milestones and objectives. Modeling and simulation are examples of applications requiring the computing speed and power offered by MPP techniques, while neural network programming may be more useful in the development of decision aids. MPP and neural network programming are important aspects of the Army's electronic battlefield concept. MPP will contribute significantly to simulation and VR components of the electronic battlefield. Only a few countries have the supporting infrastructure necessary for major R&D in these technologies. World leaders include the United States, Japan, Germany (with whom an active data exchange agreement exists), and to a lesser extent the U.K. and France.

Military requirements for processing real-time signals and imagery data severely challenge existing computing capabilities. Optical processing offers potential advantages for these

applications and is an important area of technology development where other nations have world-leading capabilities.

1) High-Performance Computing and Scalable Systems

Mass market availability of low-cost network switching and powerful microprocessors resulted in rapid proliferation and expansion of capabilities for HPC. Nearly all of the requisite knowledge and software technology required for clustering computers to achieve high performance is in the public domain. For example, the NASA-supported Beowulf program provides access to detailed guidance and software for assembling a computing cluster; the software itself can be downloaded.

As a result of the increased accessibility of the technology, the number and diversity of activities involved in HPC have increased dramatically. The following paragraphs highlight some specific examples of recognized centers of excellence in HPC research.

In France, the Institut National de Recherche en Informatique et en Automatique (INRIA) is the primary focus of computing research. Primary research is organized in five major strategic areas: control of distributed computer information, programming of parallel machines, development and maintenance of safe and reliable software, construction of systems integrating images and new forms of data, and analysis, simulation, control, and optimization of systems.

The German National Research Center for Information Technology (GMD) oversees and coordinates research in a number of areas of interest, including basic architecture and software research, autonomous intelligent systems, scientific computing, and distributed collaborative computing. The Universities of Mannheim, Karlsruhe, and Paderborn are all recognized centers of excellence in HPC.

The European Research Consortium for Informatics and Mathematics (ERCIM) comprises leading research establishments from 14 European countries. ERCIM aims are to foster collaborative work within the European research community and to increase cooperation with European industry. ERCIM's collaborative activities also extend beyond the EU. The European Commission has awarded ERCIM a grant to coordinate an EU-China industrial cooperation initiative in HPC. The initiative is also partially financed by the Chinese government through China's National Research Center for Intelligent Computing System (NCIC), with additional funding coming from European and Chinese industry. The goal is to promote Sino-European cooperation by raising Chinese awareness of EU technologies and expertise and to inform the EU business community about market opportunities in China. Participants in relevant European Strategic Program for Research in Information Technology (ESPRIT) projects will be invited to take part. This HPC initiative is part of a range of EU-China industrial cooperation activities in S&T now being organized under the auspices of the Chinese government and the European Commission.

The NCIC was founded in March 1990 under the leadership of the Steering Committee of National High-Tech R&D Program (the so-called 863 program) on Intelligent Computing System. NCIC's R&D activities in HPC include parallel and distributed computers and fundamental research on high-performance computers and intelligent computing systems, especially in the area of natural language interface. Although one of NCIC's goals is to develop competitive commercial computer products, results to date appear better suited to developing a fundamental understanding of the underlying technology than global commercial competition. The

“Dawning” family of parallel computing hardware trails the state of the art in terms of its embedded microprocessor and interconnect technologies. However, as research tools, these projects have provided a foundation for investigating effective parallel computing methods.

Research that may have application for the Army is intelligent machine translation research within the areas of theoretical research, system design, and product development of intelligent machine translation systems.

High-Performance Computing Facility, University of Victoria
Multimedia Advanced Computational Infrastructure, University of Alberta
University of Calgary, University of Lethbridge, University of Manitoba
Physical Science Computer Network, University of Toronto
Interdisciplinary Research Facility for Innovative Applications of Information Technologies, Concordia University
Réseau Québécois de Calcul de Haute Performance, Université de Montréal, Centre de Recherche en Calcul Appliqué, Université de Sherbrooke, with research centres at École polytechnique, McGill University, Université de Québec à Montréal, and Concordia University
Advanced Computation and Visualization Centre, Memorial University of Newfoundland, University of New Brunswick (Fredericton), University of Prince Edward Island, St. Francis–Xavier University

Canada has a strong initiative in distributed HPC. The Canadian telecommunication firm Nortel is a world leader in fiber-optic switching technology, and Canada has established what is advertised as the world’s first national optical R&D network, CA*net3. C3.ca is a 7-year plan to build a computational infrastructure that supports globally competitive R&D. Canada’s HPC community includes research facilities worth over \$70 million. The project will receive \$23 million in capital from the Canada Foundation for Innovation. Six universities and regional consortia, which are all C3.ca members, were approved for Canada Foundation for Innovation funding to establish facilities for computation and visualization,

including approximately a dozen parallel, shared memory, and vector systems for advanced computing and six new multimedia visualization centers.

Research initiatives of interest to the Army include parallel/distributed intelligent agents, virtual prototyping M&S, and a wide range of software research activities in parallel and distributed computing.

2) Networking

Optical-processing techniques are well suited for analysis of data generated by these high-volume throughput applications. The development of photonic devices necessary for optical computing is of significant interest to the U.S. Army and has numerous military applications. World leaders in photonics/EO include the United States and Japan, followed by France, the U.K., and Germany. Before the breakup of the FSU, Russia and its allies had a rigorous program in biomolecular/optical computing. The apparent intent of this effort was to develop a leap-ahead technology to overcome the commanding U.S. lead in conventional digital computing. Although the military imperative for this has diminished, the technological capabilities may still be of interest.

The network throughput demands of international telecommunications firms are primary drivers of the state of the art in most networking areas, among them fiber-optic communications and optical switching (including wave division multiplexing techniques). All of the major telecommunications producing nations—the United States, the U.K., Japan, France, Germany, and Canada, followed closely by China and Israel—have good capabilities in fiber-optic networks. The implementation of the 5–10-Gbps fiber-optic cable that will link Europe and intermediate points in Africa and Asia with Japan will almost certainly speed proliferation of this technology.

While Japan and selected regions of Europe may lead in deployment of high-speed, fiber-optic cables, implementation in other areas is limited primarily by economic considerations rather than by technology. In the critical area of switching, the United States, Canada, and the U.K. have the strongest technological positions, followed very closely by Germany and France.

Comprehensive management of networks is very important. The integration of data and telecommunications networks—from narrowband to broadband, terrestrial to satellite, fixed to mobile—used for standard and advanced multimedia communications is a growing need. Commercially, there is a new emphasis in electronic commerce, federated systems, and end-to-end management of distributed services. The Army has a greater need for network survivability, fault tolerance, and availability than most commercial users, but the demand is rising for these attributes in some commercial sectors, such as banking and stock trading. Even more than commercial sectors, the Army has a high demand for technologies to provide communications in a degraded mode, such as under battlefield and crisis situations. Thus, not all technologies to support Army networks can be drawn strictly from commercial sources. Adversaries often are better able to operate in degraded mode because they lack dependence on modern technology. Dynamic management and resource allocation are key to providing Army superiority.

3) Software Engineering

International software developments are enabled by widespread availability of very powerful microprocessor-based, symmetrical multiprocessing systems. A number of countries, including Israel, India, and Russia, are actively engaged in commercial cooperative software developments.

One key to achieving Army goals for M&S is the implementation of advanced algorithms in software, specifically for MPP. Only a few countries possess the supporting infrastructure necessary for major R&D in this area. World leaders include the United States, Japan, Germany (with whom there is an active agreement), the U.K., and France.

Software engineering development methodology is primarily a U.S. area of research. However, software development processes have proven to be more profitable commercially than new research in methodology. Thus, countries that have a culture of strict adherence to process are better able to produce quality software than many U.S. companies. A notable example is India.

4) Artificial Intelligence

Machine intelligence is an underlying technology for many advanced HCIs. Topics such as natural language processing, intelligent adaptive data visualization, and others properly fall into both categories.

AI (or machine intelligence or intelligent systems) is an area of worldwide research interest. One area that is particularly promising for international collaboration is artificial neural networks (ANNs) (e.g., the optical ANNs being pursued by Japan as part of the Real-World Computing (RWC) program initiative). Another area is the application of AI to so-called intelligent agents for collecting information and managing operations in a distributed battlefield C⁴I and information system. For example, Australia has a particularly strong presence and activity on the Web. Much of the work is theoretical in nature, and many of the problems are tractable with modest computing power that is widely available in the commercial market. This active and effective research in AI can be found in most developed or developing countries. Much of this work is being driven by the Internet or by requirements for managing and administering extremely

large, complex telecommunications systems. In addition to work in the United States, which is the world leader in this area, Japan's RWC initiative has a strong component of AI. Strong capabilities in intelligent agents also reside in the U.K. and Germany, followed closely by France.

Foreign countries with the highest potential for implementing AI and intelligent systems are those that have a strong background in systems technologies, AI logic, and enabling technologies: Japan, the U.K., France, Germany, followed closely by the Netherlands and Canada, and to a lesser extent Sweden. Other countries with niche capabilities in specific areas that might provide cooperative program opportunities include Israel; other European community (EC) countries, such as Italy and Belgium; and Pacific Rim nations, such as Australia, Korea, New Zealand, Singapore, and Taiwan.

Japan has significant capabilities in AI. The most prominent efforts are the Fifth-Generation Project and the RWC program. The developmental side of the Fifth-Generation effort took place at the Institute for New-Generation Computer Technology, using PROLOG and specially designed hardware. Although the effort resulted in world-class capabilities in constraint programming (logical programming used for solving nonlinear problems) and nonlinear programming, it had little impact on the development of intelligent systems because of the rapid advance in general-purpose computing and growth in the use of C and other languages for implementing intelligent capabilities.

Japan's Ministry of International Trade and Industry initiated a major effort in 1992 with the RWC program. This 10-year, \$500 million program emphasizes development of technologies matching human capabilities in information processing, namely pattern recognition and handling of incomplete information. Research is aimed at four areas: novel functions (e.g., fuzzy logic, neural logic, genetic algorithms), theoretical applications, massively parallel and distributed computing systems, and optical computing systems. Unlike the Fifth-Generation Project, the RWC program is an international effort involving the United States, the EC, Canada, Singapore, Sweden, and others.

In 1989, the Ministry of Information and Technology Integration funded a 6-year project called the Laboratory for International Fuzzy Engineering Research to consolidate and propel research into fuzzy logic. A large portion of this research is focused on developing capabilities in control systems and interfaces, computer vision and intelligent robotics, decision support systems, and fuzzy computing (e.g., fuzzy associative memories). Though originally a U.S. technology, the Japanese, through continued interest and funding, now dominate the market (80 percent market share) for fuzzy logic devices.

In addition to their extensive research, the Japanese have successfully applied fuzzy logic to a wide range of applications, from energy optimization and improved control of alternating current induction motors, audio and video compression, engine control, and robotic arm movement to visual sensor and mechanical motion coordination. Increasingly, fuzzy logic is being used for computer vision, personal computing, and telecommunications (including mobile networks).

Japanese industry has been pursuing the commercial use of neural networks since 1988, with the first commercial products reaching the market in 1990. Most of these products incorporated neural network components for self-correction of fuzzy logic process-control signals. Products incorporating neural networks include air conditioners, electric fans, heaters, refrigerators,

microwave ovens, photocopying machines, and washing machines. The combination of fuzzy logic and neural logic is commonly referred to as “soft” computing.

European countries have pursued development of intelligent systems capabilities through the EC and nationally funded efforts. These efforts have resulted in significant capabilities in AI logic and enabling technologies critical to the development of intelligent systems. This, along with their advanced supporting technological infrastructures and the economic aspect of a united Europe, will make cooperation both feasible and desirable.

Europe presents a special challenge when trying to evaluate foreign capabilities. Taken individually, many European nations have niches of excellence in specific AI and intelligent systems technologies. At face value, these capabilities could lead to a low assessment of their ability to develop large-scale, complex systems. What this fails to appreciate, however, is the unifying structure of the EC and its broad-ranged, large-scale dedicated R&D efforts. A major objective is to enhance European capabilities, thereby reducing technological dependence on the United States and Japan. With this in mind, the following paragraphs first discuss the EC initiatives, followed by individual country assessments.

Several efforts in intelligent systems are being pursued by multinational organizations under the sponsorship of the EC:

- The European Software and Systems Initiative is made up of large European hardware producers, national institutes, and software houses. Its goal is to improve software productivity and assist in the transfer of existing software tools and methods to users.
- The European Coordinating Committee for Artificial Intelligence (ECCAI) was established in 1982 as a representative body of the European AI community. Its aim is to promote the study, research, and application of AI in Europe. ECCAI has 11,000 members from Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, the Netherlands, Norway, Portugal, Russia, Slovenia, Spain, Sweden, Switzerland, and the U.K.
- The European Research Coordination Agency (EUREKA) has sponsored a number of programs to develop advanced software technology. Several software development tools created under this program are now commercially available.
- The Fourth Framework program (1994–98) is the largest effort for promoting and funding research within the EC, both in terms of funding and range of research. The principal objective is to encourage cooperative research and technological dissemination between enterprises, research centers, and universities within the EC, as well as development of cooperative programs with non-EU members. Related to intelligent systems R&D, \$3.4 billion ECUs have been allotted under the Framework program for development of information and communications technologies and \$2.0 billion ECUs for the development of industrial technologies. These areas constitute nearly half of the total \$11 billion ECU effort. Research into information technologies sponsored by the Framework program falls under the purview of the ESPRIT program, which sponsors research by means of individual projects, working groups, and networks of excellence.

The non-EC-sponsored European Computer Industry Research Center (ECRC) is dedicated to promoting technological development related to intelligent systems. ECRC was founded in 1984 by Bull SA (France), ICL (U.K.), Plessey (U.K.), and Siemens AG (Germany). This organization promotes the development of information technologies in areas of strategic interest for European industry and in emerging applications.

European countries typically are strong in the theory and application of neural logic, weaker in fuzzy logic and genetic algorithms, and very weak in CASE-based reasoning. The most notable development in genetic algorithms has been the Programming Environment for Applications of

Parallel Genetic Algorithms project, a combined effort by France, Germany, the U.K., and the Netherlands, to develop a common programming environment for the development of parallel genetic algorithms.

The U.K., Germany, and France have pursued neural logic actively to support development of indigenous electronics capabilities. Neural network research is being pursued primarily at theoretical (design and modeling) and exploratory (simulation) levels. European capabilities in theoretical research are considered on par with the United States, but trail in applied research. Simulation efforts have largely been handicapped by a lack of hardware and software for effective real-time implementation of neural networks.

The EC has been instrumental in promoting the development and transfer of enabling technology among member states. One notable project was the Portable Common Tool Environment. This interface, which makes any CASE toolset platform independent, is being promoted as a European standard. A related effort, EUROWARE, is promoting the large-scale (Europe-wide) development of software reuse technology. The principal participants in EUROWARE are France, Italy, and the U.K.

DERA is the main organization of the Ministry of Defence in the U.K. under which military R&D is conducted. DERA is the principal organization for the operational system R&D. This agency has several groups doing intelligent systems research on computer vision, image processing, image interpretation, and pattern processing. The British government is also pursuing a large-scale, indigenous commercial effort into intelligent systems. The Intelligent Systems Integration Program, an initiative of the Department of Trade and Industry and of the Engineering and Physical Sciences Research Council, is aimed at developing and integrating intelligent systems technologies into the U.K. business sector. The U.K. has a wide range of academic research and professional organizations related to intelligent systems:

- The Center for Intelligent Systems at the University of Wales, Aberystwyth, is developing AI and sensing techniques for the manufacturing industry. Research covers model-based reasoning for design and diagnosis, intelligent software for failure mode and effects analysis, intelligent instrumentation, and intelligent automation.
- The Intelligent Systems Laboratory in the Department of Computing and Electrical Engineering, Heriot-Watt University, is working on a combination of AI logic with control engineering methods to produce intelligent systems for engineering applications. It is the source of the Model-Based Intelligent Training as well as a partner in a number of ESPRIT projects.
- The University of Essex Computer Science Department has been prominent in AI education and research since the early 1970s. Topics include natural language processing, autonomous agents and robotics, intelligent autonomous systems, fuzzy control systems, genetic algorithms, machine learning, machine vision, and neural networks.
- Researchers at the University of Cambridge and the Sheffield Speech and Hearing Research Labs are developing a hybrid-neural-network/ Hidden Markov Model-based automatic speech recognition system.

CompulogNet—Dedicated to all aspects of computational logic including machine learning, constraint logic, and its applications to natural language programming

MLnet—The machine learning network of excellence started in 1994, coordinated by the GMD

EvoNet—Network dedicated to research into evolutionary computing

ERUDIT—European network in developing capabilities to handle uncertainty in information systems technology

NEURONET—Neural network of excellence, started in May of 1994, with the objective of coordinating neural network research and expanding capabilities in theory, applications, and implementation

- The Edinburgh University Department of AI specializes in natural language processing, mobile robotics, and computer vision systems through its Machine Vision Unit (MVU). MVU projects of note include LAIRD (see below).
- Location and Inspection With Range Data (LAIRD) is a consortium of companies and universities led by British Aerospace and funded by the U.K. Science and Engineering Research Council (SERC). Its aim is the investigation of 3D machine-vision techniques and their applicability in industrial environments. A recent project involves acquiring 3D models automatically from multiple range data. The project is sponsored by SERC (Applications of Computers to Manufacturing Engineering Directorate), with MVU as the main investigator. Industrial collaborators are British Aerospace and the National Advanced Robotic Research Center, Salford.
- Advanced Robotics Research Ltd. is a joint U.K. government–U.K. industries-funded research organization involved in the research of enabling technologies for advanced robotics systems.
- The Electronics Research Group of the University of Aberdeen in Scotland is notable for the range of applied neural logic research.

French research into intelligent systems has heavy governmental support. Some basic research is through the French CNRS. The most prominent CNRS research has been through R&D groups and coordinating research programs in communications man–machine and artificial intelligence. Two of the most important centers for these efforts have been the Laboratory of System Analysis and Architecture and the Laboratory of Computer Science, Robotics, and Micro-electronics. However, the bulk of advanced research is done through the five regional institutes of the INRIA.

Research in intelligent agents is being pursued by organizations associated with simulation and communications. Principally these are the Laboratory of Computer Science and AI of the Computer Science and Applied Mathematics Institute of Grenoble, Dassault, and the R&D Center of France Telecom.

Thomson–CSF is the principal developer of the EC-sponsored work in VR databases. In the realm of dynamic simulation and training, the French have developed capabilities in multi-expert and split systems (which allow presentation of synthesized or split data), HCIs, and speech recognition. Thomson–CSF has also been working to develop neural networks for use in automatic target recognition, scene analysis, signal and image processing, process control, and data fusion. A joint program with the U.K. has augmented French capabilities in real-time automated feature extraction. The French also have niche capabilities in neural logic and fuzzy logic, principally in the area of fuzzy-neural (soft computing) hybrids. Some limited work in genetic algorithms has been reported related to intelligent agents.

The major source of German government-sponsored academic intelligent systems research is through the German AI Research Center (DFKI) of the GMD. Major efforts at the research center include multi-intelligent agent systems, HCIs, knowledge validation and exploration, intelligent engineering, constraint-based programming, and multilanguage automated speech recognition. Germany has a continuing interest in developing intelligent industrial robotic manufacturing capabilities. They also have significant capabilities in machine vision, which is currently being applied to the EUREKA-sponsored Prometheus unmanned vehicle navigation program. Researchers at the Institute for Microelectronics Stuttgart are looking into building fault tolerance into neural networks. Siemens has successfully used neural logic for engine failure prediction of large induction motors and is developing a neural network system for industrial scene analysis. They are also pursuing research into genetic algorithms.

The primary R&D organization for the Netherlands is TNO. Intelligent systems research is focused on the following:

- *Perception*—Vision and imaging systems, primarily in object recognition and target detection, image analysis, visual search, image fusion, and VR. This includes visualization, speech recognition, speech synthesis, voice control, and quality testing of communication channels. Other capabilities include directional hearing, virtual acoustics, audiometry, and noise avoidance.
- *Information Processing*—Cognitive skills, decisionmaking, decision support system, C² systems, and knowledge acquisition. HCIs include dialog, user interfaces, quality of information transfer, and operator behavior monitoring.

Knowledge Technology and Methodology Group—Planning, scheduling, and software integration

SICS, intelligent Systems Laboratory—Agents and secure computing and distributed decision support

SICS, Neural Networks and Real-Time Computation Group—Consists of two RWCs and one non-RWC laboratory. The projects sponsored by each laboratory aim at better understanding of the mechanisms used by natural and AI systems, such as humans, animals, robots, and other autonomous intelligent agents

SICS, Distributed Collaborative Environments Group—Active in the area of distributed VR systems, it has developed a generic VRI, distributed interactive virtual environment, which is used as a research platform for studies into remote teleoperation, battlefield simulation, multimodal integration, and conferencing

Department of Computer and Information Science, Linköping University—laboratories devoted to intelligent systems R&D, including labs dedicated to NLP and speech recognition (fairly mature), real-time systems (the most well developed), and autonomous systems

Göteborg University—with the largest corpus of Swedish governmental text to support statistical analyses for development of machine translation/NLP

The primary organizations for defense-related R&D in Sweden are the National Defense Research Establishment, Swedish Defense Materiel Administration, Swedish National Board for Industrial and Technical Development, and Swedish Institute of Computer Science (SICS). SICS appears to be the foremost national R&D organization dedicated to the development of advanced capabilities in intelligent systems technologies. SICS is a non-profit research foundation funded by the Swedish National Board for Technical and Industrial Development and by a group of companies (Ericsson, Celsius, etc.).

Canada is actively partnering with industry and academia in intelligent systems research, largely accomplished with minimal federal government funding. Basic

research is being pursued by the Canadian Institute for Advanced Research. Advanced intelligent systems research is being done by PRECARN Associates Inc., a nonprofit organization representing a consortium of private industries, and through the Institute for Robotics and Intelligent Systems, a government-funded, university-based “Network of Centers of Excellence.”

Another notable intelligent systems R&D organization is the Intelligent Machines and Manufacturing Research Center at McMaster University (Hamilton, Ontario). The center was established in 1992 to provide a high-profile vehicle for university–industry–government research into intelligent machines and manufacturing. There is also an active participation of the Montreal-based Computer Science Research Center and Environment Research Institute (ERCIM) with French intelligent systems R&D projects. The Canada’s Nortel has an active partnership with the German firm DASA to develop capabilities in telephony-based automatic speech recognition.

One of the effects of increased computer hardware performance and communications bandwidth has been to spur rapid interest and growth in VR. Although the United States holds or shares a lead in most areas of HCI research, the U.K., which has an existing cooperative effort in HMDs with the Air Force and NASA Ames, France (visually coupled displays and digital scene generation), Canada (head-mounted stereo displays and large dataset visualization), Germany (applications to robotics and teleoperations), and Japan (visually coupled systems) have world-leading development efforts. Other countries have niches of capability, two notable examples

being the strong capability in haptic devices at the University of Pisa in Italy and Israel's work in heads-up displays.

There have been many projects sponsored by the EC for development of capabilities in systems technologies. Some of the most notable are the Falcon, which focused on developing fuzzy logic intelligent process control systems, and Wernicke, which focused research on the development of neural-logic-enabled speech recognition. In the rapidly developing area of VR, ESPRIT has established a working group called Framework for Immersive Virtual Environments. Their goals involve reducing latency of image generation, multimodal integration, tracking technology, modeling of participants, and simulation of virtual humans.

ECVNET—The network (started in 1994) dedicated to the development of capabilities in computer vision. Overall objectives include improved capabilities in movement control, image understanding, and HCI interfaces

ELSNET—The network of excellence dedicated to R&D of speech and natural language processing technologies. The multinational environment of the EC has prompted an active, long-term (since 1991) effort in this area

ICIMS—A network of excellence focused on integrating intelligent process control into manufacturing systems

b Command, Control, and Communications

As delineated in the *Joint Warfighting Science and Technology Plan*, the goal of C³ is the seamless and effective integration of capabilities for planning and preemption and integrated force management. In addition, the Army C⁴I technical architecture indicates that digitization of the battlefield is expected to rely largely on the effective use of COTS equipment.

C³ technology encompasses the capability to acquire, process, and disseminate information across force elements (including international coalition forces). This capability must be reliable, provide secure multilevel access, and be protected from enemy attacks and eavesdropping. This will require advances not only in computing hardware and software, but in the interconnecting fabric of communications.

Technical challenges exist and include developing an environmental and force structure database and reasoning mechanisms that are scalable, dynamic, extensible, and robust. In addition, the system must be affordable and offer real-time response. The decision-aiding and -planning aspects require improved machine learning and reasoning paradigms coupled with intelligent agents or aids. Decision aiding also requires a useful human-computer interface, since each decisionmaker has a uniquely preferred manner for quickly absorbing information on which to make a decision. Decision aiding should be available to Army users with the capability to have the decisions made automatically if the user chooses to operate in that mode.

A number of international cooperative opportunities support Defense Technology Objectives; this will help to achieve information superiority and operational dominance in the battlespace of the future. The breadth, diversity, and number of the areas highlighted in this subsection reflect the nature of the global information infrastructure. Areas where existing or pending agreements offer significant opportunities for cooperation are noted.

The United States leads the world in systems engineering and integration of complex C⁴I systems. Areas where international developments are likely to provide cooperative opportunities include:

- High-speed digital switching and networking techniques supporting seamless communications and robust interoperable systems.
- Machine translation software products and intelligent agents for data acquisition and retrieval.
- Intelligent systems technologies for real-time decision support.

The U.K.'s University of Edinburgh's Department of AI is conducting technical research in the areas of knowledge and information management and task and process management. Japan offers world-class capabilities in high-speed switching and networks that could be a valuable contribution to this area.

France, Germany, and the U.K. have significant capabilities in information management and distribution. In addition, Canada has strong capabilities in advanced data display. Another NATO country with noteworthy capabilities is the Netherlands, which has particular strengths in knowledge base and database science. Canada has significant ongoing efforts relative to data fusion and the underlying technology applied to military intelligence. Cooperative efforts with these countries would be beneficial in applying state-of-the-art technologies to address the data fusion problem. The following are examples of potential cooperative opportunities:

- *Real-Time Distributed AI-Based Data Fusion*—Applications of distributed intelligent systems to real-time data fusion and combat battle management. The objective is to incorporate AI into large, synthetic computing environments to handle networking and process management automatically and transparently for the network user. France has extensive experience and a sound information technology infrastructure combined with strong capabilities in battlefield communications.
- *Next-Generation Tactical Switches*—To increase information flow to and from the land forces (Army) commander. Advanced asynchronous transfer mode (ATM) switching promises many advantages to the next-generation information infrastructure for commercial as well as military tactical and strategic applications. ATM allows one to dynamically allocate bandwidth for a fixed packet (information fragments) size. Coupled with switching, packets are individually routed to their destination: a direct communication path is not set up. In other words, in a single message, individual packets can take different paths to get to their destination. France has significant capabilities in this area of technology.
- *Machine Translation*—For information exchange between U.S. and allied forces in a combined operation. Military communications offer a promising area for implementation of machine translation because of the relatively limited and specialized military lexicon. Two areas are of special interest, one with Germany and one with France. The German army has developed a prototype translation system consisting of a 16-channel recorder, a server, two workstations, and an electronic military lexicon. The German army is interested in further development of this capability in the areas of language and speaker identification. World-class research in machine translation is being done in Germany at Siemens and the University of Karlsruhe. A French–English interlingual-based machine translation system, capable of high-quality translation of complex sentences in the domain of military free-text messages, is being developed under a 4-year effort between France and the United States. Using corpus material from U.S. Army CECOM, the system will contain semantic lexicons of both French and English, each having 1,000–3,000 root word form entries, graphical user interface tools, and wide-coverage grammar parsers and generators.

1) Human–Computer Interface

The Swedish foundation SICS has a center for HCI and language engineering doing work in spoken language systems (speech recognition and natural language processing).

The impact of available computing power has had a significant impact on the development and proliferation of HCI technologies. One example is the Laboratory of Computer Science for

Mechanical and Engineering Sciences of the French CNRS. In this institute, the growing use of computers as a tool for research led to the development of a separate department for HCI. Apart from the absence of haptics, the topics covered represent a good representative view of HCI research of interest to the Army:

- *Spoken Language Processing*—Analysis, synthesis, and perception; acoustic and lexical modeling; linguistic modeling; and recognition/understanding.
- *Language and Cognition*—Architecture and semantic representation, learning, spatial and temporal reasoning, testing, and written dialog.
- *Multimodal Interaction*—Computer vision, gesture analysis and synthesis, multimodal communication, audio scene analysis, and ergonomics and human factors.

2) Seamless Communications

Seamless communication means robust, survivable, multilevel, secure communication systems that provide the warfighter access to mission-essential information over the entire operational continuum without requiring user intervention to achieve connectivity across heterogeneous networks. Seamless communication includes the technologies associated with networks, network management, and advanced radio communication systems. The technical challenge is to provide local area networks and ground mobile radio networks that will survive the hostile and demanding environment of the modern battle and that are capable of being interfaced to fixed backbone or space-based wide area networks. France, Germany, and the U.K. are major players in all aspects of communication networks and in battlefield interoperability. Canada also has significant capabilities in tactical interoperability. The following programs are of particular interest for cooperative opportunities:

- *Battlespace C²*—Seamless information transfer in C² to include collaborative planning, intelligence, logistics, and weather. France, Germany, and the U.K. have significant capabilities and ongoing cooperative relationships with the United States to develop joint C² capabilities. There is a need to address and expand this effort to effect force compatibility with Republic of Korea (ROK) forces where the U.S. Army has a large, ongoing commitment. ROK is far behind in implementing and fielding below-division C² systems.
- *Command Post Communications*—Broadband communication networks for corps, division, and brigade command posts. Germany is developing a wideband, wireless command post communication network that will provide voice, digital data, and video connectivity among the elements of a dispersed command post. This system is similar to that being investigated in the U.S. Army's Survivable Adaptive System ATD. There is potential for data exchanges and an interoperability effort between these two programs. A key German technology includes ultrafast (40 GHz) optical switching developed by the Heinrich Hertz Institute.
- *Battlefield Interoperability*—Implementation, evaluation, and validation of improved interoperability between the tactical (regiments, battalions, and companies) C² systems of different allied nations. One area of interest involves developing an intelligent translation gateway box that receives variable message formats from a command post in English and converts them in real time to French common AdatP3 message format and vice versa. A similar effort with Germany is ongoing as a follow-on to an MOU related to the combat vehicle C² system. Successful field experiments conducted in November 1997 demonstrate the feasibility of these concepts.
- *International C² Systems Interoperability*—An Army strategy for international digitization. A joint testbed facility would be established to conduct R&D that demonstrates and evaluates interoperability and implements new procedures and functions required for a digitized battlefield. Initial efforts involve Germany, but this testbed should accommodate joint testing between U.S. and other multinational forces. Success of battlefield interoperability field tests resulted in continued joint activities under the Army Tactical Command and Control System program.

- *Tactical-Level Allied/Coalition Force C² Simulation*—Providing a tactical-level C² exercise for a U.S.–French allied task force utilizing distributed interactive simulation protocols in a Janus environment. This effort will begin to evolve a plausible doctrine, tactics, and training procedure with the concomitant military language, symbology, and rank structure. It will also provide the architecture for integration of military equipment and systems to form a unified C² structure where this is politically acceptable.

Information Management Assurance and Distribution. Information management and distribution provide accurate, real-time knowledge of the enemy and the ability to automatically disseminate that information to dispersed forces and command centers. Technical challenges relate to heterogeneous, distributed computing environments; distributed database management; multilevel information security; advanced HCIs; and automated information distribution. In addition, technical challenges exist for both the commercial world and the Army in the areas of information security and assured routing and access.

3) Decisionmaking

Decisionmaking or battle command remains a combination of art and science. The nonhierarchical dissemination of intelligence, targeting, and other data—facilitated by seamless communications and effective information management—will replace the current hierarchical command structure. Essentially, units, decisionmakers, and commanders will be more independent and dispersed. Information will be voluminous, asynchronous, ambiguous, partial, and at times erroneous. Two conclusions may be drawn:

- To support this revolution in battle command, dispersed command units must be able to share a common, accurate picture of the battlespace.
- To take advantage of information, a multilayered reasoning environment is required to aid the warfighter and commanders in making battlefield decisions. This includes the use of fuzzy logic—which replaces Boolean logic by allowing partial truths rather than *completely* true or false solutions.

France and the U.K. have special capabilities in the area of fuzzy logic technology that offer opportunities for potential cooperative efforts. The French are doing world-class research on automated mission planning and decisionmaking systems. This requires evaluation of potential paths based on a perception of the current true situation. In virtually every case, this is populated by vague or uncertain data (e.g., data on enemy positions, weapon ranges, reaction time, efficiency). Conventional rule-based approaches do not work well with such data. Fuzzy logic approaches for data collection, aggregation, and potential dissemination are being integrated into an automated system to allow manipulation of vague data to increase realism of simulation and ultimately of decisionmaking.

The U.K. effort is focused on the potential payoff from incorporating fuzzy logic techniques into a large-scale battlefield decisionmaking simulation. Intelligent command aids could be extremely important in simulation and computer-generated forces (CGF). A common problem is that it is far too expensive to have human controllers “command” the CGF. Rather than using large, rule-based systems to construct “command agents” (which attempt to model individual decisionmaking entities), fuzzy logic and fuzzy inference engines are an approach that can enhance current intelligent command aids and provide more realistic and effective simulations. The conventional, rule-based implementation system designed to simulate battlefield decisionmaking (GeKnoFlexE) was developed by the U.K. (Fort Halstead) and will be the testbed system. The current rule-based inference structure will be “fuzzified” by augmenting or replacing

it with fuzzy rules and fuzzy inference mechanisms. Since the current system is nonfuzzy, direct comparisons of complexity, behavior, and other performance parameters will be possible.

Israel has strong capabilities in automated battle management that could offer an important contribution to this effort. Japan also has significant capabilities in the application of fuzzy logic techniques. Most Japanese work is related to control of industrial processes or consumer products; however, it is also applicable to military decisionmaking and mission planning.

c Modeling and Simulation

M&S objectives, as defined for this technology area, include development of a common technical framework for M&S; timely and authoritative representations of the natural environment (e.g., friend, foe, and human behavior systems); and development of an M&S infrastructure to meet developer and end-user needs. These areas are critical for achieving the JCS vision for the integration of mission planning, rehearsal, and execution—the application of which should be carried out with overwhelming force.

DMSO is leading a DoD-wide effort to establish a common technical framework to facilitate the interoperability of all types of models and simulations among C⁴I systems. This framework includes the high-level architecture and represents the highest priority effort within the DoD M&S community. HLA was approved as the standard technical architecture for all DoD simulations in September 1996.

The primary mission of HLA is to define a consistent and common picture of the battlespace. This will be crucial to the effective employment and interoperability of multinational coalition forces. HLA will define an infrastructure for linking various highly complex simulations at multiple locations to create realistic virtual worlds. Further international cooperation will be essential. These exercises are intended to support a mixture of virtual, live, and constructive simulation. HLA will identify the interface standards, information structures and exchange mechanisms, and other data required to transform heterogeneous simulations into a cohesive, synthetic environment. Such environments will support design and prototyping, education and training, test and evaluation, emergency preparedness and contingency response, and readiness and warfighting.

The growing cost of hardware development and testing in virtually every product area—coupled with the worldwide availability of low-cost computing power—has made M&S a major area of research worldwide. The International Society for Computer Simulation boasts worldwide participation and has established a “virtual” institute: the McLeod Institute of Simulation Sciences. Its purpose is to promote the advancement and dissemination of M&S technology. International institute members include University of Calgary; Laurentian University; University of Ottawa (Canada); Italian National Research Center; University of Ghent (Belgium); Polish Academy of Sciences; University of Edinburgh (Scotland); Universidad Panamericana (Mexico); Beijing University of Aeronautics and Astronautics (China); Riga Technical University (Latvia); Hungarian Academy of Sciences; Technical University of Clausthal (Germany); and De Montfort University (U.K.).

1) Simulation Interconnection

Simulation interconnection is concerned with the international development of HLA. Such requirements include development of an advanced run-time infrastructure (RTI) (time, data distribution, and large-scale federation management); development of automated tools to support

federation development; investigation of innovative techniques for supporting scalable executing systems using HLA; and development of an automated HLA compliance testing capability.

Technical challenges include establishing the architectural design, protocols and standards, and security mechanisms to facilitate the interoperability of simulations; developing the supporting infrastructure software to apply the architecture to simulation applications with the needed levels of performance; and extension of the architecture to provide time management, data distribution, and federation management services.

In addition to Canada, the U.K., Australia, and New Zealand (all of whom participate with the United States in TTCP), France, Germany, and the Netherlands have strong capabilities in M&S and in the underlying information systems technologies required to distribute and process the information. Japan has had an extensive M&S program aimed at management of large, complex, distributed enterprises. Other capabilities, including those of Israel, may also contribute.

The United States is a world leader in this area. HLA and RTI have emerged and are becoming widely accepted as de facto standards for distributed simulation by the international community.

Examples of global research in development and application of HLA include work at the Interactive Information Institute, Royal Melbourne Institute of Technology, a cross-faculty institute that is becoming a major base for simulation technology research in Australia. The Distributed Knowledge Processing Group at the University of Surrey is also actively pursuing techniques for distributed simulation. The University of Magdeburg, University of Hamburg, and German National Research Center for Information Technology are also active in this area.

2) Simulation Interfaces

This subarea addresses modeling of mission space, mission tasks, strategy, tactics, intelligent systems emulating human decisionmaking processes, and optimal resource utilization. To achieve this ability, it is necessary to develop simulations that provide consistent and reliable results through the development of common conceptual models of the mission space using authoritative representations. Common syntax and semantics must be developed to specify the warfighter mission (the entities, their actions and interactions) to the simulation developer; and to formulate and define standard data structures, dictionaries, and enumeration of complex M&S data (e.g., highly derived data, command hierarchies, artifacts of legacy systems). Areas of interest include the development of an M&S resource repository and verification, validation, and accreditation/certification standards and guidelines.

Several factors are fostering rapid growth of simulation information and representation. Coalition operations are a major theme in the use of military force. The threat to these forces, geographically dispersed and increasingly capable technologically, demands more effective transnational mission planning and rehearsal. The same requirements and capabilities are, to only a slightly lesser extent, reflected in the operations of large multinational companies. World-wide availability of low-cost, powerful information management systems are allowing exchange of data and promoting standardization of data and models for terrain, weather, and environmental effects. The resulting advances will contribute directly to improved interoperability of coalition forces.

The challenge to developing coherent, complete, and consistent conceptual models of the mission space is an extensive task. The span of military M&S covers a wide range of missions, from conventional to other-than-war missions and M&S applications, and from systems acquisition activities to mission planning and rehearsal. The distributed and interactive nature of advanced M&S capability and security concerns makes the standardization and ready availability of standardized data an extremely complex technical issue.

3) Simulation Information

The simulation information subarea is concerned with technologies that will enable—within the time of operational decision cycles—the generation of realistic and high-fidelity synthetic representation of the prevailing physical environment (natural and manmade), the natural and human elements operating within it, and their interactions with each other. These technologies will enable developers and users of M&S applications to represent the natural environment, the performance and capabilities of warfighting systems, and human behaviors (individual and group) in a manner that promotes cost effectiveness, ready access, interoperability, reuse, and confidence. This will enhance the realism of models and simulations used in military training, acquisition, and analysis by providing authoritative representation for (1) static and dynamic, natural and manmade environments, and related effects on human and system performance; (2) the performance and capabilities of warfighting systems and their effects on natural and manmade environments; and (3) human behavior (individual and group).

Technical challenges include rapid database generation and near-real-time interaction of consistent and correlated representations. The representation of human behavior must reflect the effects of the capabilities, limitations, and conditions that influence human behavior (e.g., morale, stress, fatigue). Another significant challenge will be to provide variable human behavior for friendly, enemy, and nonhostile forces, to include CGFs that exhibit platform-based behavioral modeling and command forces models through division level.

The United States has the largest body of research directed toward Computer-Generated Actors (CGAs) for military M&S. However, modeling of human behavior is an area of widespread academic research. Much of this work is focused on meeting the objectives of the synthetic theater of war. Key players in the area of CGAs in the United States include the NASA Virtual Environment Technology Laboratory, University of Houston; the U.S. Army Simulation, Training, and Instrumentation Command; and related work at the University of Central Florida, which is a recognized center of excellence for M&S.

The Advanced Distributed Simulation Research Consortium, consisting of Grambling State University, Florida A&M University, University of Houston, and University of Central Florida, conducts research in application of parallel and distributed evaluation, visualization, and AI reasoning to advanced DIS.

Human behavior modeling programs are conducted at the European Institute of Cognitive Sciences and Engineering in Toulouse, France; the University of Amsterdam, the Netherlands; and the School of Computer Science, University of Birmingham (U.K.) Cognitive Science Research Centre.

The objective of the University of Cambridge (U.K.) Cognition and Emotion program is to develop a theoretical understanding of the nature of emotion and of the cognitive (e.g., attention, interpretation, memory) and brain processes that support normal emotional behavior and

response, as well as emotional disorders. The Geneva Emotion Research Group is part of the Faculty of Psychology and Education Sciences at the University of Geneva, and it conducts research on emotions, including experimental studies on emotion antecedent appraisal, emotion induction, physiological reactions, and emotional behavior in autonomous agents. Although this work is primarily directed toward modeling and understanding of individual and group interactions in civilian settings, the underlying data and techniques should be transferable to military scenarios.

4) Simulation Representation

The simulation representation subarea addresses interfaces required for seamless integration of models and simulations with “live” systems, which may consist of instrumented individuals or platforms used for training, testing, or other synthetic environment applications. Interactions with C⁴I systems and simulations are a priority. Common operational planning and simulation tools and the development of a modular reconfigurable C⁴I interface will focus on these interfaces. This critical capability will facilitate the use of M&S in providing mission rehearsal capability and could augment existing operational planning processes and systems.

Modular interfaces that are (1) responsive and easily reconfigurable for multiple similar but heterogeneous systems, and (2) compliant with Joint Technical Architecture and the M&S common technical framework

Accurate representation of live systems and individuals in a simulation

Realistic representation of synthetic forces on tactical systems

In the subarea of simulator interfaces, leading technologies are found primarily in those countries that have been traditionally strong in dynamic training and simulation—Canada (which is also developing significant capabilities in data visualization), the U.K., France, Germany, and Japan (which is actively pursuing the development of VR for industrial applications, including visualization of complex systems and enterprises).

d Example Research Facilities

The following facilities have demonstrated expertise in C⁴ technical development:

- Canada—Carlton University, Ottawa, Network Management and Artificial Intelligence Laboratory [<http://www.carlton.ca>]
- European—Canadian Consortium, DASA, and Nortel [<http://www.bdli.de/english/katalog/daimle5a.htm>]
- Japan—The RWC Program [<http://www.rwcp.or.jp>]
- Greece—Athens High-Performance Computing Laboratory [<http://www.hpcl.cti.gr/>]; Zentren Europäischen Supercomputings Centers of European Supercomputing [<http://www.iwr.uni-heidelberg.de/zeus>].

3 Electronic Warfare

Because research in the Electronic Warfare area may require sharing of sensitive threat information and is handled on a case-by-case basis, no technology development tabulation can be shown.

a *Electronic Area and Self-Protection*

Electronic self-protection includes actions taken to protect personnel, facilities, or equipment against EW that might degrade, neutralize, or destroy combat capability. Sensor and countermeasures technologies are essential elements in the complex battle that pits defensive EW systems against the enemy's offensive systems. On the modern battlefield, this is an encounter in which a timespan of 1 or 2 seconds can mean the difference between winning or losing.

Advanced technology is critical in providing the winning edge in performance. Technical goals include development of multifunction and multispectral IR countermeasures, radar and laser warning, and real-time situational awareness. Technology challenges include development of uncooled, low false-alarm rate detectors, multicolor IR FPAs, missile detection algorithms, and more efficient, low-cost, and temperature-stable IR/UV filters. Development of high-speed wideband digital receivers based on gallium arsenide technologies will also play a key role in electronic protection, as will development of high-power, UWB jamming modulators and transmitters. This area may require sharing of sensitive threat information, system characteristics, and vulnerabilities. All cooperative efforts involving electronic self- and area protection must be handled on a case-by-case basis, and no technological areas of special interest are identified in this summary.

b *Electronic Support*

Electronic support includes actions taken to search, intercept, identify, and locate sources of radiated EM energy for threat recognition in support of EW operations and other tactical actions, such as threat avoidance, homing, and targeting. Technologies to intercept, direction-find, and locate current and emerging hostile emitters are critical for targeting and tactical situation awareness. Next-generation electronic support measures processors must offer improved emitter identification, deinterleaving techniques, direction-finding/geolocation algorithms, multipath suppression techniques, and increased capabilities in the super-high-frequency region. Continued development of correlation and templating, automated tracking, cross-cueing, and situation display tools are also important. Technical challenges include the integration of ceramic phase shifters into phased-array antennas, application-specific integrated circuits for fast Fourier transform processing, and tools and techniques for tasking and reporting from multi-intelligence sensor platforms. This area may require sharing of sensitive threat information, system characteristics, and vulnerabilities. All cooperative efforts involving electronic support must be handled on a case-by-case basis, and no technological areas of special interest are identified in this summary.

4 *Ground Combat and Tactical Systems*

Ground combat technologies support the basic Army and Marine Corps land combat functions: shoot, move, communicate, survive, and sustain. Rapid deployment, manageable logistics, and compatibility with Third World infrastructures are current topics of major interest. Specific objectives include advances in diesel and gas turbine propulsion, better track and suspension to increase cross-country mobility, and enhanced survivability through improved ballistic protection and reduced observables (including use of active armor). Table E-3 summarizes capabilities and opportunities in each technology subarea.

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TABLE E-3. TECHNOLOGY DEVELOPMENT—GROUND COMBAT AND TACTICAL SYSTEMS

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
SYSTEMS INTEGRATION						
◆◆◆◆ EC nations have capabilities in various areas		◆◆◆◆+	Japan ◆◆	◆◆◆◆	◆◆◆	Israel ◆◆◆◆+ RPVs Teleoperation Switzerland ◆◆◆◆ Armored vehicles
CHASSIS & TURRET STRUCTURES						
◆◆◆◆	◆◆◆◆	◆◆◆◆ Structure & design	Japan, China, ROK ◆◆	◆◆◆◆		Israel, Sweden, Switzerland, Italy ◆◆◆◆
INTEGRATED SURVIVABILITY						
◆◆	◆◆ Modular armor	◆◆◆◆+ Vehicle survivability		◆◆ Bulk ceramics Active protection		Israel, Sweden, South Africa ◆◆
MOBILITY						
◆◆◆◆+ Gas turbines ◆◆◆◆ Power conversion	◆◆◆◆+ Secondary batteries	◆◆◆◆+ Autonomous control Diesel engines electric drive	Japan ◆◆◆◆+ Ceramic engine Electric drive	◆◆◆◆ Electric drive components, batteries & switches	◆◆◆ Suspensions	Austria, Ukraine ◆◆◆ Diesel engines
VEHICLE ELECTRONICS						
◆◆◆◆	◆◆◆◆ Multisensor integration	◆◆◆◆+ Integrated electronics & optronics	Japan ◆◆◆◆ Displays			

Note: See page E-6 for legend.

a Systems Integration

Each ground vehicle consists of several subsystems (e.g., power and drive train, electronics, weapons, sensors) that must be integrated into a full-up, system-level technology demonstration. The primary process in the design of future vehicles is virtual prototyping. Modeling and simulation (M&S) will develop preliminary concepts, optimize design, reduce cost, and schedule maximized force effectiveness for ground vehicles. The goal is to develop lighter, more lethal, and more survivable ground vehicles that are crewed by fewer people. Virtual concepts can be readily evaluated for mobility, agility, survivability, lethality, and transportability, forming a basis for validation, verification, and accreditation. The major technical challenge is to provide the user with systems that can attain an effective balance between increased fighting capability, enhanced survivability, and improved deployability, while meeting cost, manufacturing, and reliability/maintainability goals. Specific challenges relate to developing verifiable models within a usable time frame.

The major players in ground vehicle systems integration and design are the U.K., France, Germany, Israel, Japan, and Russia, all of which have a long history of developing and manufacturing military armored systems, including main battle tanks. Switzerland also has substantial capability in armored vehicles that may be of interest, and Israel has unique experience in the use of RPVs and UAVs that may contribute to advances in teleoperation of ground vehicles.

b *Chassis and Turret Structures*

Use of composites and titanium alloy materials will result in future combat vehicles that are lighter, more easily deployed, economical, and survivable. These technologies remain key to optimizing and exploiting structural integrity, durability, ballistic protection, repairability, and signature reduction. Future vehicle chassis and turret assemblies will be fabricated through an integration of advanced designs that include combinations of lightweight structures and modular armor packages.

Using composite materials and titanium for the primary structure of a combat vehicle is a new effort. This will present significant technical challenges. Issues related to composite materials include durability, fabrication, producibility, and repairability. The primary concern for titanium is one of relatively high cost, which so far has kept it from being used in any U.S. ground combat vehicle. Advantages of titanium's potential for weight reduction, structural armor effectiveness, and corrosion resistance may overcome that cost concern.

The U.K., France, Germany, Israel, Japan, Switzerland, Italy, and Russia possess strong capabilities in vehicle chassis and turret technologies. Germany continues to be one of the few world leaders in combat vehicle R&D across all weight classes. Germany develops and fields wheeled combat vehicles that meet or exceed contemporary tracked vehicle standards and capabilities. DASA's design and prototyping have provided the basis for a German-French cooperative effort in medium-weight armored vehicles (Gepanzertes Transport Kraftfahrzeug), and their main battle tank development and prototyping continues beyond the Leopard 2 block improvements. In addition, the Embedded Gunner Simulator heavy combat vehicle technology demonstrator, developed by Krauss Maffei with firms such as Pietsch and Diehl and a host of others, incorporates state-of-the-art construction and materials fabrication technology with a special focus on signature management. Some capability in chassis and turret structures is noted in China and South Korea.

c *Integrated Survivability*

The goal of integrated survivability is to protect ground vehicles from a proliferation of advanced threats. Hit avoidance, detection avoidance, penetration avoidance, and damage-reduction technologies are critical to achieving overall vehicle survivability. Hit avoidance technologies confuse or physically affect incoming threats. Electronic countermeasures and improved sensors are key elements. Detection avoidance revolves around management of visual, thermal, radar, acoustic, seismic, and dust signatures. Armor is the major element in penetration avoidance. Damage reduction deals with flame suppression technology and fire-fighting agents and with compartmentalization of ammunition and fuel system vulnerabilities. Advances in penetration avoidance center on producing efficient armor combinations with reduced weight, space, and cost properties. The United States is currently the world leader, but other nations are improving rapidly. The Technical Cooperation Program (TTCP) nations have strong armor programs. Israel has strong capabilities, as evidenced by an indigenous development in the Merkava aimed at survivability. South Africa's Rooicat wheeled armored fighting vehicle incorporates a number of indigenously developed and integrated survivability features that include ballistic protection, obscurants, and collective CB protection.

The major technical challenge relates to the cost of the technologies required for survivability. In addition, many of the technologies have significant weight, volume, electrical power, and ther-

mal loading requirements that make their insertion into fielded systems both costly and time consuming.

The United States is the world leader in most aspects of integrated survivability, but niche capabilities may be found in countries that develop and manufacture armored systems. Germany has strong capabilities in integrated CBD and in indirect protection (detection and hit avoidance). The firm of Buck has conducted extensive research in multispectral obscurants. In direct protection, Deisenroth continues to be a leader in composite armor for light, medium, and heavy vehicles, both in integrated and modular add-on packages. Condat specializes in analytic and predictive modeling of armored systems vulnerability assessments. Russia has been a consistent world leader in active protection for 20 years. And Russian developments in bulk ceramics have potential for increased ballistic protection. Canada (Bosik) is noted for work on lightweight blast protection systems for vehicles.

Foreign military producers are undergoing mergers and acquisitions that cross many national boundaries and defense community identities. British Aerospace (U.K.), Marconi (Italy), and Alvis Vehicles and Hägglunds Vehicles of Norway are examples. In addition, much of the current worldwide heavy armor industrial activity consists of upgrade and refurbishment of the older, existing inventory instead of new item manufacture. For example, Israel rehabilitates Chinese tracked vehicles, and the Czech Republic does the same for Middle Eastern national assets.

d Mobility

Mobility focuses on the “on-the-move” function of tracked and wheeled land combat vehicles. Mobility components include tracks, wheels, engine, transmissions, and their fuels and lubricants. Technologies of interest include active noise and vibration control to increase cross-country performance; quiet, lightweight band track; and advanced high-output diesel turbine engines and electric drives. Another major area of interest is providing increased electrical power in smaller, lighter packages. Electrical power is shared across the propulsion, survivability, lethality, and auxiliary systems. Management of distributed system energy requirements remains an important factor. Electric and hybrid drive systems are also being developed. To reduce operational and logistic support costs, the numbers and varieties of both fuels and lubricants required must be reduced through design and standardization.

Another key mobility technology is the development of advanced and active suspensions for enhanced cross-country performance of wheeled and tracked vehicles. Canada is noted for activity in the development of hydropneumatic suspensions.

Technical challenges for electric drives include power capability, energy storage, torque conversion, and reduction in the structural space required for the cooling system. For advanced track systems, the major challenge is to extend the lightweight conventional track durability while reducing O&S costs. For fuels and lubricants, the challenge is to define and select optimal performance tradeoffs for a single-engine/power-train lubricant.

In addition to the United States, Japan and Germany are the world leaders in automotive propulsion. Developments in both nations, in many cases, exceed those in the United States in the commercial arena. Germany is generally considered the leader in producing commercial diesel engines for the world marketplace. Japan and Germany both have significant capabilities in functional gradient coatings, monolithic ceramics, and standard engines and high-power-sensor

diesel engines. Much of this expertise is directly applicable to military vehicles. The U.K., France, and Ukraine all produce high-density combat vehicle diesel engines that are highly competitive. Austria is noted for expertise in diesel engines as well.

Interest in electric drives is found in the major automobile-producing and -exporting countries (U.S., Japan, and Germany), which is primarily driven by growing domestic restrictions on exhaust emissions. Japan is the world leader in some aspects of electric drive technology. France has special capabilities in secondary batteries, such as lithium (Li) polymer, which are of great interest for military applications because of their high energy and power density, long-life cycle, and rapid charge/discharge features. These are also lightweight, compact, and vibration resistant, and they have no EM signature. Military applications include electric vehicle (EV) propulsion (15 kW or more of power) and silent wake. The U.K., Japan, and Russia also have strong capabilities in Li battery technology. Another foreign capability of great interest is Germany's experience in hybrid EVs. Magnet Motors has been working in this area for over 10 years and excels in the areas of multiple electric permanent magnet motors and generators and in magnet dynamic storage. Other German firms—Siemens, Asea Brown-Boveri (ABB), Aus Erfahrung Gut, and Max Planck—are world leaders in microsystem technology as characterized by a combination of power semiconductors, which will make electric drives smaller, more robust, and more responsive. Russia has special expertise in certain types of very high-energy batteries and thermal batteries, and in certain silicon carbide (SiC) switching devices related to electric drives.

Another technology area of interest for mobility is that of autonomous navigation combined with topographic map or chart display and control of vehicles. Germany and the United States have a collaborative program entitled Next-Generation Autonomous Navigation (AUTONAV) System. Participating German research laboratories and their technological contributions to the project include:

- *Universität der Bundeswehr München* will produce an advanced autonomous road navigation system with cost-effective collision-avoidance technology. For a number of years, UBM has been a leader in the European Prometheus program oriented toward the development of commercial highway automation. As part of the Prometheus program, UBM has been developing a sophisticated highway lane-following system using only normal video technology for sensor input.
- *Dornier GmbH* will provide advanced off-road obstacle detection and avoidance capabilities using laser radar technology.

e Vehicle Electronics

The goal of the vehicle electronics effort is to develop a standardized framework within which to integrate digital technologies for embedded vehicular weapons systems. This goal is important for enabling current and future ground vehicles to maintain superior combat effectiveness in the digital battlefield. The two aspects to this area are (1) integration of the electronics into the vehicle, and (2) natural and seamless interconnection of smaller crews with the electronics. Installation of a standardized digital bus greatly simplifies later addition or replacement of electronic devices and will provide maintenance specialists with a single-point troubleshooting and fault-isolation capability for modules serviced by the digital bus.

Electronic integration techniques that are scalable to many platforms
Advanced crew station design
Near-real-time distribution of battlefield information within a vehicle
Reduction of system development time and cost
Reduction of system integration time and cost

Day and night observation equipment
 Sighting and fire control, including stabilized gun control systems
 Data processing equipment, sensors, and modes logic
 Radio and navigation equipment
 Test, display, and operating equipment
 Laser applications for battle tank fire control
 Laser application for artillery fire control

The German firm Pietsch has conducted extensive crew compartment studies focusing on crew size reduction and human factors studies on topics including man-machine interface, endurance, and multiple or simultaneous tasking that results in stimulus overload. Integration of technologies such as sensor suites, optonics, and robotics has been demonstrated and continues to be pursued. Existing U.S.–German agreements are ongoing in support of efforts in this area.

Japan is the leader in commercial flat-panel display systems; however, the application, integration, and utilization of the technology to combat vehicle display systems is being accomplished to some degree in the U.K., France, and Germany.

f Example Research Facilities

The following facilities have demonstrated expertise in ground combat and tactical systems technology development:

- United Kingdom—Kidde Deugra GmbH, Kidde Gravier Ltd. [<http://www.kidde-int.com/>]
- Switzerland—International Center for Magnetic Bearings, National Research Institute for Metals [<http://www.ifr.mavt.ethz.ch/research/icmb/index.html>]
- Canada—DRES [<http://www.crad.dnd.ca>]
- Japan—NRIM [<http://www.nrim.go.jp:8080/open/usr/harada/htm21-e.html>]

5 Weapons

Army goals in weapons technology include milestones for extending the range and lethality of conventional artillery and antiarmor rounds. Conventional weapons objectives are directed toward a variety of technologies for increasing the lethality and mission effectiveness of guided and unguided weapons and mines. Russia, France, Germany, and the U.K. are major developers of conventional weapons, followed closely in capability by Italy, Sweden, Canada, and Israel. Japan, which is prohibited by its national legislation from exporting weapons, has significant indigenous capabilities, as well as strong capabilities in certain lay component technologies such as gallium arsenide microwave components, neural net and fuzzy logic pattern recognition, and hypervelocity propulsion. Table E-4 summarizes international capabilities in the weapons technology area.

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TABLE E-4. TECHNOLOGY DEVELOPMENT—WEAPONS

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
GUIDANCE & CONTROL						
◆◆◆◆	◆◆◆◆	◆◆◆◆	Japan ◆◆◆ Components Taiwan ◆◆			Israel, Sweden ◆◆
GUNS—CONVENTIONAL & ELECTRIC						
◆◆◆◆+ ETC gun	◆◆◆◆	◆◆◆◆+ ETC gun	Japan ◆◆◆ Autoloading ROK ◆◆ Rail guns	◆◆◆◆ Pulsed power Autoloading	◆ Hypervelocity	Israel ◆◆◆◆ ETC gun Australia ◆◆ Rail guns
MISSILES						
◆◆◆◆	◆◆◆◆ ◆◆◆ Hypervelocity pro- pulsion	◆◆◆◆ Vehicle integration Air-breathing rocket motors	Japan ◆◆◆ Hypervelocity pro- pulsion Air-breathing rocket motors India ◆◆ SRBM & IRBM	◆◆◆◆		Israel ◆◆◆ BMD missile Sweden, Switzerland ◆◆
ORDNANCE						
◆◆◆◆ SAFF Energetic materials IM	◆◆◆◆ SAFF	◆◆◆◆	Japan ◆◆◆◆ Components Taiwan ◆◆		◆◆ Munitions	Italy, Singapore, Brazil, India, Sweden, Switzerland ◆◆
WEAPON LETHALITY & VULNERABILITY						
◆◆◆◆	◆◆◆◆	◆◆◆◆				
RADIO FREQUENCY & DIRECTED-ENERGY WEAPONS						
◆◆ HPM Coil, rail guns	◆◆ HPM		Japan ◆◆ ETC ROK ◆◆ Multisensor fusion	◆◆◆◆ HPM RF		

Note: See page E-6 for legend.

Armor and antiarmor technologies represent a special subset of operational capabilities toward which many of the subtechnology developments discussed below are directed. Technologies of interest include improved lethal mechanisms, advanced sensing techniques for optional delivery of the lethal mechanisms, and better methods of M&S of weapons effects and system vulnerabilities. Army objectives for improvements in tungsten alloy penetrators may be furthered by cooperation with other countries, including the U.K. and France. France has strong capabilities in explosives and propulsion systems, including air-breathing hypervelocity propulsion systems. Japan has also taken steps to improve its technological capabilities in aerospace materials

and aerodynamic design for hypersonic propulsion systems. Both of these could contribute to development of long-range hypervelocity systems for the Army.

a Guidance and Control

The United States has the largest and most varied inventory of terminally guided weapons and has pioneered virtually every major technological advance in this area. Other countries, however, have all demonstrated the capability to design and fabricate various types of terminally guided weapons. France (Crotale Air Defense, Air-Sol Moyenne Portee (ASMP) (air-to-surface), Magic (air-to-air), HOT, and trilateral antitank guided weapon systems), Germany, Italy (Aspide, antiair missile), Russia, Sweden (Bofors) (look-down/shoot-down antiarmor system), and the U.K. all have designed and manufactured a variety of missile systems for a variety of mission functions.

Japan is a world leader in a number of component technologies (MEMS sensors, semiconductor and solid-state lasers, and IR detectors) used in small-body G&C, and the NAL has the expertise and facilities necessary for development of complete guidance subsystems. Also of related interest is NAL's ongoing research in hypersonic lift, which includes evaluation of aerothermodynamic effects and RF blackout. This, coupled with their superiority in fine ceramics, may provide an opportunity for cooperation in technologies that would ultimately lead to improved radomes for hypervelocity missile guidance.

Israel, South Africa, and Taiwan have indigenous capabilities for precision-guided weapons. A joint program with Israel involving their Arrow hit-to-kill tactical missile defense program is expected to go into limited operational use in the next few years.

Laser terminal homing is a critical area for advanced G&C. No other country is currently identified as having a program comparable to the Air Force's active laser terminal homing Low-Cost Autonomous Attack Submunition (LOCAAS) program. Among the specific areas of expertise where the United States leads are integration and optimization of guidance for maximum end-game lethality and thermal management and power distribution techniques for primary power. In this regard, use of a diode laser transmitter (as opposed to a diode-pumped, solid-state laser transmitter or master oscillator/amplifier configuration) reduces demand for primary electrical power (40–60 percent efficiency as opposed to 10 percent efficiency).

The United States enjoys a slim lead in the development of individual diode arrays and in laser-pumped and solid-state, diode-pumped laser sources. We also have a modest advantage in overall system design and integration by virtue of the extensive work done on a wide range of tactical, semiactive laser-homing systems. There are, however, areas of excellence abroad in supporting technologies.

Laser physics is a global endeavor with sound research being done in many different institutions. A number of countries have ongoing work in laser profiling and in laser-scale modeling of target radar cross section. The latter, while only peripherally related to full-scale target profiling, may provide useful insights into laser scattering characteristics at full scale. Similarly, a number of countries have strong capabilities in solid-state lasers. For example, in the area of components research, a large number of countries are active. Manufacturers of diode lasers are present in the United States, Canada, France, Germany, Japan, and the U.K. Other sources are identified in Israel and Switzerland. Other capabilities in this area are described in the following paragraphs.

A significant R&D effort in the area of CID is being done in Germany. The laser technology being pursued is of interest to the U.S. Army for possible use by dismounted soldiers. Siemens is a leader in developing algorithms for sensor fusion and high-speed processing, integration, and display of multisensor inputs. This has immediate application in situation awareness and could contribute to improvements in target detection and false-target discrimination techniques essential for laser terminal homing. The Fraunhofer Institut is recognized as a world leader in lasers and laser materials. The University of Frankfurt (<http://www.nformatik.uni-frankfurt.de/~brause/welcome.eng.html>) has a broad range of research in image analysis, and their Website provides useful links to related work. Other German activities include:

- Work at the University of Wurzburg in use of laser radar for localization and navigation. By contrast to existing industrial robots, the German work is directed toward landmark-independent navigation. Of note is the observation by German researchers characterizing the guidance methods as the technological bottleneck in this application.
- Research in a variety of algorithms for real-time image analysis at the University of Erlangen.
- Work in robust tracking methods for moving objects in high-noise environments.
- Work reported at the University of Hannover and the University of Harburg (the latter also working in collaboration with the Swiss Federal Institute of Technology).

Agreements with France in this technology area are in place under which potential cooperation in terminal laser homing might be explored. France is also working on an ATR algorithm running in real/near real time on a state-of-the-art processor. This is an integrated hardware/software effort currently directed toward forward-looking IR (FLIR) and radar sensing that might also be applicable to laser radar. The University of Lyons is active across a range of sub-technologies, including laser material and image analysis. Specifically in image analysis, the Center for Research and Applications in Image and Signal Processing [<http://www.creatis.insa-lyon.fr/>] is a joint effort of the CNRS National Institute for Applied Science of Lyons and the Claude Bernard University of Lyons, which consists of some 70 researchers dedicated to image engineering. The CNRS Ecole Polytechnique has also participated in international conferences on laser radar.

The U.K. has significant capabilities in laser technology and substantial efforts in radar and algorithm developments. The following are among centers of work and aspects of interest:

- University of Hull—work in optimization of algorithms for “zooming in” on images that support FLIR imaging systems.
- University of Nottingham—work primarily in real-time industrial applications of AI to image analysis.
- University of Bristol—efficient algorithms for texture analysis and classification.
- University of Cambridge—motion compensation techniques.

Japan has an active program in laser radar, much of which appears to be directed at atmospheric measurement and monitoring.

York University in Canada is a leader in laser radar technology. The main thrust of most of this effort appears to be directed toward atmospheric research, but some level of work and interest is in other aspects of laser radar. Optech

Tohoku Institute of Technology	Tohoku University
Fukui University	Yamagata University
Toshiba, Inc.	Chiba University
Mitsubishi, Inc.	University of Tokyo
NASDA	Fukuoka University
NIES	Nagoya University
The Japanese Defense Agency	Fukui University
Hitachi, Inc.	Okayama University
	Kyushu University
	Shinshu University

Inc., based in North York, Ontario, specializes in the use of laser rangefinder technology in a wide range of commercial applications. Three principal markets include airborne surveying, industrial process control, and locating/guidance applications for the transportation industry. Optech's activities include the manufacture of standard rangefinder products for established markets and the development of customized systems for new and developing applications.

Among the more radical approaches being investigated is a program at Australia's Aeronautical and Maritime Research Laboratory (one of two major laboratories in the DSTO), jointly funded by the U.S. Air Force, to investigate and develop insect vision-based algorithms for flight control and guidance of UAVs and missiles. Other countries having noteworthy work in related sub-technologies include Austria, Australia, China, Finland, Norway, and Sweden.

In addition to these individual research efforts, the European program for R&D in information technologies, ESPRIT, sponsors extensive research in image analysis. Projects under the ESPRIT program are multinational endeavors, frequently involving a mix of academic, government, and industry participation.

b Guns—Conventional and Electric

Advanced gun technology is an important component of the Army's R&D program. Weapons able to deliver effective payloads from longer range and with greater accuracy give a well-trained soldier a decisive advantage on the modern battlefield. Current propulsion technology is focused in three areas: advanced solid propellants, EM pulse (rail gun), and electrothermal-chemical (ETC) propulsion.

The United States currently has an active EM launch technology development program in cooperation with a strong program in the U.K. One of the outgrowths this joint program was the development of the world's longest free-flight EM gun test range at Kirkcudbright, Scotland. The facility has the capability of storing up to 32 MJ of energy and has a 2-km range.

The United States leads in the difficult challenge of developing an electric power generation unit capable of producing the required pulsed power within the confinements of a vehicle. The Netherlands and Germany have small-scale research in this area. South Korea is starting a development effort but has yet to develop a significant capability. Several countries are working toward integrating electric power units into vehicles.

In the area of gun propulsion, there are a number of opportunities in terms of new conventional propellants and technologies for ETC propulsion. In the longer term, advances in electrical pulse power may enable EM rail guns.

As discussed under the subtopic of insensitive munitions below, a number of countries are actively working on low-vulnerability ammunition (LOVA) propellants. The French-German Research Institute (ISL) has specifically studied the combustion behavior of hot-plasma-initiated LOVA propellant and related interior ballistics. The Australian DSTO is reported to be undertaking a comprehensive safety and suitability review of new high-performance nitramine propellants in both small- and large-caliber gun systems. Canada also appears to be doing some work in the area of hypervelocity projectiles, based on reference to a recovery technique developed by the DREV, that will allow recovery and post-flight analysis of aerothermodynamic effects for rounds up to 105 mm at 2,300 mps.

Among the most promising areas for future international cooperation are those associated with the development of pulsed power systems. Of interest, some of these are already being applied to other multinational initiatives. High-voltage/high-power semiconductor switches from ABB (based on technologies from Sweden and Switzerland) have been developed to support a French–German joint EM launcher program at ISL. These devices use a novel stacking and bonding technique to produce high-voltage, high-current stacks. In addition, a German–French consortium reportedly has been formed to exploit German capabilities in rotating machinery (specifically, German Magnet Motors GmbH.)

The Ioffe Technical Institute in St. Petersburg, Russia, has independently developed and successfully produced a new family of solid-state switches designed for high-frequency and pulsed-power applications. These are described by Army technical experts as having the potential to make significant contributions to a variety of military applications. The High Current Electronics Institute in Tomsk is an internationally recognized center of excellence for pulsed power. Both of these activities have demonstrated a willingness to participate in international programs. (See related item under RF DEWs in this subsection.) Another area of Russian research identified as having potential application to pulsed power is pulsed-explosive magnetohydrodynamics. Under a collaborative effort, the Institute of High Temperatures and the High-Energy Density Research Center in Moscow have been developing explosively driven radial electromagnetic hydrodynamics reportedly capable of repetitive operation with 10-kg explosive charges.

Japan has strong capabilities in a number of key areas, including high-temperature superconductivity under the general auspices of the Japan Fine Ceramics Center in Nagoya; high-energy-density electrochemical capacitors (key players include Matsushita, NEC, Toyobo, and Yamaguchi University); electromechanical storage, specifically a composite flywheel storage system being developed by Nippon Steel in collaboration with Mitsubishi and Marubeni Corporation; and solid-state power switching. Japan has strong industrial capabilities in high-power thyristors (Mitsubishi Electric Corporation), and high-voltage metal-oxide semiconductor (MOS) controlled thyristor switches (Toshiba Corporation, reportedly paralleling U.S. developments in this area), and is reported to have ongoing development efforts in SiC devices for high-power, high-temperature operation.

The Chinese appear conversant with the principles and literature of ETC propulsion. Research on energetic particle ignition exposed to hot plasma appears in 17th International Symposium on Ballistics. Researchers at the National Specialized Lab of New Type Electrical Machinery of the Huazhong University of Science and Technology have published research on numerical simulation of compulsators specifically for ETC gun application.

Autoloading meets what are evolving as universal requirements to reduce manning and increase firepower in ground forces. With the general trend toward downsizing, however, few development programs of any significance are in progress. Two programs are pushing the state of the art: the U.S. Army Crusader and the Japanese 155 SP howitzer. This Japanese (N155HSP) 155 howitzer is a fully automatic loading system whose performance objectives are generally comparable to the Crusader's. A prototype reportedly successfully fired at the Army Yuma test range in 1997. This model represents the continuation of a developmental effort begun in 1985. While earlier prototypes used dual rotating magazines, the current version uses a cradle that positions the shells and propellant charges horizontally behind the handling mechanism.

Sweden also has configured and evaluated some innovative tank designs using autoloading. A notable example is the UDES-19, a radical design that uses a fixed external 34-round store and an articulated loading mechanism. Although the Swedish Army has reportedly abandoned these indigenous designs in favor of procurement of the Leopard II, the basic design concepts may still be of interest.

Another autoloading concept is evident in the Austrian Panzerjäger SK105 mobile tank destroyer. This system uses a turret designed under license from a French firm, which is also used on the AMX-13 and Brazilian EE-17. A limited ready-load of 12 rounds is stored in two cylindrical magazines. This configuration can deliver very high rates of fire, but the magazines must be replenished from outside the vehicle. This vehicle has been widely sold, and by the mid 1980s was in service in Argentina, Bolivia, Greece, Morocco, Nigeria, and Tunisia.

The Commonwealth of Independent States, notably Russia and the Ukraine, are considered to be world leaders in autoloading. A 125-mm autoloader is standard equipment on its 125-mm armed T-64, T-72, T-8, and T-90 main battle tanks and on the Ukrainian-developed T-84. As is the case in other tank weapons, these autoloaders are generically different from those of the SP 155 howitzer in that they are designed to handle a cartridge round containing both propellant charge and projectile, as opposed to the separate zoned charges used for field artillery.

Despite the increasing emphasis on development and use of large-caliber systems for delivering guided weapons, direct-fire and medium-/small-caliber guns, rockets, recoilless rifles, and small grenade and mortar launching systems will remain critical to both offensive and defensive military operations. Many countries are active in production and international sales of small- to medium-caliber weapons. Among the traditional world leaders in this technology are Germany (Mauser and Rheinmetal), and France, which also has reportedly good capabilities in telescoping ammunition. Numerous other countries have established infrastructures in developing systems based on new technologies, including Austria, Brazil, Egypt, Russia, Singapore, Switzerland, and Sweden.

c *Missiles*

A number of countries (including certain developing countries) have some capability of producing standard explosives such as trinitrotoluene (TNT), cyclotrimethylenetrinitramine, nitroglycerin, ammonium perchlorate, metal fuels, hydrazine, and related compounds for military use. The United States, France, the U.K., and Japan are the world leaders in formulation and production of advanced explosives and propellants.

Advances in hypersonic/hypervelocity (Mach 6–8), shortening engagement cycle times, and increasing system lethality threat-handling capabilities will enhance close combat and short-range air defense missions. The development of hypervelocity vehicles depends greatly on advanced rocket propulsion techniques and on advances in airframe design and G&C.

Advances in propulsion technology (specifically air-breathing propulsion) are necessary to support near-term objectives of U.S. Army missile development programs.

In the area of gel propulsion, the United States appears to be the world leader. Russia is reported to have investigated this technology, but apparently has not strongly pursued it. Germany has initiated an effort, and Japan is considering it for military applications. France and the U.K. have expressed interest, but have not as yet begun serious development.

Japan, Germany, and France, followed closely by the U.K. and Russia, have significant experience in the design, manufacture, and testing of air-breathing rocket motors and components. Japan has initiated a broad-based initiative to develop materials and structural/aerodynamic design techniques for hypervelocity transport, the results of which could contribute to this effort. The focus of efforts is toward a multimission KE missile capable of being launched from multiple light platforms and hitting a target with 3–5 times the kinetic energy of tank cannons.

Japan is reported to be developing a high-performance ducted rocket system for antiship cruise missile applications. France is considered world class in air-breathing propulsion. ONERA is very active in European research. They were a primary force in the creation of the Association of European Research Establishments in Aeronautics, a group of seven research establishments created to promote cooperation and exchange. They work closely with other research activities, especially their German and U.K. counterparts, DLR and DERA. ONERA has cooperative programs with NASA, the Army, and the Air Force in aerodynamics and computational processes and with the Russian Central Institute of Aviation Motors and the Central Aerodynamic Institute, specifically in ramjet propulsion and aerodynamics. Micro Turbo (France) produces the high-performance turbojet used in an Army UAV. The Netherlands' TNO-PML is also active in a wide range of research in missile propulsion and is studying ramjet-powered projectiles for antiarmor systems.

Tactical propulsion encompasses all aspects of onboard propulsion for the delivery of ordnance, including solid- and gel-rocket motors and air-breathing propulsion for hypervelocity missiles. Liquid-rocket motors and air-breathing missile technologies common to manned and unmanned air platforms (e.g., small, low-cost gas turbine engines like those used on Tomahawk) are addressed elsewhere. Technologies for mixing and loading solid-rocket motors for tactical weapons (typically less than 600-mm diameters) are generally available worldwide. Technologies for larger rocket motors for strategic weapons not as widely dispersed. Technology for development of reduced and minimum smoke formulations has proliferated.

France, Germany, the U.K., and Japan all have varying degrees of investment in hypersonic air-breathing propulsion and in design of critical subsystems. The following are among the highlights offering promise for critical developments:

- French work in C-C composites and applications in high-temperature combustion.
- Japanese efforts in high-temperature structural ceramics, including Si and silicon-nitride compositions.

d *Ordnance*

Any country with an armaments industry can produce simple contact, time, and proximity-sensing fuses. Capabilities to contribute to advanced fusing for programmable/smart ordnance and aimable warheads and for look-down, shoot-down antiarmor weapons are primarily in the U.K. and France, with possible niche capabilities residing in Germany, Italy, and Sweden.

Japan is generally prohibited by its constitution from export sales of weapons, but specific areas where Japanese technology might enhance U.S. Army safing, arming, fusing, and firing (SAFF) capabilities include optical and IR lasers and detectors, MMW components, and ANN and fuzzy logic for use in target detection and aimpoint selection logic.

The 57-mm munition used by the Canadian navy has been selected as a vehicle for demonstration of insensitive munition (IM) approaches. An experimental round, using an explosive

(CX-84) patented by DREV, is reported to have demonstrated performance equal to that of the TNT-loaded round, with significantly improved safety characteristics. Ongoing work includes development of energetic binders and plasticizers for both explosives and propellants, which offer both improved performance and safety.

In SAFF technology, past U.S. programs provide a legacy of world leadership in canister-dispensed munitions and related technology, especially in terms of sophistication, safety, and reliability of design. France, Japan, the U.K., Germany, and Italy follow closely in overall conventional weapon SAFF design and may actually hold slight leads in specific component technologies. Singapore, South Korea, Taiwan, Brazil, India, Sweden, and Switzerland have conventional weapons fusing capabilities adequate to meet many needs. SAFF technologies of other arms producers—notably Russia and China—do not compare, due largely to deficiencies in underlying electronic component design and production.

In terms of safety and reliability of SAFF functions, no other countries approach the ability of the United States, Germany, the U.K., and France. However, any country with the electronics capability to build aircraft radar altimeter equipment should have access to the capability for building a reasonably adequate, simple height-of-burst fuze. China, India, Israel, Taiwan, South Korea, Brazil, Singapore, the Russian Federation, Ukraine, and South Africa have built conventional weapons with design features that could be adapted to more sophisticated designs providing variable burst height and rudimentary ECCM features. (This includes the technology and know-how for gun-shock hardening of electronic components and access to components for miniaturization of small-proximity sensors for submunitions.)

The United States, the primary developer in the area of electronic initiation, holds a significant lead over the rest of the world. In thermal batteries, current technologies appear to be able to provide adequate energy and power densities to meet operational requirements. However, affordability remains a barrier, particularly for large-volume items such as artillery projectiles. In terms of reserve thermal battery technology, the United States and France are world leaders, followed closely by Germany.

IMs are an area of international research, with the primary centers of activity being found in NATO and Japan. Much of the NATO work is visible and accessible to all participants through the NATO Insensitive Munitions Information Center (NIMIC). The NIMIC Website provides references to research activities in the U.K., Canada, and the Netherlands. The French organization SNPE (see below) is generally recognized as world class in energetic materials R&D.

Improved 4.5-inch ammunition round
Stingray torpedo mid-life update
Advanced short-range air-to-air missile
Proposed replacement warhead for Sea Eagle air-to-surface antiship missile
Main battle tank ammunition

Although work in IM is a worldwide endeavor, the United States appears to lead in all aspects of IM. U.S. researchers have pioneered the development of a number of key components and materials. Much of the impetus for early development of insensitive high explosives was driven by nuclear safety issues and by DOE facilities such as Los Alamos and Sandia National Laboratories, which remain at the forefront of these emerging technologies.

France appears to be the most active foreign country in IM, particularly in the areas of reaction modeling sensors and full-scale testing.

As noted previously, their goals for MURAT (the French national doctrine regarding less hazardous munitions) are the most ambitious of those under consideration. The Société National des Poudres et Explosifs (SNPE) [<http://www.snpe.fr>] is recognized as a world leader in the devel-

opment and application of energetic materials (explosives and propellants). The Centre d'Achèvement et Essai Propulseurs et Engins is responsible for testing various propellants developed by SNPE and for their adaptation to missile propulsion subsystems. Areas of IM investigation include full-scale testing of fast and slow cook-off of tactical missile systems and techniques for characterizing and evaluating responses. The Commissariat à l'Énergie Atomique is investigating shock and detonation waves in triamino-trinitro-benzene (TATB)/cyclotetramethylenetetranitramine (HMX) mixtures. One recent study demonstrated the importance of explosive microstructure to the ignition process. More recently, members of the same team applied their quasi-static model to determine the low-velocity impact sensitivity of a mixture of more than 90-percent TATB in a polymeric binder. Experimental results were in good agreement with the mathematical model. It was observed that sensitivity was not significantly affected by temperature. Pyrospace uses hexanitrostilbene in airbag detonation mechanisms.

The U.K. has a long tradition in all aspects of energetic materials and ordnance fabrication. Many of the processes used worldwide for the manufacture of materials like HMX and RDX were developed by the U.K. Since 1990, the U.K. has had a policy for introducing IM in new programs. The U.K. Ministry of Defence Ordnance Board is the focal point for munitions. The office of the Chief Inspector of Naval Ordnance has been particularly active in IM exchanges and discussion.

British Aerospace [<http://www.bae.co.uk>], successor to the U.K. Royal Ordnance Laboratory, claims to be a world leader in IM. They and DERA [<http://www.dera.gov.uk>] report a wide range of IM activities. Areas of particular emphasis and expertise include full-scale testing and testing of rocket motor structures and explosive trains. Another area of DERA IM-related research is the replacement of conventional elastomeric binders with energetic binder materials. Much of this work has been directed toward improving the aging behavior and physical properties of energetic binders, which are usually inferior to those of the inert binder materials they replace. British Aerospace, Royal Ordnance Rocket Motors, has developed and tested an adhesively bonded IM rocket motor against four environments: fuel fire, bullet impact, slow heating, and 12-m drop test. The last of these, while related to handling and not one of the defined NATO threats, is significant for IM in that the item is subjected to very substantial deceleration shock levels. The Royal College of Militarily Science, Shrivenham, has been particularly active in the NIMIC effort and in the development of standards for IM. Among the specific activities of interest at this facility have been workshops dealing with the reaction of energetic materials and munitions to impinging shaped-charge jets.

Germany's Fraunhofer Institute for Chemical Technology is a world leader in energetic materials and is working specifically in IM areas. Energetic materials are tested at the institute for sensitivity to a variety of stimuli, including shock (bullet impact, shaped-charge impact, and sympathetic detonation effects) and thermal effects (slow and fast cook-off). Related research areas include performance, sensitivity, effect of insensitive high explosives, and characterization of performance and deflagration-to-detonation time in solid-gun propellants.

As noted above, a number of countries are active in warhead design and research, M&S of terminal ballistics, and warhead effects. In recent years, the number and diversity of countries active in advanced warheads, such as EFPs, has increased substantially. A growing number of countries are also involved in research in other types of advanced warheads, including improved shaped charges. Research in these areas is an important indicator of an underlying understanding of the response of materials under high-rate deformation. This understanding

also underlies the development of other types of multipurpose warheads and aimable ordnance, as well as design of effective ballistic protection.

France is very active in both shaped-charge and EFP research, much of the latter at ISL. The EFP work includes simulation of high-density EFP liners (i.e., tantalum) and modeling of aerodynamics of optimized EFPs (in conjunction with the Ersnt–Mach Institute, Germany). The Ersnt–Mach Institute is also independently active across a broad spectrum of research topics relating to warheads and warhead effects, as is the U.K. (specifically the Royal Military College of Science and DERA. Other EFP efforts were identified in Rafael Ballistics Center (Israel), the Terminal Ballistics Research Laboratory (India), and the Aeronautical and Maritime Research Laboratory (Australia).

Japan's constitution limits military activities to self-defense and prohibits the export of military systems. As a result, Japanese efforts tend to be somewhat less visible than those of other countries. Industries identified with development, fabrication, and loading of munitions include Nissan, Aeronautical and Space Division; Kawasaki Heavy Industries [http://www.khi.co.jp/index_e.html]; Nippon Yushi; Asahi Kasei; and Mitsubishi Heavy Industries.

Canada is active in NIMIC and conducts research specific to IM at DREV. These efforts range from chemical formulation to development of specific applications, including warheads, rocket motors, and gun propellants. DREV offers extensive facilities for the preparation and study of all kinds of explosives and propellants in quantities sufficient for meaningful study. It can formulate, process, and characterize explosives and of gun and rocket propellants, including expertise in plastic-bonded explosives, low-vulnerability gun propellants, composite rocket-propellants, melt-cast TNT explosives, and synthesis of energetic polymers.

Scientists at several Chinese institutes are investigating the properties of IMs. Beijing Institute of Technology is looking at nitrogen tetroxide (NTO), TATB, and picylaminodinitropyridine; the Institute of Chemical Materials of the China Academy of Engineering Physics studies TATB; and Xi'an Modern Chemistry Research Institute, which has ties to the China North Chemical Industries Corporation as well as to the military, is looking at NTO and 1,3,3-trinitroazetidine. Nanjing Institute of S&T is investigating TATB and structurally similar compounds.

Norwegian efforts in IM began in 1980. While there has been continuing interest since, emphasis on IM has varied, with performance frequently taking precedence over insensitivity. In Norway, the Forsvarets Forskingsintitutt is reported to have had the greatest involvement in development of new energetic materials and studies of IM. However, industry has also played a key role. For example, Dyno Industrier A.S., Defense Products has been jointly funded by the Norwegian Ministry of Defense and the Swiss Defense Procurement Agency to develop reduced sensitivity, NTO-based, high-explosive compositions.

Most Russian institutions involved with explosives R&D are affiliated with one of three organizations: the Russian Academy of Sciences, the Ministry of Defense, or the Ministry of Atomic Energy. Russian literature has been largely silent on specific efforts toward IM development. It is not certain whether this is due to classification or because operational doctrine does not require its emphasis.

Sweden's BOFORS Explosives and BOFORS Weapons Systems Division have developed IM-based rounds for 40-mm and 57-mm L/70 guns that retain the same level of performance as conventional ammunition, but fulfill more stringent safety requirements. The rounds are con-

sidered IM because they have low-vulnerability ammunition LOVA propellant, insensitive plastic bonded explosive, and hexanitrostilbene igniters and boosters.

The Netherlands has been active in the NATO Insensitive Munitions Information Center (NIMIC), and TNO conducts what appears to be a comprehensive program of research in formulation and processing of explosives, propellants, and pyrotechnics in its Munitions Technology and Explosion Safety Research Division.

The United States has an extensive information base and has traditionally held a modest world lead in the warhead technology area. A large number of countries are ordnance manufacturers, many patterned after the United States' (Japan, South Korea) or the U.K.'s Royal Ordnance establishment (Pakistan, Singapore, India, Sweden). Among major weapons producers, the U.K., France, and Germany have the greatest capability to contribute to innovative developments, followed by Italy, the Netherlands, Norway, Switzerland, and Sweden (the last two in antiarmor).

Russia has had a strong program in conventional explosives and warheads and certainly has an adequate research base in detonation physics and the response of materials to support future developments. Brazil, Canada, China, Egypt, Israel, India, Pakistan, Singapore, South Africa, South Korea, and Taiwan all have arms industries at levels that would permit them to imitate the design approaches, but not necessarily the performance of critical warhead developments in the more advanced countries listed above.

e *Weapons Lethality and Vulnerability*

Two overarching security concerns affect cooperation in this area. The first is the potential compromise of U.S. intelligence collection sources and methods in programs dealing with lethality against specific foreign weapons. The second is operational security of information relating to vulnerabilities of U.S. weapons that might be exploited by a potential adversary to defeat or degrade U.S. systems. Within the limits imposed by these concerns, however, there may be opportunities for cooperative programs. In some cases, foreign participation may fill gaps in U.S. program capabilities. The U.K., France, and Germany all have strong programs in M&S of weapons effects as well as extensive empirical databases. These countries have capabilities in armored systems, with France having a particular niche capability in helicopter structural survivability.

At the theoretical level, M&S of weapons effects and the development of algorithms and techniques are fairly widespread, particularly among traditional NATO allies. Data sharing and cooperation do not typically extend to empirical data on specific weapons against operational systems. The United States has done extensive testing and probably has the largest empirical database upon which to build future critical developments.

Although the details of specific weapons and target responses are closely guarded, there is a considerable body of open international R&D activity in the underlying sciences and technologies needed to enhance weapon effectiveness and characterize target vulnerabilities. France, Germany, and the U.K. are all world leaders in this area. Highlighted institutions include the French-German Research Institute in France, the Ernst-Mach Institute in Germany (vulnerability modeling, including behind-armor effects), and DERA (Fort Halstead) in the U.K.

There is widespread global activity toward advancing the state of knowledge of the underlying principles governing the mechanical response of materials and structures to high-energy rate deformation and ballistic loading. One example is the evolution of “mesomechanics,” a field of study that attempts to characterize physical behavior across a wide spectrum of different scales—atomic, microscopic, macroscopic, and structural. This subject was the topic of a recent international conference held in Xi’an. Organizers of the conference listed included Xi’an Jiatong University; Tsinghua University, Beijing; the Chinese Academy of Sciences (China); and the Institute of Strength Physics and Materials Science, Siberian Branch of Russian Academy of Sciences, Tomsk. In addition, the European commission and universities from Australia, Canada, Germany, Greece, Ireland, Israel, Italy, Japan, Korea, the Netherlands, Portugal, Russia, Sweden, and Taiwan are represented on the International Steering Committee.

f *Radio Frequency Directed-Energy Weapons*

Electronic warfare includes any military action involving the use of EM and directed energy to control the EM spectrum or attack an enemy. The three major categories of EW are electronic attack, electronic support, and electronic protection. Directed-energy weapons (DEWs) can be considered a special type of electronic attack that are handled as a separate category to distinguish them from more traditional EW techniques. Laser weapons, RF weapons, and particle-beam weapons are the three main categories of DEW. As a practical matter, only lasers and RF weapons have advanced sufficiently to be of military value. Of these, only RF DEWs are included in this section since there is no ongoing Army research on laser DEWs.

Directed-energy systems are advanced technologies that may completely change the way military missions are organized and executed in the future. In this section, these systems include charged particle beams, neutral particle beams, antiparticle beams, and high-power microwaves (HPMs). High-energy lasers are treated in the section on laser and optics.

Besides the United States, England, France, Germany, Japan, and Russia have had substantial programs in particle beams and particle-beam-supporting technologies in general and have well-developed technical capabilities in the majority of critical elements. England has an extensive program in coil gun and rail gun development, while Germany, Russia, and Japan have some ongoing developmental work in special areas. Electrochemical and ETC gun developments are ongoing in several countries. Japan has an active program in ETC, while England, France, and Germany are involved in some special development of both electrothermal and ETC guns. The leaders in the regenerative liquid propellant gun technology are the United States, Israel, England, and Germany. The United States and Russia are world leaders in the HPM technology, but some important activity is also found in Germany, France, Switzerland, China, and Japan. Sweden, Israel, Ukraine, and Australia are also significantly involved in these activities.

France is a leading producer of HPM tubes. Significant RF source development efforts also exist in the U.K. Several other countries have limited research efforts in this area: Germany, Switzerland, China, Japan, and to a lesser extent, Sweden, Israel, and Australia.

Russia and Ukraine have significant capabilities in RF weapons. The FSU was considered the world leader in HPM at the time of its disintegration. The Russians have concentrated on development of high-power RF generators, such as various types of gyrotrons and klystron amplifiers. The United States has an ongoing R&D effort in multisensor fusion and machine-based reasoning and will be working cooperatively with South Korea (ROK) in this area. The ROK

early efforts on this joint project will be largely theoretical and mostly performed at the university level. Because the later phases of this effort will involve software development and testing, ROK has the potential to make significant contributions. The opportunity, afforded by this joint project, to evaluate operational deficiencies of current technical approaches to automated truth maintenance and for tactical situation awareness is essential. Each nation can focus its limited resources while avoiding duplication of effort. Existing agreements between the United States and ROK provide the vehicle to pursue this cooperative effort.

g Example Research Facilities

The following facilities have demonstrated expertise in weapons technology development:

- Singapore—Defence Science Organization National Laboratories [<http://www.mindef.gov.sg/midpa/whatsnew/year97/03oct03.htm>]
- NATO—NIMIC [<http://www.nato.int/related/nimic/>]
- Russia—Izhevsk Electromechanical Work [<http://www.iemz.ru/>]

6 Soldier and Human Systems

Human systems technologies and methods ensure that military personnel are properly selected, trained, and equipped to perform effectively and safely. The technologies include, but are not limited to, sensors, displays, communications, processors, logistics monitoring, and warrior protection systems. Impacts of these types of technologies include increased unit effectiveness through more effective training; improved ergonomic design of systems, including displays and decision-aiding technologies to enhance mission performance; enhanced warfighter protection; and improved mobility through advances in logistics and sustainment capabilities. Table E-5 summarizes international human systems technology capabilities.

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a Information Display and Performance Enhancement

Information display and performance enhancement technologies improve situational awareness and the common battlefield picture, synthesizing this picture with the warfighter's relevant experience and tactical knowledge and helping the commander orchestrate the collective and distributed decisionmaking process at every echelon. The primary goal is to maximize information throughput from sensors, processors, and displays to warfighters.

Most developed nations have significant research efforts in information display and performance enhancement. Interest is driven by multiple requirements, including the need for improved presentation of information to match human cognition and improved representation of human performance to improve realism and fidelity of computer-generated forces and "actors" in both simulations and operational systems.

TABLE E-5. TECHNOLOGY DEVELOPMENT—SOLDIER AND HUMAN SYSTEMS

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
INFORMATION DISPLAY & PERFORMANCE ENHANCEMENT						
◆◆◆◆+ VRIs Soldier–system interface HPM	◆◆◆◆+ Display Soldier–system interface Ergonomics Performance modeling	◆◆◆◆+ Soldier–system interface HPM	<i>Japan</i> ◆◆◆◆+ Displays VR Robotics		◆◆◆◆+ VR display	<i>Israel, Sweden, Netherlands</i> ◆◆◆ Human performance measures <i>Israel</i> ◆◆ HMD
DESIGN INTEGRATION & SUPPORTABILITY						
◆◆◆◆+ Performance modeling	◆◆◆◆+ Performance modeling Ergonomics	◆◆◆◆+ Performance modeling	<i>Japan</i> ◆◆◆◆+ Automated industry/ enterprise design			
SURVIVABILITY & PERFORMANCE ENHANCEMENT						
◆◆◆◆+ Soldier systems (physiological & psychological)	◆◆◆◆+ Soldier systems (ballistic protection)	◆◆◆◆+ Soldier systems			◆◆◆◆+ Soldier systems	<i>Australia</i> ◆◆+ Soldier systems (microclimate control)
PERSONNEL PERFORMANCE & TRAINING						
◆◆◆◆+ Dynamic training & simulation	◆◆◆◆+ Dynamic training & simulation	◆◆◆◆	<i>Japan</i> ◆◆◆ Distributed training & simulation of complex enterprises		◆◆◆◆+ Simulators & displays	<i>Australia, New Zealand, Belgium</i> ◆◆◆◆ <i>Netherlands</i> ◆◆◆ Simulators <i>Finland</i> ◆◆ Shooter training systems

Note: See page E-6 for legend.

Information management and display efforts develop methods and media to process and deliver task-critical information to individuals, teams, and organizations. Maximizing the flow of information depends on developing time-sensitive, supportable information handling and display components that serve as a visual and auditory human–system interface (HSI) for both weapons and support systems. Developing simulation interfaces is another area of keen interest. Simulations must be of sufficient fidelity to enhance mission planning and to permit diagnostic examination of emerging technologies and concepts. As a result, model development is an important aspect of this work.

A number of foreign countries have significant capabilities in HSI technologies. The United States has ongoing efforts with France and Germany in soldier–system interfaces, especially related to teleoperations. The U.K. has noteworthy capabilities in soldier–system and virtual reality interfaces (VRIs), and Canada (Gallium Software) has capabilities in VR and displays. Israel also has unique expertise in helmet-mounted displays (HMDs). Japan is a leader in displays, VR, and robotics, all of which are needed for teleoperations.

The goals of performance enhancement technologies are to enable soldiers to operate well beyond normal mental, physical, and perceptual capabilities and to enhance performance in stressful, hazardous, time-constrained, inhospitable, and remote environments. Areas of particular interest include computer-aided crisis management decision support, unmanned robotic vehicles, and mobile manipulator platform control. In addition, concepts for battlefield synchronization, on-the-move collaborative techniques, real-time decisionmaking, and visualization for distributed problem solving are becoming increasingly important.

Human performance modeling is a critical factor in meeting future Army requirements. Such modeling contributes to enhanced soldier–system battlefield performance through low-risk, quick-turnaround simulation, permitting rapid assessment of proposed systems concepts. Human performance modeling ranges from anthropometric models of impulse and acoustic detection by the human ear, through cognitive and physical workload assessment, to decision-making under stress. France is recognized as a key international source for cooperative research in these aspects of HSI. Negotiations are underway with France on auditory research and ergonomics issues. The U.K. and Germany also have very strong capabilities in human performance modeling; to a lesser but still significant extent, Israel, the Netherlands, and Sweden also have capabilities. Canada has a number of programs to study and model human factors in aircrew, crew stations, and operator–robot interactions.

b *Design Integration and Supportability*

Design integration involves the development and production a fully integrated crew weapon or information system through the use of effective design tools, HSI models and databases, and performance metrics. Human–system performance and cost variables must be part of the design process. Technology capabilities are required in human performance assessment and modeling, tools for enhancing physical accommodation, methods for human error and reliability assessment, and tools for crew station design and testing.

Manpower and personnel integration (MANPRINT) efforts will play an important role in the design integration subarea. Foreign capabilities are similar to the information management and display subarea described above. The U.K., France, and Germany offer the most capabilities in terms of applying performance modeling to systems design. Some of the world-class work that Japan is doing in automating industry and enterprise design may be applicable to the challenging aspects of integrating system-of-systems.

System supportability includes improving affordability, availability, operability, maintainability, and logistical supply to reduce life-cycle support costs. The Army must be able to provide early estimates of manpower, personnel, and training (MPT), as well as associated human performance requirements and costs for HSI, so they can be input to the acquisition and design process. The set of MANPRINT methods and tools are key elements in this effort. The goal is to have validated techniques that are robust enough to permit quantitative tradeoff analyses among various MPT variables and design options. This will allow decisionmakers to examine variations in systems performance as a function of MPT investment.

The growing complexity of weapon systems makes it increasingly difficult to support those systems with personnel who can effectively operate and maintain them. To balance soldier resources and requirements with emerging technologies, research is needed to determine the limits of attention saturation, mental workload, and manpower utilization. This is essential to maintaining full military readiness, availability, sustainability, and effectiveness. U.S.–French

cooperation in ergonomics is directly related to supportability issues. France is sharing modern ergonomic performance-measuring instrumentation and techniques, while the United States is sharing its MANPRINT suite of soldier–system performance enhancement tools.

c *Survivability and Performance Enhancement*

Survivability and performance enhancement technologies support warfighting and peacekeeping mission capabilities through full-spectrum personal protection; troop sustainment, including rations and field feeding equipment; survival and rescue; advanced airdrop (both personnel and cargo); load carriage optimization; and dismounted and mounted warrior systems integration, including warfighter systems analysis. Survivability and sustainability of individual soldiers and small operational groups for the future battlefield and for operations other than war will require advances across a wide spectrum of capabilities. These include ballistic protection, CB protection, signature reduction, enhanced food preservation and delivery, and precision cargo airdrops.

Scientific and technological efforts include nutritional performance enhancement, food preservation, food service equipment, drinking water purification, precision cargo/personnel airdrop, and airbeam technologies for lightweight, rapid-setup shelters. Individual survivability also includes all material and combat clothing systems for protection of the individual warfighter. Areas of particular interest are individual ballistic protection, countermeasures to sensors, laser eye protection, multifunction materials, and textiles. (A special case is biologically derived materials such as spider silk or bioceramics for body armor.)

Cooperative opportunities in individual survivability relate primarily to improved soldier systems. The soldier system focuses on enhancing soldier capabilities in the five areas of lethality, C², survivability, sustainability, and mobility. This encompasses everything the soldier wears, carries, and consumes in a tactical environment. France has special expertise in ballistic protection for individual soldiers. The U.K. has strong capabilities in the physiological and psychological aspects of soldier systems. Germany and Canada both have strong capabilities in materials and soldier–system integration. In addition, a niche capability in individual microclimate control has been identified in Australia.

Canada has recognized strengths in many areas of sustainability as demonstrated by the FY96 approved foreign comparative testing of a Canadian generator and multifuel burner. Canada also has significant capability in the CB and gravitational force protection for soldiers and aircrew, as well as developing test rigs for body armor. The Canadian Defence and Civil Institute of Environmental Medicine has developed survey systems to generate user feedback on clothing and protective wear. Other Canadian efforts include the development of personal cooling systems, studying human performance in cold environments, modeling personnel performance in physiological stressful environments, and developing intelligent clothing and equipment sizing systems.

d *Personnel Performance and Training*

PP&T efforts seek to strengthen unit readiness and reduce costs through advances in force management and modeling, selection and classification, human resource development, simulation-based training, training strategies, and training efficiency. Technology developments of interest include the advanced distributed interactive simulation and VR technologies that can have a major impact on individual, collective, joint, or multinational training in all environments.

Other thrust areas are development strategies for selection and classification and leader development, including design of aptitude tests and performance metrics.

Manpower and personnel issues are of concern to all countries wishing to field and maintain an effective military capability. International cooperation in manpower and personnel is taking place through a variety of mechanisms. The United States, the U.K., Canada, Australia, and New Zealand pursue collaborative research and actively exchange information of defense R&D projects through TTCP. Examples of such collaborative research include selection tests for tank gunners and effects of workload levels and stress on decisionmaking. Collaborative research also occurs through the Defense Research Group (Panel 8, Human and Biomedical Sciences) of the NATO Armaments and Research Organization. For example, the United States is gaining valuable information regarding the fielding of computer-based selection tests in Germany and Belgium and on the use of distance learning technologies in European countries.

An important set of training challenges arises from the need to develop strategies for individual and collective training that provide an effective and affordable mix of live exercises and synthetic training environments. Live force-on-force tactical engagement simulation remains a key element of the training strategy for both the United States and its major allies, but the increased lethality and longer ranges of U.S. weapon systems and improved C⁴I systems are pushing the limits of current U.S. laser engagement training systems and their corollary test and evaluation instrumentation systems. A key goal will be to develop a set of training technologies (strategies and performance metrics) that adequately reflect emerging communications and information technology, modern warfare conditions, and new doctrine.

A number of foreign countries have significant capabilities in training and simulation technology. Canada, France, Germany, the Netherlands, and the U.K. have made valuable contributions, and each represents considerable leveraging opportunities. Australia has hosted several international simulation conferences and symposia to expand its knowledge, increase its capability, and broaden its use of simulation. The U.K. has established an industrial advisory board to monitor simulation activities in the United States and advise on military use in the U.K. Germany is experimenting with injecting virtual targets into live sights, a key challenge for embedded training and live-to-virtual linkages. Canada's advanced display systems would be useful for all types of simulations, and the U.K.'s and France's ability in human performance modeling and VR technology could enhance battlefield representations. The Netherlands has assumed a prominent role in Europe as a technical expert in the use of training simulation technology and has orchestrated several major demonstrations of advanced distributed simulation technology in support of NATO vision and goals. Israel has significant capability in computer- and laser-based tactical training systems.

Australia, Canada, New Zealand, the United States, and the U.K. have established working groups in VR and distributed simulation under TTCP's Training Technology Panel HUM-2. NATO Army Armaments Land Group 8 is identifying standard agreements for training interoperability among member nations, and NATO Research and Technology Panel Number 8 is investigating human factors issues in the use of VR for military purposes.

e Example Research Facilities

The following facilities have demonstrated expertise in soldier and human systems technology developments:

- Canada—Defense and Civil Institute of Environmental Medicine
- Australia—Land Operations Division, Defense Science and Technology Organization [<http://www.dsto.defence.gov.au/esrl/lod/index.html>]
- Finland—Noptel [http://www.noptel.fi/nop_eng/index.html]
- Netherlands—Command and Control and Simulation Division, TNO–PML [<http://www.tno.nl/institut/fel/div2/>]

7 Biomedical

Biomedical concerns relate to preserving and optimizing the health and performance capabilities of military personnel in peace and war. Individual service men and women are the most essential and vulnerable component of military systems. Disease and nonbattle injury exceeds battle-related injuries as the major cause of military casualties. The force structure now confronts additional threats from weapons of mass destruction (WMD) exposure to pathogens endemic in developing nations, operational stress, and harsh climates. The existing medical infrastructure in the regions to which troops are deployed is often modest; therefore, appropriate treatment of U.S. personnel requires evacuation to base hospitals at significant distances from the site of injury.

For humanitarian reasons, and because biomedical technologies are dual use, much of the research and technology is widely shared. Virtually all developed nations (including the U.K., France, Germany, and Japan) have significant national research programs that can contribute to U.S. Army requirements. The spread of AIDS and other diseases, such as Ebola, and the emergence of antibiotic-resistant bacterial strains worldwide have spurred medical and biomedical research. Medical and biomedical research in many nations is not focused on military requirements. However, knowledge related to the prevention, treatment, and control of disease is important to the defense community during deployment to new areas or in response to the biological agent threat. Telemedicine is a related rapid growth area. This technology includes networking of healthcare facilities by satellite and the use of high-resolution video to permit treatment of injured or wounded military personnel at sites distant from high-quality medical care facilities. As physicians become geographically distant from combat arenas and as medics become the primary care providers, telemedicine capabilities are essential to the survival and wellness of the soldier. Table E–6 summarizes international biomedical technology capabilities.

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TABLE E-6. TECHNOLOGY DEVELOPMENT—BIOMEDICAL

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
INFECTIOUS DISEASES OF MILITARY IMPORTANCE						
◆◆◆◆ Human and patho- gen genome & drugs Tropical	◆◆◆◆ Human and patho- gen genomes & drugs	◆◆◆◆ Human and patho- gen genomes & drugs	Japan ◆◆◆◆ Human and patho- gen genomes & drugs	◆◆◆◆	◆◆◆◆ Human and patho- gen genomes & drugs	Switzerland, Israel ◆◆◆◆ Human and patho- gen genomes & drugs
MEDICAL CHEMICAL, RADIOLOGICAL, & BIOLOGICAL DEFENSE						
◆◆◆◆ Vaccines Drugs	◆◆◆◆ Vaccines Drugs	◆◆◆◆ Vaccines Drugs	Japan, Singapore ◆◆◆◆ Vaccines Drugs	◆◆◆◆	◆◆◆◆ Vaccines Drugs	Switzerland, Cuba, Israel, Netherlands ◆◆◆◆ Singapore ◆◆ Vaccines Drugs
MILITARY OPERATIONAL MEDICINE						
◆◆◆◆ Imaging Food additives	◆◆◆◆ Imaging	◆◆◆◆ Imaging Food additive	Japan ◆◆◆◆ Imaging		◆◆◆	Sweden, Israel ◆◆◆◆
COMBAT CASUALTY CARE						
◆◆◆◆ Blood substitute Biological response modifiers	◆◆◆◆ Blood substitute Biological response modifiers	◆◆◆◆ Blood substitute Biological response modifiers	Japan ◆◆◆◆ Blood substitute Biological response modifiers	◆◆◆ Blood substitute	◆◆◆◆ Blood substitute Biological response modifiers	Switzerland, Israel ◆◆◆◆

Note: See page E-6 for legend.

a Infectious Diseases of Military Importance

This technology area seeks to protect soldiers from infectious diseases normally encountered in a deployed area. A related goal is to return soldiers to duty as rapidly as possible. Infectious diseases pose a particular threat to operational effectiveness because most Americans lack immunity to diseases that are endemic in other regions of the world.

The deployment of forces is frequently associated with increased incidence of illness in persons who have not previously resided in the region. Viral or bacterial disease is present in a high proportion of persons who report for sick call. As the number of forces to be deployed is reduced in “reachback” concepts and the requirement for sustained performance increases, reducing sick call is more important than ever for sustaining force projection capability. Global surveillance of infectious diseases provides a database that can be used to determine what immunization or other protection of individuals is needed prior to deployment. Several agencies gather data on endemic diseases: the Center for Disease Control, World Health Organization (WHO), and Pan-American Health Organization. A comprehensive database of such information can function as a clearinghouse for defense and public health requirements. This database could function as an early warning system for an outbreak of infectious diseases, whether caused by organisms endemic to an area or disseminated by terrorist or nation/state entities. The information would serve to alert pharmaceutical firms and the defense community to increase production of vaccines and antibiotics.

The U.K. has several areas of expertise in tropical diseases. The Liverpool School of Tropical Medicine researches programs in the control and management of malaria; this effort is part of the World Health Organization (WHO) activities in tropical diseases. Novel vaccine approaches are in development at Oxford Bioscience.

The genomics of the human is currently being defined through the Human Genome Project in the United States, the U.K., France, Germany, and Japan, with collaborations in other global regions. The Medical Research Council (MRC) (U.K.), the Centre Nationale de la Recherche Scientifique (CNRS) (France), the German Cancer Institute, and the Gesellschaft Biotechnologische Forschung (GBF) are among the contributors. The definition of the genome of pathogens is underway in many national laboratories and pharmaceutical firms. An example is the proteomic database (SwissPro Protein Database), which is readily available on the Web.

At present all major chemical and pharmaceutical companies (e.g., DuPont, ICI, Elf-Acquitaine, Ciba-Geigy, Smith-Kline) are multinational. Several other nations are noted for capabilities that may be of interest to Army applications. Switzerland and the Netherlands both have world-class pharmaceutical industries. Singapore has some capability, including new bioprocessing facilities. Australia is already a cooperative partner with the U.S. Army Medical Research Institute of Infectious Diseases. Some countries, including Kenya and Thailand, represent opportunities of cooperation because of geographical location of disease occurrence and not because of any resident technical capability.

b Medical Chemical, Radiological, and Biological Defense

The objective of the medical chemical defense program is to preserve combat effectiveness by timely provision of medical countermeasures in response to joint service defense requirements. A major challenge is the development of pretreatments (vaccines, immune enhancers, prophylaxis), protectants (antivirals and antibiotics), or antidotes that are effective and safe for human use. Both rapid and long-acting antichemical and antibiological agents are required, as are skin decontaminants and protective compounds. Cooperative programs exist between the U.S. Army Medical Chemical Defense Research Program and agencies in the U.K., Canada, Israel, Germany, Australia, and other nations for the development of technologies to protect soldiers from chemical warfare agents. The primary U.S. programs are concerned with modeling the 3D structure of acetyl cholinesterase in order to design countermeasures to inhibit this enzyme.

The primary goal of medical biological defense is to ensure the sustained effectiveness of armed forces operating in a biological warfare environment. The related tasks include the development of new vaccines, superantigens, sensor systems, antivirals/antibacterials, and immune enhancers. Such approaches will reduce lethality and enhance the return of the soldier to duty.

Most nations with advanced medical care or advanced industrial hygiene and safety capabilities have some level of expertise in personal protection. Nations with extensive pharmaceutical capabilities also have vaccine production capability. The U.K., France, Germany, Russia, and Israel have extensive capabilities in meeting the needs for sustained operational effectiveness.

France has several private and national research centers related to pharmaceutical and vaccine protection against biological agents. Rhone-Poulenc, now merged with Hoechst of Germany, produces and markets drugs and vaccines on the global market. The Institut Pasteur in Paris has an excellent history developing vaccines.

The University of Toronto has expertise in DNA-based vaccine development. Allelix Biopharmaceuticals in Toronto has capabilities in drug and vaccine production. Adherex in Ottawa uses the cell binding characteristics of bacteria to design novel countermeasures. Viron Therapeutics in the U.K. examines the role of viral proteins in turning off immune responses. The definition of these viral inhibition mechanisms can assist in the design of novel immunogens.

Germany has several major efforts in drug development, vaccine production, and design of adjuvants. Gesellschaft für Biopolymer–Berlin has an active program in adjuvant development. The German Cancer Institute in Heidelberg and GBF in Braunschweig have active programs in drug and vaccine development. Hoechst, now a partner of Rhone–Poulenc in France, has an active R&D program in drug development.

WHO has promoted the development of new vaccines. One outcome is the joint effort to produce and market a diphtheria, pertussis, tetanus, hepatitis B vaccine by the National Institute of Public Health and the Environment (RIVM), Bilthoven Netherlands; Bio Farma in Bandung, Indonesia; and Rhein Biotech in Maastricht.

Cuba has two vaccine production facilities, and both are marketed internationally. The Center for Pharmaceutical Chemistry produces vaccines for meningitis type B. The National Center for Scientific Research of Cuba produces anticholera vaccine.

c *Military Operational Medicine*

The goals of this effort are to protect soldiers from environmental injury and material/system hazards, develop safety and design criteria for military systems, sustain individual and unit health under stress (sustained operations conditions), and quantify performance criteria. The technologies include management of sleep, iconography, and food additives (e.g., tyrosine, melatonin) to increase alertness. Germany, Sweden, and former Soviet Union (FSU) states have had extensive programs correlating human physical performance with nutrition and sleep cycles. These programs are primarily sustained in university and sports medicine organizations.

Functional magnetic resonance imaging (MRI), a major advance in this area, permits training of personnel to criteria defined by the user and testing of subjects in simulators. This technology effectively permits visualization of neural activity in an alert, awake human and correlates the activity with sensory input/output, cognitive activity, or muscle tone. Work pioneered in the United States and the U.K. led to the emergence of this field in the neurosciences. Among the nations producing instruments capable of functional MRI are the U.K., the Netherlands (Phillips), Germany (Bruker), and Israel (Elscent). The Oxford Centre for the Functional Magnetic Resonance Imaging of the Brain (U.K.) has good resources related to this technology.

d *Combat Casualty Care*

This program aims at saving lives far forward in the combat arena. Issues of concern include far-forward resuscitation, minimizing lost duty time from minor injuries, reducing unnecessary evacuations from site, and decreasing resupply requirements of forward echelons of care. Canada (Hydro Biotech) has developed a containment system to protect casualties and medical personnel from biohazards.

Technical challenges include overcoming the toxicity of oxygen-carrying hemoglobin and blood substitutes, stanching abdominal bleeding, and applying hemostatic agents to wet surfaces of hemorrhaging wounds. Major efforts have been underway to identify blood substitutes that

have minimal toxicity to recipients. Perfluorocompounds have been tested in the United States, Japan, and other industrialized nations. The Green Cross organization in Osaka, Japan, has a long history of work in this area. Terumo Corporation in Kangawa has efforts in resupply of blood cell components. The Russian Research Institute in Hematology and the Russian Military Medicine Academy, both in St. Petersburg, have programs relating to blood substitutes. The University of Nottingham in the U.K. has an active program evaluating blood substitutes.

e Example Research Facilities

The following facilities have demonstrated expertise in biomedical technology development:

- Germany—German Cancer Research Center [http://www.dkfz-heidelberg.de/index_e.htm]
- Netherlands—The National Institute of Public Health and the Environment [<http://www.rivm.nl/>]
- Sweden—Department of Biomedicine; Nuclear, Biological, and Chemical Defense Division; Defense Research Establishment
- Canada—Allelix Biopharmaceuticals [<http://www.allelix.com>]

8 Chemical/Biological Defense

The Chemical and Biological Defense (CBD) program includes efforts to develop passive and active deterrents to the use of WMD. These deterrents include chemical and biological (CB) detection, information assessment (including identification, modeling, and intelligence), contamination avoidance, protection of individual soldiers and equipment, and collective protection against WMD. Table E-7 summarizes international chemical/biological defense and radiological technology capabilities.

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a Detection

Current U.S. Army policy is to not enter contaminated areas. Although the idea of avoiding a contaminated area is still important to the Joint Service program, more emphasis is being placed on detecting and identifying a CB threat prior to arrival into critical areas.

The most rapid changes in technology capabilities are currently seen in the area of detection. Private sector and federal investment is strong. The detection components include point and standoff platforms, sample concentrators, and patterned or digital readouts. Because the technology has applications in the defense arena and in the environmental monitoring, medical, and pharmaceutical industries, it is a dual-use technology. The growth of sensor technology is among the most rapid in all industrial sectors, and it is driven by perceived needs in the medical and environmental health communities.

The identification and detection of biological agents may be achieved by point or standoff systems. The former depends on direct interaction of the sensor matrix with agent materials or extracts; the latter relies on some spectral method used at a distance. Point detection systems function through the use of specific- and high-affinity binding materials (antibodies or other immunological binder; DNA/RNA binders, receptors, combinatorial materials) that will bind to and recognize biological agents of interest. In addition to binding materials, the point detector system includes four components: collector, trigger, detector, and identifier.

TABLE E-7. TECHNOLOGY DEVELOPMENT—CHEMICAL/BIOLOGICAL DEFENSE*

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
DETECTION						
◆◆◆◆ Sensors Microfluidics Lab on chip Proteomics	◆◆◆◆ Sensors	◆◆◆◆ Lab on chip Proteomic Microfluidic	Japan ◆◆◆◆ Sensors Humanoids Robotics China ◆◆◆◆ Sensors	◆◆◆◆ BW detection sensors	◆◆◆◆ Lab on chip Sensors	Netherlands, Israel, Switzerland, Sweden ◆◆◆◆ Singapore ◆◆◆◆ Solid phase micro extraction
PROTECTION						
◆◆◆◆ CB protective clothing, including mask & body cover	◆◆◆◆ CB protective clothing & body cover	◆◆◆◆ CB protective clothing & body cover	Japan ◆◆◆◆ Body cover China ◆◆◆◆ Body cover	◆◆◆◆	◆◆◆◆ CB protective clothing & body cover	Singapore, Israel, Netherlands, Switzerland ◆◆◆◆ Sweden ◆◆◆◆
DECONTAMINATION						
◆◆◆◆ Biodegradation	◆◆◆◆	◆◆◆◆	◆◆◆◆		◆◆◆◆ Bioremediation	Israel, Sweden, Finland ◆◆◆◆
MODELING & SIMULATION						
◆◆◆◆ Weather patterns Computer systems	◆◆◆◆ Weather patterns Computer systems	◆◆◆◆ Weather patterns Computer systems	Japan ◆◆◆◆ Weather patterns Computer simulation	◆◆	◆◆◆◆ Weather patterns Computer simulation	Netherlands, Israel ◆◆◆◆

Note: See page E-6 for legend.

*Smoke and Obscurants section is not included.

Standoff biological agent detectors detect a threat agent by means of optical or other spectral properties inherent in the agent. These detectors generally rely on light scattering or absorbance of IR light by the target agent. The difficulty is that all life forms (pollen, fungus, bacteria, virus) have these signature materials, so the probability of a false-positive signal is high. France has active programs using laser-light scattering as detection elements, and an extensive program in light detection and ranging (long-range standoff biological detection and ranging) technology.

An operational German system, the Fuchs nuclear, biological, and chemical reconnaissance system, has advanced point-detection capabilities. The United States has joint agreements with Germany for integrating new technologies developed in either nation into the Fuchs platform. The United States, the U.K., and Canada are working to improve the Biological Integrated Detection System by conducting joint test and evaluation procedures. The Czech Republic has contributed elements for detection of nerve agents; Poland has contributed technology related to spore detection. The United States, the U.K., France, Germany, Japan, Switzerland, and Israel have advanced capabilities in the general area of biological sensors. Russia had a significant capability in this arena, but it has degraded significantly during the past 6 years.

Biodetection sensor systems include genomics, proteomics, receptors, and combinatorial materials possessing selective, high-affinity binding characteristics for biological agents. They include patterned surfaces to which the binding materials are attached in an addressable manner. The fluidic systems containing the biopolymers of the biological agent are another sensor compo-

ment, as is the transduction of a binding event, between agent fragment and sensor surface, into an optical or electrical signal and the subsequent alert that a superthreshold level of agent has been detected.

In the U.K., Brax Ltd. (genomics), Imperial College (microfluidics), and the Laboratory of Government Chemists in Teddington (laboratory on a chip) have excellence in sensor and detector technologies. The Teddington facility has teamed with Glaxo, Wellcome, Kodak, and Unilever. The MRC Laboratories have expertise in genomics and proteomics. Other U.K. corporations with technologies related to biodetectors and sensors include Zeneca and Isis Innovation; the Imperial Cancer Center is a governmental facility with strong capabilities in genomics and proteomics; DERA has expertise in transitioning CBD technologies to defense-related systems.

Corporations and government laboratories in France with expertise in detection technologies include Rhone-Poulenc, CNRS, and Genset. The recent merger between Rhone-Poulenc (France) and Hoechst (Germany) provides major transnational strength in genomics. Rhone-Poulenc (Rho-Bio subsidiary) has an extensive database on genomics of disease resistance in plants. Other corporations with international holdings and cooperative studies include Bio-Merieux, Cazuax, the Centre D'Etudes du Bouchet (CEB), Transgene, Pasteur-Merieux-Connaught, Giat, and Elf-Aquitaine/Sanofi.

Germany has developed capabilities in genomics, proteomics, microfluidics, and mass spectroscopy. The German Cancer Institute in Heidelberg is a leader in profiling gene expression and in production of a chip containing protein/nucleic acid probes. The probes are synthesized on the chip. The proteomic database [<http://www.mann.embl-heidelberg.de/Default.html>] is a primary source for sensor elements. The GBF in Braunschweig has major research efforts in genomics and proteomics. GBF is cofunded by the private sector and serves as a transition between basic and applied research. Sequenom is a joint U.S.-German venture aimed at developing a DNA chip for a detector. Among the leading microfluidics developers are the Max Planck Institut Colloids and Interfaces in Teltow-Seehof. Another German corporation, Bruker-Franzen, has developed advanced mass spectroscopy electrospray methods for applications in detectors. The merged Hoechst and Rhone-Poulenc entity has capabilities in all areas of biodetection, individual and group protection, and modeling. Other German industries with major strengths in this area include Bayer, Boehringer Mannheim, and Boehringer Ingelheim. Boehringer Ingelheim has a long history of trade with the East European market. Degussa also has valuable niche strengths in this area.

Canada has detector development capabilities in both academia and the private sector. The University of Alberta has an excellent center for developing the "laboratory on a chip." Procyon (London, Ontario) also has capabilities in this arena. The Computing Devices of Canada, Dycor, and Defence Research Establishment-Suffield (DRES) are noted for capabilities as well.

Several Japanese companies have interests in detection systems. Fuji films, Nikon, and Takara Shuzo have capabilities in the area of thin films. The Tsukuba research laboratories, including the NEC Tsukuba facility, has developed technology for miniaturization of sensor/detector elements. These capabilities represent leading-edge technology centers in detection and data fusion. Another important area is the integration of detection systems with robotics for use in areas too hazardous for personnel. Erato has developed a robotic insect model and the Riken Biomimetic Control Center, Nagoya, has biomimetic strength in robotics. Sony Corporation is modeling an in-silico simulation of a biological organism (*C. elegans*). The Tokyo Institute of Technology and the University of Tokyo are academic institutions with strength in micro-

robotics. Honda Corporation developed a humanoid prototype robot; Mitsubishi Heavy Industries, Sony, and Omron also have humanoid robotics capabilities.

The Groningen Biomolecular Sciences and Biotechnology Institute (GBB) in the Netherlands, has expertise in drug detection. It is partnered with Ciba–Geigy (Switzerland), Hercules (Netherlands), Novo–Nordisk (Denmark), and Roussel–Uclaf (France) in pharmaceutical technologies that have application to detection and individual and group protection. The MESA Research Institute at the University of Twente in Enschede has developed expertise in microfluidics with applications in screening, detection, and drug discovery.

Switzerland has leading-edge capabilities in detection, drug discovery, and development by virtue of its long history of excellence in pharmaceuticals. Large pharmaceutical firms, including Ciba–Geigy, and a new biotechnology industry contribute to this strength. Novartis, which has advanced genomics capability, and the SwissPro Protein Database are centered in Switzerland. Swiss quality control systems for the production of pharmaceuticals use sensor systems that have application to biological agent defense.

Two primary biotechnology entities in Israel are at the leading edge of detector and sensor systems. Yeda Research and Development Company is affiliated with Weizmann Institute in Rehovot; Yeda has a long tradition of developing advanced sensors for various sectors including defense. Technion, in Haifa, has strength in sensor interfaces and prototype production.

Eurona Medica, in Upsala, Sweden, has research programs in gene profiling and drug response. This technology has direct applications to detection and screening technologies. The University of Umea in Sweden is developing new data-reduction techniques for detection. Private sector and national laboratories in the Peoples Republic of China have partnership agreements with several U.S. biotechnology firms. The University of Science and Technology of China has x-ray lithography capability that may be used in the design of sensors. Poland is noted for its efforts in food safety and detection of biologicals in food; Singapore is similarly noted for efforts in water monitoring. Cuba has expertise in vaccine development against meningitis (type B) and cholera; it may have capability in detecting agents that cause the disease.

b Protection

Biological and chemical protection includes both individual and collective protection of Army assets. The individual protection capabilities include vaccinations, body coverings, and transport of persons exposed to agents. Post-exposure aspects of individual and group protection include antibiotics, antivirals, antifungal compounds, and immune-enhancing compounds (biological response modifiers). The group protection includes ventilation and air control inside as well as on the surface of vehicles.

Canada, Germany, and France have programs for improving individual protection body covering. These efforts are directed toward identifying leaks in the protective equipment and improving body cooling for persons in the protective gear. Israel has developed several masks that may be protective against biological agents, as well as an extensive civilian mask program. The DERA CBD Sector (U.K.), Defense Science Organization (Singapore), Prins Maurits Laboratory (PML) (Netherlands), and AC Laboratorium Spiez (Switzerland) have active programs developing or testing clothing or body coverings protective against CB agents. Singapore has also cooperated with several countries in providing a test ground for hot and humid conditions.

Current collective protection filters for combat vehicles require periodic replacement. The surfaces and filters must be replaced relatively frequently after exposure to CB agents. After extended use in an attack-free environment, the filters must be replaced at fixed intervals. Pressure swing absorption technology, developed in gas exchange systems, is a primary approach used to achieve collective protection. German expertise in filter system development and U.K. expertise in temperature swing absorption technology provide capabilities related to collective protection. The pressure swing absorption technology was developed by the chemical gas purification industry. Polymer grafting capability in Israel (Yeda Corporation) and Sweden (Center for Chemistry and Chemical Engineering, Lund) has applications to improved design of collective protection systems.

c Decontamination

Decontamination is focused on developing new (noncorrosive) capabilities for decontaminating equipment and large areas (such as ports and airfields). One part of this effort is bioremediation—the use of biological organisms to clean up wastes and CB agents. Bioremediation has utility with regard to both cleaning a contaminated area and reducing signatures in a contained environment. The biological organisms resident in the area of the waste material frequently have utility in achieving degradation of the contamination. *Pseudomonas* is one example of an organism that degrades nitrotoluenes, spent fuels, and other organic waste products. Current chemical methods used to achieve decontamination of soils and waste materials are themselves toxic to the environment in large volumes. Enzymes are also being considered for decontamination of equipment, as are reactive sorbents and several nonaqueous methods.

Several corporate entities have expertise in bioremediation; Bio-Logic Remediation Ltd. in Scotland; GBB and Zeneca in the Netherlands; Eberhard in Kloten, Switzerland; Bioforj in Guelph, Canada; HP-Biotechnologie in Witten, Germany; the University of Karlsruhe in Germany; and GMG International in Sweden. Microbiologists in Tel Aviv have expertise in bioremediation of coastal sands contaminated with oil spills; the Israeli group isolated bacteria from oil spill-contaminated beaches, and the organisms degraded oil. U.S. private sector groups have technology exchanges with some of the foreign firms identified above.

Canada has a strong effort in decontamination, including the reactive skin decontamination lotion and the Canadian Aqueous System for Chemical-Biological Agent Decontamination products. The U.K. has also restarted a fledgling program in this area. Several older technologies from former Warsaw Pact countries are of interest to the large area decontamination problem.

d Modeling and Simulation

A large portion of the technology used for M&S is the dispersion of CB agents common to that used for weather forecasting and environmental pollution control. Nations with advanced satellite capability will also have strength in the modeling of CB agents dispersed above ground. These include the U.K., Canada, France, Japan, Germany, Israel, China, and Russia. The technology required for determining and predicting wind flow patterns at discrete altitudes above sea level, on a real-time basis, remains to be developed.

The U.K. and Israel have developed an urban agent dispersion model. The U.K. and Canada have refined current hazard assessment models to include casualty prediction and are moving forward into probabilistic models.

e Example Research Facilities

The following facilities have demonstrated expertise in chemical/biological defense technology development:

- France—Pasteur–Merieux–Connaught [<http://www.aventis.com>]
- Japan—NEC Tsukuba Research Laboratories [<http://www.labs.nec.co.jp/Eng/index.html>]
- United Kingdom—DERA [<http://www.dra.hmg.gb>]
- Netherlands—Organization for Applied Scientific Research—Prins Maurits Laboratory (TNO–PML) [<http://www.tno.nl>]

9 Engineering, Combat Construction, and Countermine

Table E–8 summarizes international engineering, combat construction, and countermine technology capabilities.

TABLE E–8. TECHNOLOGY DEVELOPMENT—ENGINEERING, COMBAT CONSTRUCTION, AND COUNTERMINE

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
CIVIL ENGINEERING & ENVIRONMENTAL QUALITY						
♦ ♦ ♦ ♦ + Environmental protection Bioremediation Regulatory compliance Lightweight bridging Response of conventional structures to blast	♦ ♦ ♦ ♦ + Environmental protection Bioremediation Demil of energetic materials ♦ ♦ ♦ ♦ Survivable structures High-performance construction materials	♦ ♦ ♦ ♦ + Environmental protection Bioremediation ♦ ♦ ♦ ♦ Response of hardened structures to conventional weapons	<i>Japan</i> ♦ ♦ ♦ ♦ + Environmental protection Bioremediation Bridging, highways, buildings Infrastructure Crash survivability			<i>Nordic Group, Israel</i> ♦ ♦ ♦ ♦ + Environmental protection Bioremediation
MINES & COUNTERMINES						
♦ ♦ ♦ ♦ IMF	♦ ♦ ♦ ♦	♦ ♦ ♦ ♦ Ordnance package design EM interference	<i>Japan</i> ♦ Intelligent systems	♦ ♦ ♦ ♦	♦ ♦ ♦ ♦ Demining	<i>Italy</i> ♦ ♦ ♦ ♦ Mines

Note: See page E–6 for legend.

a Civil Engineering and Environmental Quality

This technology area focuses on critical civil engineering and environmental quality problems related to training, mobilizing, deploying, and employing a force at any location at any time. The goal is to provide an environmentally sustainable, military-unique infrastructure at the lowest possible life-cycle cost.

The problems of meeting national and international environmental standards and of engineering-affordable and -sustainable facilities and infrastructures in a climate of reduced funding are common to all of our potential partners. Remediation of environmental pollution and maintenance of infrastructure are areas of considerable importance to the civil sector as well, and most industrialized nations have active programs in techniques, materials, and M&S to support requirements analysis and design.

Civil engineering subareas include conventional facilities, airfields and pavements, survivability and protective structures, and sustainment engineering. The primary thrust of technologies for conventional facilities is to revitalize and operate DoD's aging infrastructure at an affordable cost. In airfields and pavements, the major effort is to reduce life-cycle costs. Survivability and protective structures address reliable and affordable structural hardening, retrofit hardening, and camouflage, concealment, and deception to increase survivability and force protection, from the foxhole to the deeply buried command structure, against threats from conventional munitions, terrorists, and advanced precision penetrators.

Foreign capabilities of most interest are in the areas of high-performance construction materials (France), material systems and response of conventional structures to blasts (U.K.), and response of hardened structures to conventional weapons (Germany). The U.K. and Germany develop and market military systems for lightweight bridging and other civil engineering applications, and they have sound capabilities in alloys and structural designs for such systems. As mentioned earlier, France has special expertise in developing crash-survivable and energy-absorbing materials. Japan has a significant capability in structural design and in practical engineering of crash-survivable vehicles and structures. Japan also has a large civil structures program (bridges, highways, buildings, etc.) that has military significance.

Environmental quality subareas include cleanup of contaminated sites, compliance with all environmental laws, pollution prevention to minimize Army use and generation of wastes and adverse affects on the environment, and conservation of our natural and cultural resources. The U.K. has been a leading force in the development of international standards for environmental management systems. Many of the current draft International Standardization Organization (ISO) standards are patterned after existing British standards. Japan, the U.K., Germany, France, Israel, and the Nordic Group all have significant efforts in bioremediation—the use of biological organisms or their products (enzymes) to breakdown or neutralize a wide range of contaminants. The French in particular have had a longstanding interest and strong effort in biodegradation and demilitarization of energetic materials. The international community has a growing concern for cleaning up organophosphate-insecticide-contaminated sites. An effective enzymatic treatment for this purpose might also be adopted for decontamination of nerve agents. We can anticipate that growing awareness of environmental effects as regional and global issues and the emergence of international standards for their effective management lead to opportunities for increased cooperation to improve pollution prevention, environmental protection, techniques for monitoring and compliance, and remediation—particularly with EC countries and Japan, which are moving rapidly toward adoption of the ISO 14000 standard.

b Mines and Countermines

Humanitarian concerns have led to increasing international pressures to outlaw land mines. At the same time, military forces worldwide see mines as meeting critical mission needs. The growing global concern about increased proliferation of mines points to the need for international development and adoption of new design standards and mine-clearing capabilities.

One potential solution—more intelligent mines and minefields—is of global interest. Opportunities for cooperation in intelligent mine/minefield technologies are found in countries that couple historical capabilities in state-of-the-art land mines with strong capabilities in advanced sensors, electronics, and telecommunications, such as the U.K. and France, followed closely by Italy and Germany. Canada is doing substantial work in the subarea of mines and countermines. An MOU between CECOM and its Canadian defense laboratories counterpart in staffing

will expand cooperation. Russia has been a major operational user of landmines and should have substantial empirical experience from which to draw.

The U.K. has significant strength in all areas relating to intelligent minefields (IMFs), including signal processing and antiarmor weapons. Traditionally, the U.K. has been strong in intelligent systems, and researchers at Fort Halstead in the U.K. are actively pursuing fuzzy logic techniques and fuzzy inference engines to enhance current intelligent command aids. The present system, called “GeKnoFlexE,” is a conventional, rule-based implementation designed to simulate battlefield decisionmaking. This will be used as a baseline and testbed for investigating the relative benefits of incorporating fuzzy rules and a fuzzy inference mechanism. The results may provide insight into ways to enhance the performance of operational decisionmaking. Since the current GeKnoFlexE system is completely deterministic, direct comparisons of complexity, behavior, and other performance parameters will be possible.

Germany has strong across-the-board capabilities. It is particularly strong in ordnance package design (including warhead fabrication for antiarmor weapons) and is heavily involved in C⁴I efforts to improve interoperability. Strong telecommunications are an essential element in IMF. The International Command and Control Systems Interoperability Project with Germany is part of the Army’s strategy for international digitization. Its objectives are to create a joint testbed facility to conduct R&D efforts needed to implement, evaluate, and validate improved interoperability between the U.S. and German (C²) forces. Within the EC, Germany is recognized as a technological leader in telecommunications.

France also has strong capabilities, particularly in telecommunications. Much of the mobile subscriber equipment design is based on French technology. A current U.S.–French treaty requires multinational fire support from C² centers of either nation. In addition, fire-support battalions of either nation may be mission assigned to brigades of the other nation. France has good capabilities in intelligent systems, particularly for real-time operations. As in many other countries, organizations are actively investigating applications of ANNs and fuzzy logic to military systems. Work at the defense firm Matra has been identified as being of interest in this area. France also has strong capabilities in batteries and might be able to contribute to advanced technology to meet primary power requirements.

Israel has strong capabilities in most areas of IMF technology and specifically in one of the critical aspects—acoustic sensors. Acoustics efforts include adaptive beamforming algorithms, sound-cancellation techniques to eliminate platform and wind noise, and neural network algorithms for target identification. Israel has demonstrated sensor fusion techniques that significantly increase the acoustic detection and identification performance of sensors. Israel is reported to be in the final phases of development for advanced helicopter detection, sniper, and mortar location systems.

Japan has the necessary sensor and electronics capabilities to implement an IMF concept. Japan is assessed to be among worldwide leaders in two areas that may contribute to future IMF concepts. The first is in practical application of intelligent systems. Japan’s ongoing RWC initiative is heavily invested in neural networks. Second, work in optical ANNs, if successful, has the potential to increase effective processing throughputs by orders of magnitude.

Sweden is nearly on par with the world leaders in most aspects of technology. Ericsson, a recognized leader in communications, has a significant background and experience in the develop-

ment of antiarmor weapons, including mortar-launched EFP munitions. Canada has strengths in C⁴I and telecommunications and has strong capabilities in acoustic signal processing.

The countries identified above are working at or near the state of the art; however, the technological building blocks of IMF are widely available. Other countries capable of developing some degree of IMF capability include Italy, Switzerland, Norway, the Netherlands, Russia, Ukraine, India, and South Africa.

Although a number of nations are involved in mine clearing activities, Canada's expertise in countermines is particularly noteworthy. DRES has an ongoing initiative in this area covering a wide spectrum of activities, including remote minefield detection and improved breaching methods. DRES, with support from DREO, is developing a multisensor, teleoperated mine detector. The system uses a sophisticated multisensor data fusion scheme using magnetic, ground-penetrating radar and IR sensors to detect potential mines, and it uses thermal neutron activation technology to confirm the presence of explosives to reduce false alarms. The system has been evaluated in comparative testing and reportedly performed as well as U.S. technology, particularly with respect to false-alarm discrimination.

With the recent worldwide visibility of the landmine problem, many nations have taken a new interest in developing close-in mine detection and mine neutralization technologies. Italy and Canada have initiated programs to test and evaluate mine detection equipment. In the counter-mine area specifically, leaders in developing mine detection and mine neutralization equipment include France, Germany, the U.K., Israel, South Africa, Russia, and the United States. Germany continues to be a leader in EM interference hand-held detectors, with Forster and Vallon. Dornier has developed standoff minefield detection sensors together with Carl Zeiss, using ATR algorithms by the Fraunhofer Institute. Elta of Israel has developed a ground-penetrating radar for use on remotely controlled ground vehicles. Both Israel and Russia have been leaders in developing advanced mechanical and spoofing technologies to be mounted on ground platforms. South Africa has developed new methods of using multiple canines for mine detection and of providing blast protection for countermines vehicles. Canada and the U.K. have recently invested heavily in humanitarian demining detection technologies and systems. Austria and Australia are noted for capabilities in these areas as well.

c Example Research Facilities

Canada—DRES [<http://www.crad.dnd.ca/>] has demonstrated expertise in engineering, combat construction, and countermines technology development.

10 Materials, Material Processes, and Structures

Advances in materials and processes are integral objectives of a number of ASTMP programs, including materials for aeropropulsion, characterization of structures for rotorcraft, ballistic protection for soldier systems, materials and structures for hypervelocity missiles, and structures for ground vehicles. Table E-9 summarizes international materials/processes capabilities.

a Material Processes for Survivability, Life Extension, and Affordability

The Army's materials, processes, and structures program provides enabling technologies to construct every physical system or device used by the Army. This program provides unique solutions and options that increase the level of performance and durability and reduce the maintenance burden and life-cycle costs of all Army systems. Material technology focuses on

materials with superior properties required for use in structural, optical, armor and antiarmor, CB and laser protection, and infrastructure applications. All classes of materials are included—metals, ceramics, polymers, composites, coatings, energetic, semiconductors, superconductors, and electromagnetically functional materials.

As the table illustrates, a number of countries have strong capabilities in advanced materials. The U.K., France, Japan, and Germany have expertise in metal alloys and composite materials. Noteworthy here is the special capabilities that France is developing in carbon-carbon (C-C) and other ceramics and in the design of crash-survivable structures (noted elsewhere in this annex). In addition, Israel has niche capabilities in metal alloys and organic matrix composites.

TABLE E-9. TECHNOLOGY DEVELOPMENT—MATERIALS, MATERIAL PROCESSES, AND STRUCTURES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
MATERIAL PROCESSES FOR SURVIVABILITY, LIFE EXTENSION, AND AFFORDABILITY						
◆◆◆◆ Metal alloys Composites Polymers Lightweight engineering structures Smart structures Embedded sensors Control of composites processing ◆◆◆◆+ Welding & joining; beryllium processing	◆◆◆◆ Metal alloy Composites Ceramics C-C ceramic part fabrication Energy-absorbing structures Smart structures Bridging Control of composites processing	◆◆◆◆ Metal alloys Composites Ceramics Functional gradient coatings Engineering structures Smart structures Embedded sensors Bridging Control of composites processing	<i>Japan</i> ◆◆◆◆+ Ceramics Composites Polymers Ferrous alloys Polymer processing Engineering structures Bridging Embedded sensors <i>China</i> ◆◆◆◆+ Metal alloys Composites ceramics <i>India</i> ◆◆+ Metal alloys Composites ceramics <i>ROK</i> ◆◆◆+ Tungsten beryllium processing	◆◆— Welding Joining Ti Structures Ion-beam coating Structural ceramics ◆— Ti alloy	◆◆ Ceramics Composites	<i>Israel</i> ◆◆ Metal alloys Organic matrix composite <i>Netherlands</i> ◆◆ Ceramics <i>Austria</i> ◆◆ Refracting metals <i>Australia</i> ◆◆ Composites
MANUFACTURING TECHNOLOGY						
◆◆◆◆ Cooperative efforts—CASE tools; industrial robotics			<i>Japan</i> ◆◆◆◆+ Fuzzy logic for process control ◆◆◆◆ Industrial robotics <i>China</i> ◆◆◆+ Hot isostatic pressing CVD Boron and carbon fibers MMCs	◆◆— Welding Joining		

Note: See page E-6 for legend.

Japan has been and is expected to continue to be a major developer and producer of fibers and matrix feedstock for advanced polymer composites that are essential for many advanced materials. Japan has also maintained its leadership position in the development of ceramic- and polymer-based composites. The driving forces behind the effort in the R&D of advanced composites are the aircraft industry, space program, and defense industry. The overall scope of Japan's advanced composites research is not as extensive as that in the United States, but the quality in some respects is comparable. Japan is a world leader in "fine ceramics"—high-purity ceramics with specific performance characteristics, as opposed to bulk ceramics that might be employed for ballistic protection.

In Europe, the BRITE/EURAM program has 35 percent of its effort dedicated to materials and technologies for product innovation, 14 percent to technologies for the aeronautical sector, 14 percent to technologies for other transport means, and 37 percent to production technologies. Emphasis is placed on three themes:

- Materials with wide-ranging application—priority will include nanostructured materials, new and improved structural and lightweight materials for construction, transport and high-temperature materials, ceramics, ceramic matrix composites (CMCs), and biomaterials.
- Materials production and transformation processes—production of fine and specialty chemicals, minerals, metals, polymers and their composites.
- Sustainable use of materials—environmental and safety impact of new materials, materials that are easy to cycle, waste management, and new applications of renewable raw materials.

Germany is among the world leaders in structural ceramics. Much of its emphasis has been on developing materials for automotive and aerospace applications. Research centers include the BeaTec application center machining technology for advanced materials (Fraunhofer Institut für Produktionstechnologie IPT Aachen), Fraunhofer Institute for Ceramic Technologies and Sintered Materials, IKTS Dresden and Ceramics Department at Cologne, and the German Aerospace Research Establishment Materials Research Institute.

The U.K. program includes research at University of Birmingham Advanced Materials Department; the School of Industrial and Manufacturing Science, Cranfield University [<http://www.cranfield.ac.uk/sims/>]; the Department of Materials, Queen Mary and Westfield College, London [<http://www.materials.qmw.ac.uk/>]; the Oxford Centre for Advanced Materials and Composites [<http://www.materials.ox.ac.uk/research/index.htm>], University of Oxford; the Department of Engineering Materials, University of Sheffield [<http://www.shef.ac.uk/uni/academic/D-H/em/>]; and the University of Nottingham. The U.K. also has considerable expertise in the defense establishment and in the private sector directed specifically toward lightweight armor applications of ceramic materials. The U.K. advanced ceramics project [<http://www.ceram.co.uk/>] conducts research across a wide array of topics, including several specifically related to armor: aluminum nitride for armor applications, hot-pressed B₄C for armor applications, injection molding of silicon nitride, and fabrication and evaluation of dense sintered SiC.

France has traditionally had a strong program in high-temperature ceramics and in armored systems. The Geopolymer Institute [<http://www.insset.u-picardie.fr/geopolymer/>], University of Picardie at Saint Quentin, is involved in research dealing with the geosynthesis of inorganic molecules, geopolymer chemistry yielding high-performance ceramics, fire-proof composites, ceramic tooling, and special and high-performance concrete.

The Netherlands maintains research programs in technical ceramics, including the Centre for Technical Ceramics in the Department of Solid-State Chemistry and Materials Science at the

Eindhoven University of Technology (where extensive research in Sialon materials is reported) [<http://www.chem.tue.nl>] and in the Technical Ceramics subgroup of the Research Group of Materials Science and Engineering [<http://www.phys.rug.nl/mk/research>], at the University of Groningen.

Canada has a variety of university research programs in ceramics, including work at the Technical University of Nova Scotia, [<http://www.dal.ca/daltech/researchcentres.html>] and in the Ontario Centre for Materials Research–Ceramic Processing Facility at McMaster University Hamilton, Ontario [<http://www.mse.mcmaster.ca>]. In addition, there are at least two established Canadian suppliers of soft body armor tested to U.S. National Institute of Justice (NIJ) standards. These firms have the resources and the incentive to develop more advanced armor configurations to meet competition from other suppliers who have begun to market composite ceramic/ballistic fabric body armor.

China is building a large composite materials S&T capability with research on polymer matrix composites (PMCs), metal matrix composites (MMCs), CMCs, and C-C composites. China is also heavily involved in work on functional composites, microstructures and interfaces, fatigue and fracture, and properties characterization. The principal performers of this work are the Beijing Institute of Aeronautical Sciences (BIAM) and the Shanghai Institute of Ceramics (SICCAS). In addition, there are at least 12 other universities and institutes involved in this research. China is very interested in cooperative programs with researchers around the world and has instituted a number of agreements.

India is involved in a strong research program in composite materials, particularly PMC; some MMC effort is also in progress. The principal laboratories performing this research work are the NAL; the Indian Institute of Science, Bangalore; and the National Physical Laboratory. Although one of their major goals is to establish strong indigenous capabilities, India is still dependent on foreign nations for assistance, and thus they are very interested in establishing worldwide cooperative agreements in specific areas.

The vast Russian materials S&T establishment is slowly deteriorating because of economic difficulties. Some institutes (such as the Paton Metallurgical Center) still exist, although many of the leading researchers have left. Russia is very interested in any foreign cooperative agreements that would bring some funding into the country.

Materials processing includes all technologies by which raw or precursor materials are transformed into useful materials or components with the requisite properties and at an acceptable cost for Army applications. These technologies include casting, rolling, forging, sintering, polymerization, composite lay-up and curing, machining, and chemical vapor deposition. Coating processes are of special interest because they affect many devices and components. Ion-beam-assisted deposition and pulsed-laser deposition are two areas of keen interest. Improved process control techniques are also sought, especially related to resin-transfer-molded composites and Smartweave armor materials.

Several foreign capabilities are of interest in the materials processing subarea. The U.K. has strengths in welding and joining. Germany has unique capabilities in explosively formed projectile (EFP) and other warhead metallurgy, as well as processes for deposition of functionally gradient materials. France has special skills in high-density tungsten carbide ceramics that have potential for armor technologies. Austria also has tungsten processing research of interest. The European BRITE/EURAM program includes projects related to composite structures such as

design tools for advanced composites, manufacturing of complex or hybrid composite structures, and reliability and quality. The main goal of these efforts is cost reduction.

Compared to U.S. research institutes, the Japanese have placed more emphasis on processing/fabrication science. The Japanese composites industry has played a leadership role in advancing textile-preforming technology based on weaving, braiding, knitting, and stitching. A considerable interest exists in combining resin transfer molding, resin film infusion, and pultrusion techniques with fabric preforms for polymer composites manufacturing. The technologies are fairly well developed in industry.

Ongoing activities in Japan include work in microwave curing and low-cost manufacturing based on resin film infusion, resin transfer molding, and automated tape placement. This work is being carried out in collaboration with U.S. industry. Other notable innovations in Japan include five-axis weaving, which is enabling the production of wider 3D woven fabrics for ballistic and impact resistance, and a braiding/pultrusion system that enables the production of high-performance composites at low cost. Japan has developed improvements in the processing of CMCs through the polymer pyrolysis route. The quality of products is better than that of products fabricated via the chemical vapor deposition route. The continuing improvement of the quality of high-temperature ceramic fibers, the availability of polymer precursor materials, the fiber surface treatment technology, and the development of sealants have all contributed to advancements in CMC technology.

Formerly strong Russian capabilities in welding and ion-beam coating are declining. South Korea has a noteworthy program in tungsten penetrator technology that could be beneficial to the United States. Specific heat treatment processes for tungsten alloys have been developed that offer the potential to enhance impact strength for penetrators. China's BIAM and SICCAS establishments are pursuing a wide range of processing technologies such as hot isostatic pressing, self-propagating synthesis, spray atomization, codeposition, and liquid infiltration.

This subarea focuses on developing structural elements with a high level of structural integrity that are inspectable, are analyzable, and can survive the harsh combat environment. To be cost effective, the design must integrate advanced structural concepts that are compatible with mass production manufacturing technologies. Japan is noted for having developed products with complex shapes and thick sections on a routine basis using fully automated machines.

The structures must also be designed to specific vibration and noise levels to maintain crew comfort and a low noise signature. Particular emphasis is on design tools, modeling, failure and fatigue, and life prediction analysis. In addition, developing NDE techniques for identification and quantification of defects and anomalies in composite structures is important. Most European nations and Japan have extensive capabilities and programs in NDE technologies.

A growing area of worldwide research interest is smart structures—instrumented structural designs that adapt to external conditions and stimuli to optimize performance. Closely related to this is the use of embedded sensors (usually based on fiber optics) for monitoring performance and structural conditions. The U.K., France, and Germany have significant capabilities in this area and offer potential opportunities for cooperation.

b *Manufacturing Technology*

Manufacturing technology focuses on technologies that will enable the industrial base to produce reliable and affordable materials and products. It requires integration of all aspects of manufacturing from raw materials through design and integration of components, subsystems, and systems. In the future, international developments are likely to drive greater standardization in manufacturing engineering support tools, including CASE, virtual prototyping, and enterprise integration and control technologies. Already we are seeing rapid growth in technologies for distributed design and management of very complex enterprises in highly industrialized countries, notably Japan, the U.K., France, Germany, and throughout the EC. This trend will be further supported and enabled by the growth of the Internet and its underlying telecommunications infrastructure. Ultimately we can expect to see a seamless integration of distributed M&S with enterprise operation, which will further speed the international exchange of advanced manufacturing capabilities.

China's BIAM and SICCAS claim to have established small-batch production capabilities. BIAM produces boron fibers and B/Al composites using hot isostatic press procedures. BIAM also claims to be producing SiC particulate (SiCp)/Al alloy composites. SICCAS claims to have established a pilot line to produce 1,200–1,500 g of carbon-fiber-reinforced aluminum using domestically produced carbon fibers. BIAM is also working in the area of carbon-fiber-reinforced magnesium.

c *Example Research Facilities*

The following facilities have demonstrated expertise in materials, materials processing, and structures technology development:

- Europe—Basic Research for Industrial Technologies in Europe—European Advanced Materials Program
- China—Beijing Institute of Aeronautical Sciences
- Canada—Structures, Materials and Propulsion Laboratory, Institute for Aerospace Research
- India—National Aerospace Laboratory

11 Sensors and Electronics

This section is divided into two areas: sensors and electronics. Sensors are critical systems for intelligence gathering and situational awareness. They are the multispectral “eyes and ears” for our forces. Electronics are enabling for developing components critical to military applications, such as lasers or display technologies. The battlefield environment reviews the impact of the terrestrial and lower atmosphere environment on sensors and systems. Table E–10 summarizes international sensors, electronics, and battlespace environment technology

a *Sensors*

The topic of sensors encompasses a wide range of diverse physical phenomena and technology, including seismic/acoustic ground sensors and EM sensors in all regions of the spectrum, from extremely low-frequency magnetic anomaly detection to space-based UV and even shorter wave optical devices. Sensor technologies also include associated capabilities for acquiring and processing sensor data to derive useful information regarding the operating environment, as well as the location, identity, and activities of friendly and adversary forces.

TABLE E-10. TECHNOLOGY DEVELOPMENT—SENSORS AND ELECTRONICS

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
SENSORS						
RADARS						
◆◆◆◆	◆◆◆ Optical switching of microwave power	◆◆	Japan ◆◆◆◆ + Electronic components		◆◆	
ELECTRO-OPTICAL						
◆◆ Optical processing	◆◆◆◆ + IR FPA Laser sensors Multidomain sensors	◆◆◆ IR FPA Laser sensors	Japan ◆◆◆◆ + Photonic devices Laser applications ◆◆ Image Intensifiers ROK ◆ Thermal Imaging			Netherlands ◆◆◆◆ Image Intensifiers
ACOUSTIC, MAGNETIC, & SEISMIC						
◆◆◆◆ + Acoustic sensors Seismic	◆◆ Seismic					Israel ◆◆◆◆ Acoustic sensors
AUTOMATIC TARGET RECOGNITION						
◆◆◆◆ Signal processing CID	◆◆◆◆ Signal processing CID	◆◆◆◆ Signal processing CID	Japan ◆◆◆ Signal & image processing ROK ◆			Israel ◆◆◆◆ Target recognition Signal processing
ELECTRONIC DEVICES						
INTEGRATED PLATFORM ELECTRONICS						
◆◆◆◆ Vehicle integration	◆◆◆◆ Multisensor integration	◆◆◆◆ Vehicle integration				
ELECTRONIC MATERIALS						
◆◆◆ SOI, SiC	◆◆◆◆ SOI ◆◆◆ SiC	◆◆◆ SOI, SiC	Japan ◆◆◆◆ + SOI, SiC China ◆◆◆ ROK, Taiwan ◆◆ SOI, SiC	◆◆◆ SiC ◆◆◆ SOI		Sweden ◆◆ Czech Republic, Netherlands, Israel ◆ Current & predicted weather
MEMS						
◆◆◆	◆◆◆◆	◆◆◆◆	Japan ◆◆◆◆ + China ◆ ROK, Taiwan ◆◆	◆◆	◆◆	Switzerland, Netherlands ◆◆◆ Belgium, Sweden, Norway, Greece, Spain ◆◆

TABLE E-10. TECHNOLOGY DEVELOPMENT—SENSORS AND ELECTRONICS (CONT'D)

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
PORTABLE ELECTRICAL POWER						
◆◆◆◆ Batteries Rotating machinery HTS	◆◆◆◆ Batteries Fuel cells Rotating machinery	◆◆◆◆	Japan ◆◆◆◆+ China ◆◆ India ◆ ROK ◆	◆◆◆— Fuel cells Rotating machinery	◆◆◆+ Fuel cells Electromechanical storage	Israel, Italy, Spain ◆◆ Austria., Belgium, Australia, Denmark, Netherlands, Poland, Ukraine, Switzerland ◆

Note: See page E-6 for legend.

Radar is the primary sensor for all-weather detection of air, ground, and subsurface targets. It includes wide-area surveillance radars, tactical reconnaissance radars, and airborne and ground fire-control radars. Areas of special interest involve the phenomenology of ultra-wideband (UWB) synthetic aperture radar to enable detection and classification of stationary targets that are subsurface or concealed by foliage or camouflage. Foliage-penetration and ground-penetration systems are the major goal. UWB techniques are also in use in biomedical applications. Most radar research is applicable to military applications. Major technical challenges include understanding wave propagation in background/clutter environments; developing high-power, low-frequency, and wideband system capability; and developing components and algorithms to support high-probability detection and classification with low false-alarm rates. Affordability is a major issue because sensors are so prevalent on the battlefield.

**Real beam search on-the-move
targeting against stationary
ground targets**
Buried target detection
Enhanced spatial resolution
MMW antennas and scanning
Affordability

The U.K., France, and Germany, and to a lesser extent, Japan and Israel all have significant capabilities and niches of excellence. Noteworthy highlights include France's expertise in optical distribution and switching of microwave energy and Japan's world leadership position in electronic components. Monolithic microwave integrated circuit components are especially important for millimeter wave (MMW) radars, and the U.K., France, Germany, and Japan all have strong capabilities in this area of technology.

**Growth and processing of thin-film materials
for uncooled detectors**
**Monolithic integration of detector, readout,
and processing modules**
**Material growth and processing for multicolor
FPAs**
Fusion algorithms for multidomain sensors
Performance against countermeasures
Multidomain signature databases
Diffraction optical element design
**Integration of diffraction optical elements,
detectors, and post-processing circuitry**
**Affordable and effective laser hardening
against multifunction, multiband lasers**

EO sensors provide passive/covert and active target acquisition (detection, classification, recognition, and identification) of military targets, and also allow military operations under all battlefield conditions. Platforms include combat personnel, ground combat and support vehicles, tactical rotary-wing aircraft, manned/unmanned reconnaissance aircraft, and BMD/TMD. EO sensors are increasingly important in weapon systems of all kinds.

France is recognized as a world leader in state-of-the-art IR focal plane arrays (FPAs). Their work on HgCdTe large-area staring arrays could be important for future multi-domain smart sensors. The Army Research Laboratory and scientists from LETI (Grenoble, France) are cooperating to

develop techniques to grow buffer layers on Si that would allow integration of the HgCdTe detectors and Si readout in much larger arrays. A new technique is being investigated that promises far lower defects for much larger arrays. France also has special capabilities in short-wavelength (visible and UV) lasers that are very important for some optical countermeasures and standoff biological agent detection. Appropriate laser media are required to take full advantage of advances in laser diodes and diode pumping technologies. The Université de Lyon has special expertise in highly efficient laser emission and extensive knowledge of UV-emitting materials.

Japan is a world leader in all aspects of photonics and is strongly positioned in laser applications. Their camouflage, concealment, and deception technology dominates consumer electronics and may provide future leveraging opportunities for military applications. Germany has made significant progress in processing IR images and in multisensor integration. At the Fraunhofer Institute in Freiburg, considerable research is conducted in quantum well and superlattice materials for detectors spanning the spectral region from UV to long-wave IR.

The U.K. has special expertise in optical processing, optical components, and optoelectronics (OE). Photonic processors using this technology offer inherently high bandwidth, compactness, power efficiency, and immunity to EM interference. The noninterfering nature of light and its propagation characteristics lend themselves to future massively parallel, high-speed information processing. Finally, the Netherlands has special capabilities in second-generation image intensification that could be of value. The United States has diverted its major effort to production of third-generation image intensifiers based on III-V compound semiconductor photocathodes. The Netherlands has continued to improve the multi-alkali photocathodes.

Acoustic, magnetic, and seismic sensors provide real-time tracking and target identification for a variety of battlefield ground and air targets. Advances in digital signal processing devices and algorithms have led to significant improvements in acoustic sensors, making them more feasible and affordable. Attended and unattended systems have application against both continuous signals (such as engine noise) and impulsive signals (such as gun shots). Acoustic sensors involve the use of microphone arrays to detect, locate, track, and identify air and ground targets at tactical ranges. Target information from multiple acoustic sensor arrays is digitally transmitted to a remote central location for real-time battlefield monitoring. Enhanced hearing for individual soldiers is another important area, and techniques to extend the soldier's long-range hearing and frequency response are being developed.

Most modern armies have some ongoing work in battlefield acoustic sensors, with no one country having a dominant capability. The U.K. and France offer strong capabilities related to seismic sensors, and Israel provides unique opportunities in acoustic sensors. Current efforts in acoustics include adaptive beamforming algorithms, sound cancellation techniques, and neural network algorithms for target identification. Israel has been developing advanced helicopter detection, sniper, and mortar location systems based on acoustic sensing. The United States has been conducting joint exercises with the Israeli army, and future cooperation will provide potential solutions to acoustic propagation problems, long-range target detection algorithms, and detection in the presence of wind and platform noise.

Advanced target identification algorithms
Multitarget resolution
Detection
Platform and wind-noise-reduction techniques
Compact array design for long-range hearing

The goal of automatic target recognition (ATR) sensors is to provide sensors with the capability to recognize and identify targets under real-world battlefield conditions. ATR systems will allow weapon systems to automatically identify targets (and friendly forces), which will increase lethality, reduce the number of costly weapons used, and eliminate or reduce the cost of losses from friendly fire. The technical challenge is to provide high identification rates with very few false alarms for a large number of target classes. Supporting technologies include processors, algorithms, and development tools, including M&S. Current efforts focus on single and multiple sensor ATR algorithm development.

Most countries have active development programs aimed at enhancing ATR capabilities. Underlying feature extraction and pattern recognition algorithms are common topics of academic research. Adaptation of these algorithms for effective military use demands access to specific target and threat characteristics, information that is closely held by all nations to protect sensitive collection methods and sources. Several areas are of special interest for possible cooperative efforts. Japan has done extensive work in visual systems for industrial robots and in Kanji character recognition. While not directed to military ends, the underlying techniques may be of interest. The U.K., France, and Germany have strong capabilities in signal processing for ATR and combat identification (CID), and are close enough allies to share some sensitive target/threat information. Germany has particular expertise in CID of friendly troops that is important for reducing fratricide and improving situational awareness. France has special expertise in ATR algorithms for use in multisensor (forward-looking IR, MMW, and possibly laser radar) systems that could be helpful in developing real-time multisensor techniques. In addition, Israel has strong capabilities in target characterization that could be applicable to a number of efforts, including signature measurements in radar/MMW, signature rendering in the visual and IR regimes, and target-acquisition modeling for imaging IR sensors. The United States has held a cooperative signature workshop with Israel that covered a number of areas associated with ATR, including topics on characterization of target/clutter, synthetic scene-generation modeling, target acquisition model enhancement, dynamic measurements using super high-resolution MMW, and model validation.

Integrated platform electronics focuses on the integration of technologies, disciplines, standards, tools, and components to physically and functionally integrate and fully exploit electronic systems on airborne (helicopters, RPV, and fixed-wing), ground, and human platforms. Integrated platform electronics can result in dramatic cost and weight savings while providing full mission capability. The major technical challenge lies in determining an architecture that is sufficiently robust to readily accept commercial technology innovations. Improving reliability, an important challenge, can lead to reduced logistics and deployment burdens while containing support costs. In addition, standardized image-compression techniques and architectures are of current interest to permit transfer of images with sufficient clarity and update rates to support digitization of the battlefield.

Cooperation in this area leads not only to enhanced performance, but also contributes to standardization and interoperability of coalition forces. Those countries most advanced in development and production of advanced military vehicles offer the best potential for cooperative efforts. The U.K. and Germany have special capabilities in vehicle integration that is of interest, and France has special expertise in multisensor integration that is relevant to integrated platform electronics.

b *Electronic Devices*

Electronics plays a crucial role in battlefield supremacy, enabling or affecting virtually every aspect of warfighting. Electronic devices comprise the following major subareas of technology: EO, MMW components, RF devices, electronic materials, microelectronics, MEMS, nanoelectronics, and portable power sources.

Microelectronic technology is one of the key areas that gives the United States superior military capabilities. These technologies, used in the production of every weapon system in the U.S. arsenal, enable dramatically higher performance and reliability with smaller size and weight. Lithography involving wafer delineation, resist processing, and maskmaking are prime determinants of feature size, and hence density of integrated circuits, and therefore are one of the most critical elements in achieving the high speed and high density required for military systems.

Lithography is the key technology driver for the semiconductor industry. Relevant capabilities include the extension of optical lithography to 180-nm design rules, x-ray and electron beam direct write down to 50 nm, and extreme UV lithography using 10- to 14-nm soft x-ray photons. Japan is the world leader in lithographic development. The Association of Super-Advanced Electronics Technologies (ASET) is a government-funded consortium of 24 companies established in 1996. The ASET program is concentrated in the areas of electron beam direct writing, super-fine synchrotron radiation lithography, ArF excimer laser lithography, and super-high precision mask fabrication.

Lucent Technologies, Inc., Applied Materials, Inc., and ASM Lithography Holding N.V. (Netherlands) are cooperating in accelerating the development of Scattering With Angular Limitation Projection Electron-Beam Lithography. It is emerging as a viable choice for production lithography generations below 180-nm critical dimension technology and as a production-worthy manufacturing tool for building future generations of silicon chips. Several of the world's leading semiconductor companies also have expressed interest in supporting this effort.

Integrated processing has become the newest technology driver for the semiconductor industry, with cluster tools as the conceptual force. Cluster tools can be used for plasma-enhanced chemical vapor deposition (CVD), dry etch, high-pressure oxidation, rapid thermal anneal, and numerous other processes. They can be used either as a batch system performing one process or as a system doing sequential processing steps. Anelva (Japan) is one of the leaders in batch-type cluster processing equipment. Only Japan manufactures a complete range of microelectronics production equipment. It is the world leader in the development and production of lithographic equipment. France, Germany, the Netherlands, and the U.K. produce some types of production equipment. None produces a complete line of equipment, although a few items are rated at the state of the art. Liechtenstein/Switzerland produces the greatest variety of microelectronics production equipment. Although South Korea and Taiwan have large integrated circuit production industries, both countries are in the process of establishing their own capability to manufacture state-of-the-art production equipment.

A rapidly developing technology is the use of semiconductor processing for fabricating MEMS devices. These include sensors and actuators that are fabricated using integrated circuit production processes. Advanced device and process concepts exploit integrated, colocated actuators, sensors, and electronics to achieve new functionality, increased sensitivity, wider dynamic range, programmable characteristics, and designed-in reliability and self-testing. MEMS inserted into weapon systems, ranging from smart munitions and sensors to high-maneuver-

ability aircraft and friend-or-foe identification systems, will bring new levels of situational awareness, information to the soldier, and precision strike capability. R&D and production are widespread, with the United States, Europe, and Japan in the forefront of both. European countries in various consortiums such as NEXUS are spending approximately \$350 million yearly on R&D, concentrating mainly on the biomedical field. Small countries such as Sweden, Norway, Denmark, Finland, Greece, Spain, Ireland, and Hungary have small, concentrated R&D. In Japan, most R&D programs are supported by the Ministry of International Trade and Industry (MITI) and the Micromachine R&D Center. Japan's R&D is widespread, with major programs in biomedical technology, robotics, sensing, actuators, displays, and printers. MEMS activity in Canada is basically centered on university research; in the last few years, however, industry has become interested in MEMS and its applications. Institutes such as the National Optics Institute, Telecommunications Research Laboratories, and the Alberta Microelectronic Centre have fostered much of the industrial activity by providing links to university research.

This technology area also includes the preparation and processing of new and current electronic materials, from the purification of the basic elements to the final wafer or substrate material ready for device fabrication. They include silicon on insulator (SOI) made by high-energy implantation of oxygen into a heated silicon substrate and SiC for rad-hard and high-temperature applications. An important military application of SOI is its increased radiation hardness, particularly to the areas of dose-rate survivability and single-event upset. SiC-based electronics and sensors can operate in hostile environments where conventional Si-based electronics (limited to 350°C) cannot function. SiC's ability to function in high-temperature, -power, and -radiation conditions will enable large performance enhancements to a wide variety of military systems and applications. These include high-current, -voltage, and -speed requirements of CW and pulsed-electrical subsystems in emerging hybrid-electric and all-electric combat vehicles. Soitec of France is a major player in developing and applying this technology. Soitec is in partnership with silicon giant Shin-Etsu Handotai (Japan) to develop SOI for the future 300-mm market. The Microelectronics Laboratory at the Catholic University of Louvain (Belgium) is a leading academic center on SOI technology. Epitronics, a business unit of Advanced Technology Materials, Inc., and the Advanced Technology Research Laboratories of the Nippon Steel Corporation (Japan) have announced the development of advanced 8-inch separation by implantation of oxygen (SIMOX) silicon wafers. Mitsubishi Materials Silicon Corporation is in partnership with Ibis Technology Corporation, the leading manufacturer of IBIS 1,000 high-current oxygen implanters and a major supplier of SIMOX wafers. Epigress of Sweden is a major producer of reactors for SiC as well as devices and process technology in SiC. Swedish efforts include work being done at the Royal Institute of Technology and ABB. Other countries with large R&D efforts are Germany, Japan, the U.K., and South Korea.

Portable electric power is one of the most essential components for Army operations. Although the soldier is more familiar with the problems of encumbering power supplies, reduction in size and weight with increased performance, reliability, and survivability is just as critical for mobile platforms. Examples of critical parameters for a potential power source source are energy density, activation time, self discharge, and in some cases fuel.

As the era of the digital battlefield unfolds, there is a growing need for smarter and more self-reliant individual soldiers. This amplifies the demand on computing, communications, and overall situational awareness. As a result, man-portable power requirements increase with estimates ranging from 50 to 500 W. Future subsystems that will require electric power include enhanced hearing, night-vision devices, computers, voice and data communications, helmet

displays, individual navigation, weapon rangefinders, and individual climate control. In addition, environmentally friendly power supplies are highly desirable, as are the minimized accompanying thermal, acoustic, and EM signatures. The most promising near-term technologies for the soldier are solid polymer Li-ion batteries and proton exchange membrane (PEM) fuel cells.

Mobile platform power encompasses the generation of primary or auxiliary power for hybrid- or all-electric military vehicles, remote facilities (manned and unmanned), or sensors. These platforms combine the prime propulsion and onboard electrical power generation functions. Such an energy system has operational advantages of reduced signature, increased energy density, lower weight and volume, and greater reliability and flexibility in configuration.

Solid polymer Li-ion batteries are an ideal solution for portable power. They utilize a plastic electrolyte or polymer with carbon electrodes and are very flexible, enabling these batteries to be molded into most any configuration. Their ability to be conformed to curved surfaces, as well as commercial-sector-driven production, makes this an extremely ambitious and affordable future technology.

Li-ion batteries are commercially produced in China, Denmark, France (Saft), Germany, Japan, South Korea, Taiwan, and the U.K. These batteries are needed to satisfy the current thrust in EVs and to control the space battery market. Japan is a world leader in virtually all aspects of portable electrical power, with strength in batteries, fuel cells, and power-control devices.

Other technologies address portable power. Fuel cells, an alternative to internal combustion engines, reduce acoustic signatures and vibration and are environmentally friendly. Fuel cells are classified by their electrolyte and operating temperature: solid-oxide fuel cell (650–1000°C), molten-carbonate fuel cell (650°C), phosphoric-acid fuel cell (200°C), and PEM fuel cell (25–90°C). PEMs are currently the only viable fuel cell option for man-portable power because of reduced startup times, minimal thermal and IR signatures, and smaller volume. Alkaline and phosphoric-acid fuel cells, however, may be utilized in larger portable power constructions (e.g., electric vehicles (EVs)). Ballard Company of Canada is the world leader in the development of PEMs, with strong competition from Japan and Germany. Companies in many countries are working this technology primarily for developing EVs. Continued commercial development will expedite affordability for military applications. In Japan, Toyota has invested \$500 million over 5 years, while primary R&D centers are in Germany (Daimler-Benz and Siemens), Norway (Norsk-Hydro), Sweden (Volvo), the U.K. (Vickers), Italy (DeNora), Spain (ICP, ICV), Switzerland (Scherrer Institute), and Denmark (basic research) are primary centers of R&D.

Rotating machinery consists of engines, turbines, and flywheels. For portable power, micro-engines or flywheels can provide power or storage, respectively. Portable electric power on the battlefield may require up to several megawatts. As a primary energy source, even the best engines consume their own weight in fuel within approximately 10 hours. Hence, operational system weight is a function of fuel storage in providing electric power, and as a result, fuel supply will dominate logistics. Many foreign countries have significant capabilities in the different aspects of rotating machines. Austria, France, Germany, Italy, Japan, and the U.K. all have significant strengths in high-power-density, middle-distillate engines. Deutz of Germany has particularly strong capabilities in advanced diesel engines. In electric motors, generators, and alternators, Russia, Switzerland, Germany, Japan, and the U.K. all have significant capabilities. In electromechanical storage, Canada, France, Germany, Japan, Russia, Ukraine, and the U.K. all have significant capabilities. Much of this interest is based on EV development. The German firm Magnet-Motor is recognized for flywheel development.

High-temperature superconductivity (HTS) is enabling for breakthroughs in EV propulsion. Areas of application are motors, fault current limiters, magnetic energy storage, and transformers. Much research, however, has gone specifically into HTS wire. Copper wires generate waste heat (which cannot be reclaimed) and resistive loss, reducing system efficiency. In addition, these wires have limited capability for carrying large currents. Japan is the world leader in developing HTS devices such as superconducting motors, generators, magnetic storage, and HTS wire, with research development at Showa Electric Wire and Cable Corporation, Tohoku University, Toshiba Corporation, Matsumura Laboratory, Center for HTS (University of Tokyo), and the Electrotechnical Laboratory. The European Network for Superconductivity has participants from many countries, the majority of which include France (10), Germany (19), Italy (11), Spain (6), and the U.K. (9). Complementary members include Austria, Belgium, Denmark, Finland, Israel, Norway, Sweden, Switzerland, and the Netherlands. In addition, an international effort has been aimed at developing an Nb₃Sn HTS conductor for the International Tokamak. Germany has strong capabilities in HTS, including generic technologies (materials, magnets, cryogenics), energy research (superconducting generators), and special expertise in medical technologies (MRI, biomagnetic measurements). Russia has shown strong capability in high-magnetic-field research. Additional activities (mostly in joint efforts with United States or Japanese firms) involving HTS wire and cable are underway or beginning in Denmark, Italy, South Korea (Pohang Superconductivity Center), and Switzerland.

c Example Research Facilities

The following facilities have demonstrated expertise in sensors and electronics technology development:

- United Kingdom—DERA Image, Pattern, and Information Processing [<http://www.dra.hmg.gb>]. Several research groups within DERA include DERA Computer Vision and Image Processing Group (Chertsey); DERA Image Processing and Interpretation Group (Malvern); DERA Pattern and Information Processing Group (Malvern).
- Korea—Center for Electro-Optics
- South Africa—CSIR [<http://www.csir.co.za/>]
- Canada—Defense Research Establishment—Ottawa [http://www.crad.dnd.ca/highlights/dreo_e.html]
- Netherlands—Organization for Applied Scientific Research—Physics and Electronics Laboratory—Sensor and Weapon Electronics [<http://www.tno.nl/instit/fel/div3/feldiv34.html>]

12 Battlespace Environment

The battlespace environment technology area encompasses the study, characterization, and prediction of the terrestrial and lower atmosphere environments to assess their impact on personnel, platforms, sensors, and systems. The goal is to enable tactics and doctrine to exploit that understanding and optimize new system designs. The technologies and capabilities addressed in this section are critical to realizing the JCS long-term strategy for information superiority and dominant battlespace knowledge. Table E-11 summarizes international technology development in the battlespace environment area.

An understanding of battlefield environments and effects is essential to all aspects of a military system's life cycle, from M&S for design, through mission planning and rehearsal, to actual configuration and programming of sensors and weapons in execution. Here, cooperative international programs are needed to ensure that coalition forces can interoperate effectively with a

TABLE E-11. TECHNOLOGY DEVELOPMENT—BATTLESPACE ENVIRONMENT

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
TERRESTRIAL ENVIRONMENTS						
◆◆◆◆ All	◆◆◆ All	◆◆◆ All	◆◆ All	◆◆ Cold regions	◆◆◆◆+ All	Finland, Norway, Sweden ◆◆ Cold region Switzerland ◆◆ All Israel ◆ Topography Italy ◆ All
LOWER ATMOSPHERE ENVIRONMENTS						
◆◆◆ All	◆◆◆ Current and predicted weather	◆◆◆ Current and predicted weather	◆◆◆◆ Current and predicted weather	◆◆ Current and predicted weather	◆◆◆◆ All	Denmark, Netherlands, Sweden, Switzerland ◆◆ Current and predicted weather Israel, Italy, Finland ◆ Current and predicted weather

Note: See page E-6 for legend.

common and consistent understanding of the battlespace and with an ability to receive and process environmental information required to execute the battle.

At the overall C⁴I system level, the United States has explicitly addressed this area in such efforts as the Advanced Battlespace Information System study. This has given the United States a significant advantage in specific application of knowledge of environmental effects in the battlespace.

a Terrestrial Environment

Terrestrial environment is subdivided into two subcategories: cold region engineering and topography. Cold region engineering focuses on militating against the dramatic effects of winter weather on operations conducted by the U.S. Army. To do this, effective decisionmaking tools, mission planning/rehearsal, and knowledge of how sensors, systems, materials, and personnel perform in cold environments are required. This challenge is not confined to the effects of temperature; it also includes the detrimental effects of snow, ice, and the state of the ground, whether frozen or thawing. This last challenge greatly affects the projection and mobility of forces, mine clearing operations, and earth excavation required for force projection and construction.

Snow, ice, and frozen ground alter the propagation of acoustic and seismic energy and interfere with thermal signatures, greatly reducing the effectiveness of weapon systems and sensors. Icy conditions change fixed- and rotary-winged aircraft performance; affect safe operation of equipment on roads, airfields, and bases; affect the ability to communicate; and impact power sup-

plies and engine startup. Technical challenges relate to developing and validating models of these phenomena and finding ways to enable operations to continue in spite of them. Most northern countries have significant capabilities and programs in cold environment research, in particular, Canada, Norway, Finland, Sweden, and Russia. Several groups include the Scott Polar Research Institute (University of Cambridge, U.K.), the Cold Research Technology Center (University of Technology, Lule, Sweden), and the Robots and Sensoristics group within Italy's Antarctic Research Program. Smaller programs exist in more temperate countries through Arctic and Antarctic research expeditions.

Identify terrain features automatically
Develop a total force positioning and navigational capability
Achieve 3D, dynamic, multispectral scene visualization
Generate terrain and weather environments in near real time

Topographic research focuses on better understanding the terrain through improved data generation, analysis, and representation. Efforts are needed to provide technology for rapid digital terrain data generation, terrain visualization, terrain analysis, data management, and realistic mission rehearsal and training. Topographic capabilities are found in many European countries, Japan, and Israel. For example, one software group (Skyline Software) in Israel has marketed a digital terrain package that simulates static and dynamic 2D and 3D objects and weather phenomena, such as fog and clouds.

Technical challenges in this area relate to transport and diffusion of gases and particulates, atmospheric flow, measurement systems that resolve microscale dynamical structures, dynamic and optical characteristics of aerosols and instrumentation for their detection and analysis, and remote sensor concepts and software. Germany has world-class capability in aerosol research, in particular the Gesellschaft für Aerosolforschung (the Association for Aerosol Research), which was the world's first society completely devoted to aerosol research. Canada is a world leader in all areas of terrestrial environment research. The U.K. has strong capability in all areas as well, with France and Germany following as an additional source of European activity.

b Lower Atmosphere Environments

Lower atmosphere environments research focuses on atmospheric measurements, data ingest and distribution, analysis of forecast data, weather prediction, atmospheric propagation effects, weather for simulation, and development of weather decision aids. Three technology thrusts are current battlespace weather, predicted battlespace weather, and decision aids.

For maximum situational awareness, accurate and timely information on current weather and atmospheric conditions over the battlefield is critical. One of the technical issues is the need for short-notice, up-to-the-minute weather forecasts anywhere in the world. Remote sensing and existing meteorological sites and services will be enabling for this task. Further technical issues include continued research in remote sensor algorithms, meteorological satellite data extraction accuracy, and dynamics of the atmosphere. Most countries have capability in these areas, with particular excellence noted in the U.K., Canada, Germany, France, and Japan.

Prediction of battlespace weather not only concentrates in the temporal domain, but the spacial as well. Basic research focuses on modeling processes, transport, and diffusion spanning all scales, including optical effects caused by the turbulence in the atmosphere such as scintillation on propagating waves. The integration of ballistic, aerosol transport, and diffusion models into weather prediction codes and the integrated meteorological system is a desired goal. Most coun-

tries with advanced weather technology capabilities are actively researching weather prediction and atmospheric phenomenology.

The whole of these data should be presented such that a decisionmaker is at ease and has maximum confidence in selection and employment of battle parameters such as weapons and other materials. Weather impact decision aids will allow a commander to employ weather as a combat multiplier for U.S. forces. A major objective of this effort is to develop real-time weather and environmental models that will provide common weather effects, features, and phenomena for all services. Milestones include incorporating the impacts of acoustics, illumination, propagation, obscurants, terrain-coupled wind transport, and weather forecasts. Essentially, weather impact decision aids will translate conventional battlespace weather information such as clouds, visibility, and temperature into specific performance information for mission planning and execution. For example, one group in New Zealand has a mailing list for people involved in the merging of AI with meteorology, with many subscribers from around the world [<http://www.mcs.vuw.ac.nz/comp/Research/met-ai/>]. Outside the United States, little work is available in decision aids applied to weather modeling. Canada is the leader in this area, with the U.K., France, and Germany providing the only additional work.

C INTERNATIONAL COOPERATIVE OPPORTUNITIES IN BASIC RESEARCH

Access to international capabilities in basic research offers a potential vehicle for both near- and long-term return on investment. Within the overall Army S&T strategy, one key objective is to emphasize high-leverage opportunities, fostering partnerships where we anticipate the best prospects for sustained excellence in the sciences leading to technology development. This includes cooperation with both foreign government and industries to access niches of technical excellence that can best be coupled to existing and future Army technology goals. This section provides a snapshot of international basic research capabilities and trends having potential to address one or more of the long-term research goals identified in Volume I, Chapter V, of the ASTMP. Many of the identified present and potential cooperative research opportunities overlap those highlighted in the previous section and indicate prospects for long-term partnerships and further cooperative advances based on existing programs or new initiatives. In addition, examples of research facilities doing world-class work in areas of interest to the Army have been identified.

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The following discussion and trend tables clearly portray the international scope of S&T. As might be expected, opportunities for cooperation in basic research are far more pervasive and widely dispersed than those for applied research in technology discussed above. Increased global accessibility of scientific information is such that no researcher is out of touch with his or her field. Collaborative research across international boundaries is commonplace.

Taken as a whole, the trends charts indicate a high and growing level of scientific research capabilities abroad in virtually every aspect identified as important to the U.S. Army. This suggests the importance of an international cooperative strategy that can effectively encompass both immediate opportunities and long-range cooperative partnerships.

1 Mathematical Sciences

Basic research in applied analysis and physical mathematics directly contributes to the modeling, analysis, and control of complex phenomena and systems active within the Army. Applied mathematicians define practical boundaries, set the framework of analysis, and act as collaborators for scientists and engineers on many development projects. It is often the case that seemingly unrelated research affects the development of critical technologies. The classic example is the influence of advances in control theory on the development of nonskid brakes.

Many nations show significant capability in a number of areas identified as having potential impact on the future of Army technologies. This is consistent with the fact that many advanced applied mathematics efforts involve only a small number of researchers and have minimal hardware requirements. Thus, even nations without an extremely powerful industrial or research base can have a few specific points of excellence in mathematics.

Germany, France, and the U.K. are all considered being on par with the United States in a number of areas of mathematics research. Each of these countries is noted for developing partnerships between academic and industrial groups working on mathematical problems directly related to modeling and manufacturing issues. In general, Canada and Japan are also working at or near this high level. Both China and India exhibit strong potential research efforts, which are constantly improving and will conceivably soon be world leading. Russia shows a declining capability, largely due to lack of resources. For example, though many important numerical methods for modeling physical phenomena were developed in the Soviet Union in the 1950s and 1960s, current research is no longer considered to be world leading. In addition, Ukraine is noted for a traditional weakness in more basic research and tends to be stronger in development areas. Many other small countries have very strong mathematical talents, including Holland, Denmark, Hungary, Israel, Poland, Romania, Greece, Sweden, and Norway. Significant efforts are also underway in the Pacific Rim (especially Singapore and Malaysia) to develop mathematical research enterprises, but these are not yet of world-class stature. Table E-12 summarizes international research capabilities for each major mathematical science research area.

a *Applied Analysis*

Research in applied analysis contributes to the modeling of physical processes critical to the development of new technologies in a variety of fields, including smart materials, flow control, electromechanics, and optics. For example, computational fluid dynamics (CFD) studies in the U.K., Canada, and Israel can contribute significantly to missile, rotor, and explosive design.

b *Computational Mathematics*

Many specific areas of computational mathematics hold promise for military applications. Research in numerical methods and optimization is the basis for many advances in fluid dynamics, material behavior, and simulation of large mechanical and computational systems. Advanced work in finite element analysis in France and Germany can be applied to the problems of the design and function of complex mechanical structures.

c *Probability and Statistics*

Research in probability and statistics, especially stochastic analysis and statistical methods, is integral to the development of simulation methodologies, data analysis systems, and complex image analysis technology, including new approaches to computer vision for ATR. Fuzzy logic

TABLE E-12. BASIC RESEARCH—MATHEMATICAL SCIENCES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
APPLIED ANALYSIS						
◆◆◆◆ Fluid dynamics	◆◆◆◆ Dynamic systems Digital image restoration Partial differential equations	◆◆◆◆ Fluid dynamics Nonlinear dynamical systems	Japan ◆◆◆ China ◆◆+ India ◆◆ Fluid dynamics	◆◆◆ Mechanics	◆◆◆	Israel ◆◆◆ Fluid dynamics
COMPUTATIONAL MATHEMATICS						
◆◆◆◆	◆◆◆◆	◆◆◆◆	India ◆◆◆◆ Japan ◆◆◆ China ◆◆	◆◆	◆◆	Sweden ◆◆◆ Numerical optimization Israel ◆◆◆ Computational physics
PROBABILITY & STATISTICS						
◆◆◆◆	◆◆◆◆ Levy processes	◆◆◆◆	Japan ◆◆◆◆ Fuzzy logic India ◆◆◆◆ China ◆◆	◆◆◆	◆◆◆+	Austria ◆◆◆ Fuzzy logic
SYSTEMS & CONTROL						
◆◆◆+	◆◆◆◆ Control theory	◆◆◆◆	Japan ◆◆◆+ China, India ◆◆	◆◆	◆◆	
DISCRETE MATHEMATICS						
◆◆◆	◆◆◆◆ Linear algebra Network flows Symbolic computing	◆◆◆	Japan ◆◆◆ China ◆◆	◆◆	◆◆+	Hungary ◆◆ Czech Republic ◆◆ Computational geometry

Note: See page E-6 for legend.

research in Japan is an example of international research that can significantly contribute to Army goals in these areas.

d Systems and Controls

Systems and control theory work have also been used as the basis for the development of computer systems, as well as applications in robotics. Research areas include work in control in the presence of uncertainties, robust and adaptive control for multivariable and nonlinear systems, and distributed communication and control. France is considered a world leader in control

theory research. The U.K., Germany, Japan, Canada, China, and Russia have significant capabilities in this area as well.

e *Discrete Mathematics*

Also of interest are international research efforts in linear algebra (France) and computational geometry (Czech Republic), which are applicable to the development of new computer network hardware and software platforms.

f *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in mathematical sciences:

- Europe—ERCIM [<http://www.ercim.org/index.html>]
- United Kingdom—Basic Research Institute in the Mathematical Sciences [<http://www.uk.hpl.hp.com/brims/>]
- Japan—Research Institute for Mathematical Sciences, Kyoto University [<http://www.kurims.kyoto-u.ac.jp/>]
- Russia—Euler International Mathematical Institute [<http://www.pdmi.ras.ru/EIMI/>]

2 Computer and Information Sciences

Computers and information systems are pervasive in virtually all military systems and operations and are essential for maintaining the present leading position of U.S. military capabilities. The computer and information sciences research area addresses fundamental issues in understanding, formalizing, acquiring, representing, manipulating, and using information. The advanced systems, including the software engineering environments and new computational architectures facilitated by this research, will often be interactive, adaptive, sometimes distributed or autonomous, and frequently characterized as intelligent. Table E-13 summarizes international research capabilities for each major computer and information science research area.

a *Theoretical Computer Science*

Theoretical computer science is directed at extending the state of the art of high-performance computers, an enabling technology for modern tactical and strategic warfare. Research in this area includes development of formal models underlying computing technology, optimization of input/output communications, and design of new computing architectures and parallel systems. Although the United States is the world leader in most aspects of theoretical computer science, many other nations show strong capabilities, including Germany, the U.K., Canada, Israel, France, Russia, Poland, and Sweden.

b *Software Engineering*

Formal methods of software engineering are the software parallels to improving the computer hardware addressed in computer studies. U.S. software development has been a driving force in enhancing the overall tactical and strategic capabilities of the U.S. armed forces. The United States has been the world leader in computer science and most areas of software development that contributes heavily to systems engineering and systems integration capability, an overwhelming strength for U.S. military. However, a number of countries have capabilities in various aspects of the overall science. Canada has world-class capabilities in software prototyping,

TABLE E-13. BASIC RESEARCH—COMPUTER AND INFORMATION SCIENCES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
THEORETICAL COMPUTER SCIENCE						
◆◆◆ Mathematical programming	◆◆	◆◆◆◆ Mathematical programming	Japan ◆	◆◆	◆◆◆◆ Theory of computation	Israel, Netherlands ◆◆◆◆ Poland ◆◆◆ Sweden ◆◆
SOFTWARE ENGINEERING						
◆◆◆◆ Requirements engineering Software reuse	◆◆	◆◆◆◆ Requirements engineering CASE	Japan ◆◆ Software reuse	◆◆	◆◆◆ CASE Software process improvements Verification and validation	Sweden, Denmark Netherlands ◆◆◆ Australia ◆
KNOWLEDGE BASE/DATABASE SCIENCES						
◆◆◆◆ Database management	◆◆	◆◆◆	Japan ◆◆	◆—	◆◆◆ Database management	Sweden, Netherlands ◆◆◆
NATURAL LANGUAGE PROCESSING						
◆◆◆◆ Speech recognition Automated translation	◆◆	◆◆◆◆ Speech recognition	Japan ◆◆	◆	◆◆ Symbolic computation	Sweden, Netherlands ◆◆◆◆

Note: See page E-6 for legend.

as well as being active in most other areas. India is becoming strong in software prototyping, development, and evolution by virtue of knowledge transfer by U.S. companies employing Indian subsidiaries and subcontractors for software development.

c Knowledge-Based/Database Sciences

The U.K. is a leader in most areas, with extensive capabilities in knowledge base/database science. Other countries have niche capabilities (e.g., Sweden, the Netherlands). Russia's previously strong capabilities in all areas of computer and information sciences are gradually declining because of budget constraints and aging hardware.

d Natural Language Processing

Natural language processing has taken on an increased importance with the use of multinational/multilanguage forces in the field. The need for rapid communication between such forces is essential to the efficient and safe military cooperation between them. Germany has numerous universities engaged in natural language processing, making it the most active country in the world, outside of the United States. The U.K. is also a leader in most areas of natural language processing, with many of its universities having advanced research programs. Various universities in Sweden, in addition to the Royal Institute of Technology, have programs relating to natural language translation. France and the Netherlands are also quite advanced and have active programs in language processing. Commercial interests are active in bringing research to the market, particularly in the U.K.

e Example Research Facilities

The following facilities have demonstrated expertise for providing cooperative opportunities in computer and information sciences:

- European Consortium—The European Network in Language and Speech [<http://www.elsnet.org>]
- United Kingdom—Center for Speech Technology Research, University of Edinburgh [<http://www.cstr.ed.ac.uk/>]
- Sweden—Department of Numerical Analysis and Computing Science, Royal Institute of Technology [<http://www.nada.kth.se/index-en.html>]
- Canada—Department of Computer Science, University of Waterloo [http://www.math.uwaterloo.ca/CS_Dept/homepage.html]

3 Physics

Basic research in physics broadly supports advanced technology developments by providing insight into the nature and interaction of energy and matter and contributes to technologies with a wide range of civil and military applications. Areas of interest to the U.S. Army include nanoscience, photonics, and processes and technology related to obscured visibility, novel sensing, optical warfare, and image analysis enhancement. For example, this research enables ongoing advancement in microminiaturization and optical subsystems. This will then improve sensor capability and continue development of image analysis and target recognition systems. As Table E-14 shows, a wide range of countries possess capabilities in the major physics research areas.

a Nanoscience

The objective of nanoscience programs is to develop the capability to manipulate atoms and molecules individually, assemble them into nanometer-sized devices, and exploit the unique physical mechanisms that operate in these devices. Nanoscience has potential applications in a wide range of civil and military technologies. This includes both improved materials and electronics.

In materials, nanoscience research is directed at developing lighter and stronger structures, advanced lubricants, abrasive-resistant materials, biosensors, etc. Research in Fullerenes and nanotubes is included in these efforts, as well as coatings deposited using nanomaterials.

In electronics, research includes studies in quantum devices, microlithography, and molecular electronics. The goals of these programs include ultra-high-speed devices that consume less power, ultra-high-speed computers, alternative storage mechanisms for computers, and field emission cathodes. Much of this involves research in submicron lithography, offering smaller, faster devices that consume less power.

b Integrated Sensory Science

The U.S. Army's ability to operate under conditions of poor visibility is enhanced by improving sensing capabilities. Recognition systems that utilize only spatial information are severely limited in their ability to detect objects with low contrast or in environments containing camouflage or deception. Multispectral and hyperspectral IR imagers promise to provide sensor input that can be exploited to improve the performance of recognition systems in these circumstances. Integration of radar sensors further improves recognition and targeting. Novel and improved

TABLE E-14. BASIC RESEARCH—PHYSICS

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
NANOSCIENCE						
♦ ♦ Materials Electronics	♦ ♦ ♦ ♦ Materials ♦ ♦ Electronics	♦ ♦ ♦ ♦ Materials ♦ ♦ ♦ Electronics	<i>Japan</i> ♦ ♦ ♦ ♦ Materials Electronics <i>ROK, Taiwan</i> ♦ ♦ Electronics	♦ Electronics	♦ Electronics	<i>Switzerland</i> ♦ ♦ ♦ Materials ♦ ♦ Electronics <i>Israel</i> ♦
INTEGRATED SENSORY SCIENCE						
♦ ♦ ♦ ♦ Sensors Lasers	♦ ♦ ♦ ♦ Sensors Lasers	♦ ♦ ♦ ♦ Sensors Lasers	<i>Japan</i> ♦ ♦ ♦ ♦ Sensors Lasers <i>ROK</i> ♦ ♦		♦ ♦ ♦ Sensors Lasers	<i>Israel</i> ♦ ♦
NONLINEAR OPTICS AND NONLINEAR DYNAMICS						
♦ ♦ ♦ CB sensors	♦ ♦ ♦ CB sensors	♦ ♦ ♦ CB sensors	<i>Japan</i> ♦ ♦ ♦ Nonlinear materials <i>China</i> ♦ ♦ + Nonlinear materials <i>Taiwan</i> ♦ ♦ Nonlinear materials		♦ ♦ ♦	<i>Israel</i> ♦ ♦ ♦ CB sensors <i>Australia</i> ♦ ♦ ♦
PHOTONICS						
♦ ♦ ♦ ♦ Signal processing Optical switching OE	♦ ♦ ♦ ♦ Signal processing Optical switching OE Optical computing	♦ ♦ ♦ ♦ Signal processing Optical switching OE	<i>Japan</i> ♦ ♦ ♦ ♦ Optical computing Signal processing Optical switching OE <i>ROK, Taiwan</i> ♦ ♦	♦ ♦ —	♦ ♦ ♦	<i>Israel</i> ♦ ♦ ♦ ♦ Signal processing <i>Sweden</i> ♦ ♦ ♦ <i>Australia</i> ♦ ♦ +
IMAGE ANALYSIS						
♦ ♦ ♦ ♦ Software & modeling	♦ ♦ ♦ Software & modeling	♦ ♦ ♦ Software & modeling	<i>Japan</i> ♦ ♦ ♦ Software & modeling <i>Taiwan</i> ♦ ♦		♦ ♦ Software & modeling	<i>Sweden, Israel</i> ♦ ♦ ♦ Software & modeling

Note: See page E-6 for legend.

radiation sources and detectors will provide new capabilities for the U.S. Army. Germany, France, the U.K., and Japan have world-class capabilities in the areas of laser application for sensing and other sensor development. Research in this area can contribute to the objectives of the Army STO III.D.16, Integrated Situational Awareness and Targeting.

c *Nonlinear Optics and Nonlinear Dynamics*

Research in optics studies develops optical sensors and sources, nonlinear optical processes, tunable sources, and materials with special reflective, absorptive, and polarization properties to perform specialized remote sensing techniques (e.g., CB agent detection). China is developing better capabilities in the study of nonlinear materials. The U.K., Germany, and France have broad capabilities in the area of CB sensing by optical devices.

d *Photonics*

Photonics is the technology of generating and harnessing light and other forms of radiant energy, the quantum unit of which is the photon. Research seeks to develop optical subsystems for military applications such as information storage, displays, optical switching, signal processing, and optical interconnections of microelectronic systems. The U.K., France, Germany, Japan, and Italy have ongoing research in various photonics areas. Russia has a strong but declining capability in photonics research. Research in obscured visibility seeks to provide the U.S. Army with the ability to operate on the ground in poor visibility and to have significant control of physical signatures. The U.K., France, and Japan have significant capabilities in the related technology areas. Germany, Israel, Sweden, Canada, and Belgium have capabilities that also merit consideration.

Typical research projects in the optoelectronic (OE) area include microwave modulation of diode lasers, optical fiber signal processing, and optical control of microwave and MMW semiconductor devices. There is extensive collaboration with groups in a number of U.K. universities; a European Network is being established.

e *Image Analysis*

The objective of image analysis research is to develop the fundamental limits and theoretical underpinnings of object recognition and image analysis. These areas are of growing importance because of the increasing speed of modern weapons and the need for faster and more accurate identification of friend or foe. It also applies to the development of novel technologies for mine detection, medical imaging, and geophysics. This is an area where a number of countries are developing broad capabilities, including the U.K., France, Germany, and Japan. Israel, Canada, Turkey, and Sweden have important niche capabilities.

f *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in physics:

- Multinational—Nanoscience (Materials) [<http://dmxwww.epfl.ch>]
- Germany—Max Born Institute for Nonlinear Optics and Short-Pulse Spectroscopy, Rudower Chaussee 6, D-12489 Berlin [<http://www.mbi-berlin.de/>]
- Australia—Australian Photonics Cooperative Research Centre [<http://www.photonics.com.au/tindex.htm>]
- Germany—Photonic Optical Interconnection Technology Project, Fraunhofer Institute for Applied Solid-State Physics [<http://www.fhg.de/english>]
- Japan—Department of Physics, Kyoto University [<http://www.scphys.kyoto-u.ac.jp/index-e.html>]
- Korea—Photonics Research Center

- Sweden—Chalmers University of Technology and Göteborg University, Photonics, High-Speed Electronics and Nanoscience/Quantum Devices [<http://www.chalmers.se/researchprofile/nanoscience.html>]
- United Kingdom—The Institute of Microwaves and Photonics, School of Electronic and Electrical Engineering at the University of Leeds [<http://www.IMP.leeds.ac.uk/>]

4 Chemistry

Basic research in chemistry applies to Army applications such as WMD defense, fuels, and munitions. Chemistry efforts are also strongly tied into interdisciplinary research in advanced materials, physics, and the biological sciences. A large number of international basic research programs in chemistry can contribute to Army goals in this area. International capabilities in chemistry research are summarized in Table E-15.

a Chemical Detection

A number of countries are active in materials R&D for chemical detection. The U.K. and Canada have world-class capabilities, and they have ongoing efforts to provide better defense against chemical agents. They have been at the forefront of chemical defense for many years and can be expected to continue devoting resources to this area. Israel, Sweden, Finland, France, Germany, Czech Republic, Poland, China, the Netherlands, and Japan also have some capabilities. Research facilities in surface plasmon resonance systems, redox systems, and field effect transistors are present in Israel, Sweden, and the Netherlands.

b Power Sources

Soldier power systems will provide the 21st century warrior with power sources that are enabling for a host of man-portable electronic devices, ranging from communications and sensors to weapons. Where the typical Land Warrior can be expected to require as much as 250 W of power for various subsystems, the warfighter will be a significant component of the future digitized Army. Assimilation of current power technologies into use by the soldier on the battlefield is anticipated for the near future. Lithium rechargeable batteries and fuel cells are expected to become the primary sources of energy. Further, combinations of advanced capacitors with rechargeable batteries make for smart hybrid devices where the battery provides power and is recharged by the capacitor. Batteries with Li chemistries are affordable and environmentally friendly replacements to the nickel cadmium, nickel metal hydride, and Li thionyl chloride (which is environmentally unsafe) rechargeables that are currently used. In particular, Li polymers are very pliable, having the ability to be packaged in most any size and shape. Li batteries are expensive to produce, although continued advances in this chemistry will bring the cost down for improved affordability. Japan is a world leader in the development of Li batteries, while Canada has specific capability in Li polymers. Much of the development in Li batteries stems from powering space vehicles. France and Germany have significant programs in all Li chemistries. Nations such as Israel, China, Russia, and the U.K. demonstrate capability in niche chemistries of the Li family.

A secondary source for near-term soldier power systems are fuel cells. However, because of the irreducible weight of the requisite energy converter, fuel cells are more effective for missions requiring greater than approximately 1 kWhr. The use of PEM fuel cells in equipment has been demonstrated in the battery cavity of a field radio. Fuel cells offer the advantage of significantly reduced thermal and acoustic signatures, with their primary byproduct being water, but are only in the early phases for battlefield usage. Currently, PEM fuel cells demonstrate practical

TABLE E-15. BASIC RESEARCH—CHEMISTRY

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
CHEMICAL DETECTION						
◆◆◆◆	◆◆◆	◆◆◆	Japan ◆◆◆ China ◆◆◆	◆◆◆	◆◆◆◆	Australia ◆◆◆◆ Israel ◆◆◆ Poland, Sweden, Czech Republic, Finland, Netherlands ◆◆
POWER SOURCES						
◆◆◆ Batteries	◆◆◆◆ Batteries	◆◆◆◆ Batteries Flywheels	Japan ◆◆◆◆ + Li Batteries China ◆◆	◆◆◆— Flywheels	◆◆◆ + Li Polymers PEMs	Israel, Italy ◆◆ Batteries
EXPLOSIVES & PROPELLANTS						
◆◆◆	◆◆	◆◆◆◆	Japan ◆◆◆◆ Missile propellants ROK ◆◆◆	◆◆◆—	◆◆◆◆	Sweden, Israel ◆◆◆◆
ENERGETIC MATERIALS						
◆◆◆◆ Smart munitions	◆◆◆◆ Smart munitions	◆◆◆	Japan ◆◆◆ Smart munitions China ◆◆◆ India ◆◆	◆◆◆	◆◆	Sweden ◆◆◆ Israel, Australia, South Africa ◆◆
DEMILITARIZATION/ ENVIRONMENTAL REMEDIATION						
◆◆◆◆	◆◆◆	◆◆◆	Japan ◆◆ ROK ◆◆	◆◆	◆◆ Soil Ground water	

Note: See page E-6 for legend.

applicability for soldier power. Ballard of Vancouver, Canada, is the world leader in this area, with strong global presence by Germany and Japan. Italy demonstrates significant capability, with other European countries following suit.

In the far term, nuclear power and rotating machinery (flywheels) offer further solutions for soldier power. The former has yet to come to practical design due to significant system implementation issues associated with radiation near biological tissue and societal mistrust of ionizing radiation. The specific energy of radioisotopes, however, which can be greater than 100 mW/hr/kg, combined with more efficient energy converters, could easily solve power generation issues for the unmanned future soldier. Continued efforts may also see the development of other power technologies for the infantry (e.g., thermophotovoltaics, biological energy

sources (for milliwatt applications), advanced capacitors and converters). Canada is noted for efforts to develop biomass-derived fuels for gas turbines.

c Explosives and Propellants

Basic research is often undertaken to solve problems of explosive/propellant effectiveness or to compile properties sufficient to improve detection or identification. U.S. Army applications include the basic outgassing chemistry for detection of mines and charges. Chemistry used to mimic vehicle IR signatures is applicable to decoy flares. Chemistry of propellant bonding provides insight into the life-cycle projections for U.S. Army missile systems. Germany, with a world-class tradition of expertise in chemistry, leads in most of these areas. U.K. expertise across broad chemistry areas is fertile for international interest. Japan's space interest promotes expertise in missile propellants. Long-term military requirements underscore ongoing basic research in Israel, Singapore, and the ROK. Research in Russia suffers from lack of operating capital.

d Energetic Materials

Army interest in energetic materials focuses on energetic compounds made from environmentally friendly synthesis techniques. Over 20 countries have some capability to produce standard energetic materials, such as TNT, RDX, HMX, nitrogen carbon, ammonium perchlorate, metal fuels, hydrazine and compounds, for use in missile, CW/BW, and "smart" munitions applications. The United States, along with France, the U.K., and Japan, maintains a lead in the formulation and production of advanced energetic materials for use in smart munitions. Russia and China have at least researched the synthesis of many of the substances; other countries, including Italy, South Africa, Sweden, Brazil, and Egypt, have a selective capability to produce some of the materials. An increasing number of non-NATO countries have the technology to formulate energetic materials for munitions and weapons applications, their capabilities being limited primarily by the availability of the listed advanced materials and the lack of computational and experimental capability to design and synthesize new molecules and polymers.

e Demilitarization/Environmental Remediation

The United States has a strong lead in research related to demilitarization, installation restoration, and pollution prevention. Sensing pollution, destroying pollutants, and practices that prevent pollution all lead to more efficient or more effective military operation. Of foreign countries, the U.K. has the strongest potential. Canada has significant efforts in the chemical characterization of contaminated soil and groundwater. France and Germany have some capability, but the potential for military applications is weaker due to budgetary constraints.

f Example Research Facilities

The following facilities have demonstrated expertise for providing cooperative opportunities in chemistry:

- Germany—Max Planck Institute for Colloids and Interfaces [http://www.mpikg-golm.mpg.de/index_e.html]
- Netherlands—Munition Technology and Explosion Safety Division, TNO-PML [<http://www.pml.tno.nl/homepage.html>]
- South Korea—Environmental Chemical Engineering Laboratory, Seoul National University [<http://ecel.snu.ac.kr/>]
- Canada—Institute for Integrated Energy Systems [<http://www.iesvic.uvic.ca/fuelcell/>]

5 Materials Science

Army interests in materials science basic research focus on materials, processes, and properties that improve the performance, increase the reliability, or reduce the cost of Army systems. All industrialized and rapidly developing countries have materials-related activities and capabilities. Many nations can now produce materials for specific military usage, including materials engineered to defeat enemy threats and those that improve the survivability of systems in the field. Table E-16 summarizes international research capabilities in each major research area of materials science.

TABLE E-16. BASIC RESEARCH—MATERIALS SCIENCE

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
MANUFACTURING & PROCESSING OF STRUCTURAL MATERIALS						
♦ ♦ ♦ ♦ Steel, Al, Ti Superalloys Intermetallics Joining PMCs, MMCs	♦ ♦ ♦ ♦ Steel, Al, Ti Superalloys Intermetallics Joining PMCs, MMCs	♦ ♦ ♦ Steel, Al, Ti Superalloys Intermetallics Joining PMCs, MMCs	<i>Japan</i> ♦ ♦ ♦ ♦ Steel, Al, Ti Superalloys Intermetallics Joining PMCs, MMCs Ceramics <i>China</i> ♦ ♦ ♦ ♦ + Al, Ti Superalloys PMCs, MMCs, CMCs <i>India</i> ♦ ♦ <i>Vietnam</i> ♦	♦ ♦ — Al, Ti, steel PMCs, MMCs	♦ ♦ Steel ♦ ♦ PMCs ♦ ♦ Intermetallics	<i>Austria, Sweden, Israel, South Africa</i> ♦ ♦ Steel <i>Sweden, Spain, Israel</i> ♦ ♦ PMCs <i>Sweden</i> ♦ ♦ Superalloys <i>Sweden</i> ♦ ♦ Intermetallics <i>Israel, Italy</i> ♦ ♦ C-C composites <i>Norway</i> ♦ ♦
MATERIALS FOR ARMOR & ANTIARMOR						
♦ ♦ ♦ ♦ Personnel Vehicular Penetrators	♦ ♦ ♦ ♦ Personnel Vehicular Penetrators	♦ ♦ ♦ ♦ Personnel Vehicular Penetrators	<i>Japan</i> ♦ ♦ ♦ Personnel Vehicular Penetrators	♦ ♦ — Personnel Vehicular Penetrators		<i>Australia</i> ♦ ♦ ♦ Personnel Vehicular Penetrators <i>Israel, Slovakia</i> ♦ ♦ Armor <i>Israel, Sweden</i> ♦ ♦ Antiarmor <i>Israel</i> ♦ ♦ Personnel

TABLE E-16. BASIC RESEARCH—MATERIALS SCIENCE (CONT'D)

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
PROCESSING OF FUNCTIONAL MATERIALS						
◆ ◆ ◆ Electrical Magnetic Optical Maintenance Corrosion	◆ ◆ ◆ Electrical Magnetic Optical Maintenance Corrosion	◆ ◆ Electrical Magnetic Optical Maintenance Corrosion	<i>Japan</i> ◆ ◆ ◆ ◆ Electrical Magnetic Optical Maintenance Corrosion <i>China</i> ◆ ◆ ◆ ◆ + Electrical Magnetic Optical Maintenance Corrosion <i>India</i> ◆ ◆	◆ ◆ — Electrical Magnetic Optical Maintenance Corrosion		<i>Slovakia, Italy, Netherlands</i> ◆ ◆ Electronic & electrical <i>Norway</i> ◆ ◆ Powder metallurgy, casting, metal forming, corrosion silicon MEMS <i>Netherlands</i> ◆ ◆ Magnetic <i>Netherlands, Israel, Italy</i> ◆ ◆ Optical <i>South Africa</i> ◆ ◆ ◆ Piezoelectric composites
ENGINEERING OF MATERIAL SURFACES						
◆ ◆ ◆ Coatings Ion implantation Sputtering Surface resistance to wear & corrosion	◆ ◆ ◆ Coatings Ion implantation Sputtering Surface resistance to wear & corrosion	◆ ◆ Coatings Ion implantation Sputtering Surface resistance to wear & corrosion	<i>Japan</i> ◆ ◆ ◆ Coatings Ion implantation Sputtering Surface resistance to wear & corrosion <i>China</i> ◆ ◆ ◆ ◆ + Coatings Ion implantation Sputtering Surface resistance to wear & corrosion	◆ ◆ —	◆ ◆ Coating	<i>Australia</i> ◆ ◆ ◆ ◆ + Coatings Ion implantation Sputtering Surface resistance to wear & corrosion <i>Switzerland, Sweden, Netherlands, Italy</i> ◆ ◆ Coatings <i>Italy, Sweden, Netherlands, Switzerland</i> ◆ ◆ Machining Finishing Polishing <i>South Africa, Israel</i> ◆ ◆ Diamond deposition

TABLE E-16. BASIC RESEARCH—MATERIALS SCIENCE (CONT'D)

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
NONDESTRUCTIVE CHARACTERIZATION OF COMPONENTS						
◆◆◆ Metrology Systems MRI	◆◆◆ Metrology Systems MRI	◆◆ Metrology Systems MRI	Japan ◆◆◆ Metrology Systems MRI China ◆◆◆+ Metrology Systems MRI	◆◆— Metrology Systems MRI	◆◆— Metrology Systems MRI	Sweden, Switzerland ◆◆ Metrology Italy, Sweden ◆◆ NDE

Note: See page E-6 for legend.

a Manufacturing and Processing of Structural Materials

Processing of materials is critical to Army interests. It ranges from synthesis of precursor materials through microstructural developments and into production of useful components at acceptable costs. Materials processing includes such topics as polymerization, composite lay-up, physical and chemical vapor deposition, and surface modifications.

Many nations have significant capability in the manufacturing and processing of advanced materials of interest to the Army. The U.K., France, Germany, and Japan are at or near the forefront of research into the processing of steels, titanium, aluminum, PMCs, MMCs, superalloys, intermetallics, and C-C composites. Expertise in these areas also resides in the FSU, especially Russia. Niche capabilities can be found in many other countries (e.g., advanced steel research in Austria, Sweden, Canada, and South Africa; C-C composite expertise in Israel and Italy). Growing capabilities are developing in Asia and the Pacific Rim, particularly in China, India, and South Korea.

Smart materials are those that can sustain sensory capabilities, actuator activity, and information processing as part of their basic microstructure. Design, synthesis, and processing of such materials is a chemical challenge because it is done at the atomic/molecular level. Applications such as damage detection and control, vibration damping, and precision manipulation and control motivate the field. At the microstructural level, challenging areas of interest include phase transitions (e.g., SMAs), layer-by-layer design of materials, materials with defective structures that can sustain sensing and response, biocomposites, piezoelectric ceramics, multifunctional macromolecules, and others. This area offers large payoffs in areas such as delamination control of composite helicopter blades and increased battlefield survivability of materials by means of active damage control. World activity in smart materials continues to grow rapidly. Japan is a clear leader in some aspects. France, Germany, and South Korea also have growing programs.

Japan also has strong capabilities in virtually every area of the underlying materials technology related to ceramics. The ceramics R&D program is heavily funded and increasingly coordinated at the highest levels (MITI). It involves a large infrastructure of government laboratories, universities, and private industry. The pervasive commercial potential of ceramics has led Japan to make it one of their continuing high-priority items. The Japan Fine Ceramics Center in Nagoya, founded in 1987, institutionalized ceramic R&D in Japan. Its aim is to extend Japan's already considerable capability in both precompetitive "basic" research by consortia and in sophisticated proprietary research up to a pilot plant level. The central role of the Japan Fine Ceramics

Center as the setter of standards and IPOCs makes it an ideal point of entry to the Japanese ceramics infrastructure at large.

b *Materials for Armor and Antiarmor*

Armor materials include those specifically designed to protect equipment and personnel from enemy threats. Antiarmor materials are used in the projectiles, penetrators, shaped-charge liners, etc., designed to defeat enemy armor. For armor, the U.K., France, Germany, Israel, and Russia are overall world leaders; the United States is the leader in developing antiarmor projectile materials. The U.K., France, Israel, Sweden, and Russia have very significant and relevant dense alloy capabilities.

Thick-sectioned, glass-reinforced PMCs are of interest to the Army because they offer weight savings while providing to other systems useful, stringent characteristics, with controlled costs. Among these characteristics are ballistic protection for personnel, equipment, emplacements, and vehicles. Most overseas work, done in the commercial sector, is focused on manufacturing and processing issues. The U.K., France, Canada, Germany, and Japan have broad capabilities and research in PMCs. Israel, Spain, and South Korea have important and growing capabilities.

c *Processing of Functional Materials*

Processing of functional materials is key to deriving military advantage from specialized optical, magnetic, electrical, and electronic devices. Optical systems of interest include waveguides, lenses, mirrors, laser hosts, and sensor covers. For magnetic materials, the Army is concerned with data recording media, signature control, power supplies, and motor applications. For electrical materials, the focus is on solenoids, minesweeping, and high-field magnets. Electronic materials are the foundation of the Army's electronic systems, so they are of interest for logic, amplification, memory, display, delay, signal generation, sensing, and switching functions.

For processing of functional materials, the United States generally has led overall, but others (France, the U.K., Germany, Japan, Switzerland, and Russia) have strong capabilities. Japan is more advanced than the United States in some areas of electronic materials. The U.K., Russia, Japan, Israel, Germany, France, and China are very active across several areas of optical materials. For magnetic materials, the United States is the leader overall, although Japan has some capabilities. The U.K. is capable in high-permeability magnetic alloys. For magnetorestrictive alloys, Sweden and the U.K. have technologies comparable to those of the United States. Many other nations are active in selected areas of magnetic materials. For electrical materials, the United States has the lead in superconducting wire. Japan, Germany, Italy, and the U.K. have capabilities in wire processing. High-temperature superconducting materials work is performed globally, with the United States in the lead with prototype wire processing.

The processing of nonlinear optic materials is important to the Army because of the materials use in wavelength conversion in some laser systems and in personnel eye protection. The materials must be very uniform and of some high purity; the selection of useful materials currently is limited. The U.K., France, and Russia have strong efforts in preparation and characterization of nonlinear optic materials, and Japan and Israel have credible capabilities. Hungary and China are also working extensively in this area.

Fire-retarding materials for vehicles are of significance to the Army to protect personnel from conflagrations and to allow assets to return to operation as rapidly as possible. These materials

are essential to enabling Army systems to perform under battlefield conditions. This capability allows for sustainability of vehicles involved in force projection and advanced land combat. In addition to being fire retardant, these materials must be easily applied to vehicles and not produce toxic products when exposed to high temperatures. The countries with strong capabilities in these areas are the U.K., France, and Israel.

d *Engineering of Material Surfaces*

Precise control, fabrication, and modification of materials' surfaces are areas with great impact on Army systems. The surface is the region where the component meets its operating environment, which may be chemical, mechanical, thermal, EM, etc., in nature. It is the region within which failure usually originates during system performance or storage. Thus, activity in areas including machining, ion implantation, chemical vapor deposition, sputtering for coatings, and adhesion of protective layers are of interest in the engineering of surfaces for Army applications.

Materials' surface engineering capabilities are widely held across the world. For precision machining and polishing, Japan, Germany, France, and the U.K. are very strong, along with Switzerland and Sweden. For coatings of many types, France, Germany, the U.K., and Russia are among the leaders. Areas of strength exist abroad in ion implantation and thin-film diamond deposition in France, Japan, Germany, and the U.K.

Wear and corrosion costs the Army several billion dollars each year because of premature failures, excessive wear of systems and components, application and removal of protective coatings and paints, and need to have high spares inventories to meet all these challenges. Corrosion control and avoidance is a challenging scientific area, as is tribology (the study of surfaces in contact). These areas are exceptionally important for maintainability and affordability, in terms of life-cycle costs, for Army systems. Nearly all industrialized nations have programs of some extent in wear and corrosion. The strongest are in the U.K., Germany, Japan, France, Sweden, and Switzerland, with niche capabilities existing elsewhere.

e *Nondestructive Characterization of Components*

Nondestructive evaluation of components divides into a few focus areas. For quality of materials produced, France, Germany, the U.K., other European nations, and Japan have increased capabilities with NDE systems. In all aspects of metrology, Japan is excellent, as are the U.K., France, and Germany. Switzerland and Sweden also excel in selected areas. All of these nations are paying growing attention to automation in the use and interpretation of NDE, both for product quality and process control.

f *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in materials science:

- Netherlands/Italy—Institute for Advanced Materials, Joint Research Center [<http://www.ehis.navy.mil:80/bwnews19.htm>] [<http://www.jrc.nl>]
- Israel—Israel Institute of Metals, Technion Research and Development Foundation [<http://www.ehis.navy.mil:80/bwnews20.htm>] [<http://www.technion.ac.il/technion/trdf/metal/>]
- India—Indian Institute of Science, Department of Metallurgy [<http://www.metalrg.iisc.ernet.in/>]
- Vietnam—The Institute of Materials Science [<http://www.atip.org/public/atip.reports.99/atip99.001.html>]

6 Electronics Research

Basic research in electronics supports advanced technology development with many applications. Important examples include continued advancement in solid-state devices, telecommunications, microwave and MMW circuit integration, image analysis, and low-power electronics. Table E-17 shows that many countries host capabilities that support military applications and a wide range of civil applications.

TABLE E-17. BASIC RESEARCH—ELECTRONICS RESEARCH

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
SOLID-STATE & OPTICAL ELECTRONICS						
◆ ◆ ◆ MEDEA Semiconductors	◆ ◆ ◆ ◆ MEDEA, LETI, LIMMS Semiconductor device s	◆ ◆ ◆ ◆ MEDEA Semiconductors	<i>Japan</i> ◆ ◆ ◆ ◆ LIMMS, ASET Solid-state research Integrated optics <i>ROK</i> ◆ ◆ Solid-state research	◆ ◆		<i>Belgium</i> ◆ ◆ OE <i>Ireland</i> ◆ ◆ Solid-state & optical electronics
INFORMATION ELECTRONICS						
◆ ◆ ◆ General telecommu- nications Various antennas Digitized battlefield	◆ ◆ ◆ General telecommu- nications Battlefield commu- nications	◆ ◆ ◆ General telecommu- nications Heterogeneous net- works	<i>Japan</i> ◆ ◆ ◆ Most phases of tele- communications (both fiber & wire- less) <i>ROK, Singapore</i> ◆ ◆ General telecommu- nications	◆ ◆		<i>Netherlands</i> ◆ ◆ ◆ Digitized battlefield <i>Sweden, Finland</i> ◆ ◆ ◆ General telecommu- nications <i>Austria</i> ◆ Information fusing
ELECTROMAGNETICS						
◆ ◆ ◆ ◆ Terahertz technol- ogy Quasi-optics Microwave tubes Antennas	◆ ◆ ◆ ◆ Terahertz technol- ogy Microwave tubes Antennas ASET Magnetic storage	◆ ◆ ◆ ◆ MMW technology Microwave tubes Antennas	<i>Japan</i> ◆ ◆ ◆ Terahertz technol- ogy Acoustic wave devices Microwave tubes Antennas	◆ ◆	◆ ◆ Microwave tubes Antennas	<i>Spain</i> ◆ Quasi-optic wave- guides

Note: See page E-6 for legend.

a Solid-State and Optical Electronics

This area of research concentrates on the development of advanced semiconductor devices, advanced millimeter and submillimeter systems, and short-wavelength lasers. Basic research is directed at ultra-fast devices, devices operating at lower power levels, and OE devices. Japan and a number of European countries are active in these areas. For example, the U.K. is noted for research in the synthesis of novel phosphor materials. Researchers in Italy are collaborating with the Army on understanding breakdown mechanisms in heterojunction devices.

In Japan, ASET, a research partnership of 35 Japanese, 4 foreign affiliate companies, and 1 foreign company, conducts a very large effort. ASET's projects are in the fields of silicon large-scale integration technology, magnetic storage, and EO display technology. Much of the effort in

Europe operates under the umbrella of the Microelectronic Development for European Applications (MEDEA), with a goal of developing new semiconductor process technologies. Specific organizations involved in these or similar studies are SGS–Thomson (France), Fraunhofer Institute for Applied Solid-State Physics (Germany), and LETI (France).

In OE, the University of Ghent (Belgium) is active in photonic integrated circuits and optical coupling; the University College (U.K.), the University of Duisberg (Germany), and Thomson (France) are active in microwave photonics; and Toshiba, Fujitsu, and NEC (Japan) are active in short-wavelength lasers.

b Information Electronics

Research in most phases of information electronics is worldwide. Digitization of the battlefield is a research concept at TNO–FEL (Netherlands) and DERA (U.K.). Research programs in active antennas are underway at Ministry of Posts and Telecommunications (Japan), Dornier Satellite Systems and University of Karlsruhe (Germany), TNO–FEL (Netherlands), University of Bradford (U.K.), and Alcatel (France).

c Electromagnetics

Terahertz research is quite widespread. Among the organizations active in this technology are the University of St. Andrews (Scotland), University of Urlangen (Germany), and the Research Institute for Electrical Communication/Mizuno Laboratory (Japan). Research organizations actively pursuing work in various phases of microwave equipment (e.g., microwave antennas, waveguides, tubes) include the Universidad Publica de Navarra (Spain), Microwave and Antenna Systems (U.K.), and CNRS (France).

d Example Research Facilities

The following facilities have demonstrated expertise for providing cooperative opportunities in electronics research:

- Japan—ASET (Lithography) [http://www.aset.or.jp/r_index1-e.html]
- Korea—Opto-Electronics Research Center
- France—LETI (and its subsidiary GRESSI) [http://www.rdt.ccea.fr/home_leti-uk.htm]
- Netherlands—TNO–FEL [<http://www.tno.nl/>]

7 Mechanical Sciences

The field of mechanical sciences is divided into the areas of structures and dynamics, solid mechanics, fluid dynamics, and combustion and propulsion. Structures and dynamics encompasses the disciplines of structural dynamics, M&S, and air vehicle dynamics. These areas are crucial for weapon platform stability, weapon lethality, and smart weapon development. Solid mechanics includes topics relating to the mechanical behavior of materials, the integrity and reliability of structures, and tribology. These topics are important for damage propagation and control, weapon penetration mechanics, and platform life prediction. The priority areas within fluid mechanics include unsteady aerodynamics, aeroacoustics, and vortex-dominated flows. These areas help provide a better understanding of the phenomenon associated with projectile behavior, blast patterns, and chemical dispersion. Combustion and propulsion covers research in small gas turbine propulsion, reciprocating engine propulsion, and novel gun propulsion technology. These research fields contribute to efficient turbomachinery components, enhanced

engine air utilization, and novel ignition mechanisms. Table E-18 summarizes international research capabilities in each major research area of mechanical sciences.

TABLE E-18. BASIC RESEARCH—MECHANICAL SCIENCES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
STRUCTURES & DYNAMICS						
◆◆◆◆ Smart/active structures M&S Structural acoustics	◆◆◆◆ Smart/active structures M&S	◆◆◆◆ Smart/active structures M&S	<i>Japan</i> ◆◆◆◆ Smart/active structures M&S <i>ROK</i> ◆◆◆◆ Smart/active structures <i>India, China</i> ◆◆◆◆ Smart/active structures M&S	◆◆◆ Smart/active structures M&S		<i>Italy</i> ◆◆◆◆ Smart/active structures M&S <i>Brazil, Israel, South Africa, Poland</i> ◆◆◆ Smart/active structures
SOLID MECHANICS						
◆◆◆◆ Material behavior Structure reliability	◆◆◆◆ Material behavior Structure reliability	◆◆◆◆ Material behavior Structure reliability	<i>Japan</i> ◆◆◆◆ Structure reliability ◆◆◆ Material behavior <i>China, India, ROK</i> ◆◆◆ Material behavior Structure reliability	◆◆◆ Structure reliability ◆◆ Material behavior		<i>Italy, Spain, Israel</i> ◆◆◆ Material behavior Structure reliability <i>South Africa, Turkey, Sweden, Norway, Slovenia, Denmark, Australia</i> ◆◆ Material behavior Structure reliability
FLUID DYNAMICS						
◆◆◆◆ CFD, theoretical ◆◆◆ Experimental	◆◆◆◆ CFD, theoretical ◆◆◆ Experimental	◆◆◆◆ CFD, theoretical ◆◆ Experimental	<i>Japan</i> ◆◆◆◆ CFD, theoretical ◆◆ Experimental <i>India</i> ◆◆ CFD, theoretical	◆◆ CFD, theoretical	◆◆◆◆ CFD, theoretical	<i>Belgium</i> ◆◆◆◆ CFD, theoretical <i>Italy</i> ◆◆◆◆+ CFD, theoretical <i>Netherlands, Sweden, Australia</i> ◆◆◆ CFD, theoretical

TABLE E-18. BASIC RESEARCH—MECHANICAL SCIENCES (CONT'D)

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
COMBUSTION & PROPULSION						
◆◆◆◆ Small gas turbine Reciprocating engines Solid/liquid gun	◆◆◆◆ Small gas turbine Solid/liquid gun ◆◆ Reciprocating engines	◆◆◆◆+ Reciprocating engines; solid gun; Small gas turbine	<i>Japan</i> ◆◆◆◆ Reciprocating engines ◆◆◆ Solid/liquid gun Small gas turbine <i>ROK</i> ◆◆◆ Reciprocating engine <i>ROK, India</i> ◆◆ Solid gun	◆◆◆◆ Novel gun propulsion ◆◆◆ Small gas turbine Reciprocating engine	◆◆◆◆ Solid gun Reciprocating engines Small gas turbine	<i>Finland</i> ◆◆◆ Reciprocating engines <i>South Africa</i> ◆◆◆ Solid gun <i>Netherlands, Switzerland, Italy</i> ◆◆ Small gas turbine <i>Australia</i> ◆◆◆◆ Solid gun Reciprocating engines Small gas turbine

Note: See page E-6 for legend.

a Structures and Dynamics

The area of structures and dynamics consists of structural dynamics, M&S, and air vehicle dynamics. Within structural dynamics, the highest priority research is in ground vehicle and multibody dynamics, structural dampening, and smart structures. Achieving the goal of significant vibration reduction in Army vehicles will result in substantial increases in weapon platform stability, weapon system reliability, weapon lethality, and crew performance. Within air vehicle dynamics, there is priority research in integrated aeromechanics analysis, rotorcraft numerical analysis, helicopter blade loads and dynamics, and projectile elasticity.

The U.K., Germany, Italy, France, and Japan all demonstrate world-class capabilities in smart/active structures. South Korea has made notable progress and should be recognized as having similar world-class capabilities. In addition, India, China, Brazil, Israel, South Africa, Poland, Turkey, Russia, and Ukraine all demonstrate potential future applications in the same area. The U.K. continues to be the foreign leader in R&D concerning structural acoustics.

b Solid Mechanics

In the area of solid mechanics, the research topic areas are the mechanical behavior of materials, the integrity and reliability of structures, and tribology. The classes of materials of interest are functional gradient materials and heterogeneous materials. Within mechanical behavior, the primary research thrusts are material responses in the state of nonequilibrium or in transient states—as in impact and penetration mechanics—and damage initiation/propagation. In addition, the mechanical response under coupled effects of electric, magnetic, and thermal fields is of great interest. Research in the area of integrity and reliability of structures focuses on damage tolerance, damage control, and life prediction. In the area of tribology, dynamic friction, lubrication, and surface topology in low-heat-rejection environments are emphasized.

For the solid dynamics area, the U.K., France, and Germany all exhibit world-class capabilities in the area of mechanical behavior of materials. Japan, Italy, Spain, and Israel all show some

world-class capabilities. India, South Korea, China, Norway, Slovenia, Sweden, Denmark, South Africa, Turkey, and Australia show capabilities in a few points of material behavior. In the research area of structural reliability, the U.K., France, Germany, and Japan have world-class capabilities. Italy, Spain, and Israel exhibit several areas of strength in the field. South Africa, Turkey, Australia, Norway, Slovenia, Sweden, Denmark, China, India, and South Korea have a few well-developed capabilities. Russia and Ukraine have the resources to develop excellent capabilities in all areas of solid dynamics, but do not currently have world-class capabilities.

c *Fluid Dynamics*

Research in fluid dynamics can provide a better understanding of the phenomenon associated with projectile behavior, blast patterns, and chemical dispersion. Future advances would enhance the ability to predict the capabilities of smart munitions, integrated propulsion systems, flight dynamics, G&C systems, and CB threat behavior. Fluid dynamics research priority areas are unsteady aerodynamics, aeroacoustics, and vortex-dominated flows. Complementary research using CFD for multibody aerodynamics would provide the capability to predict and define submunition dispensing systems. Multidisciplinary research in this area will lead to hypervelocity launch technology and to low-speed military delivery systems.

Through the increasing use of commercially available CFD codes, the EC is quickly coming up to speed in the area of computational M&S. The U.K., France, and Germany continue to have a strong hold in this area, while many of their neighbors, including Belgium, the Netherlands, and Sweden, show great potential. Studies in the U.K., France, and Japan have contributed significantly to missile, rotor, and explosive design. Continued lack of support in Russia and the Ukraine, however, has led to their lack of increasing capabilities. The experimental aspect of fluid dynamics has taken secondary priority to the advancement of increasingly powerful CFD techniques. Despite this trend, the U.K., Germany, France, and Japan have maintained mature capabilities in this area.

d *Combustion and Propulsion*

Combustion and propulsion research supports advanced technology development in small, gas turbine engine propulsion; reciprocating engine propulsion; and solid, liquid, and novel gun propulsion technology. The development of high-performance, small, gas turbine engines requires basic research in turbomachinery stall and surge, as well as advances in CFD simulation. These basic research areas directly contribute to highly loaded, efficient turbomachinery components. Reciprocating engine technology research tends to move forward at a more evolutionary pace, with advances in ultra-low heat rejection, enhanced air utilization, and cold-start phenomena as priority areas. Solid gun propulsion technology requires research priorities to be placed on ignition and combustion dynamics and high-performance, solid-propellant charge concepts. Liquid gun propulsion requires priority research in atomization and spray combustion; ignition and combustion mechanisms; and combustion instability, hazards, and vulnerability. Novel gun propulsion depends on ECT propulsion, active control mechanisms, and novel ignition mechanisms.

In the combustion and propulsion area, the U.K., Germany, and France demonstrate world-class capabilities in small, gas turbine engine development. Germany in particular seems to be improving in small-scale gas turbine research. Canada, Australia, Russia, and Japan approach this level of capability in limited areas, but show good potential over the next decade to make significant contributions to small, gas turbine power-to-weight ratio improvement. The Nether-

lands, Switzerland, and Italy have capabilities in a few areas of gas turbine work. Germany leads in reciprocating engine development technology, with Japan also demonstrating world-class capability. Both countries excel particularly in the application of ceramic materials to low-heat-rejection technology. The U.K. also demonstrates excellent reciprocating engine development capability, with France, Canada, Australia, Finland, and South Korea exhibiting good future potential. Russia and Ukraine have demonstrated mature research in the past, but limited resources are causing a decline in future potential. Novel gun propulsion technology leadership is still maintained by Russia, but its future growth potential may be limited. The U.K. leads in the field of liquid gun propulsion development technology, with Japan showing significant potential. Solid gun propulsion development technology is improving in a number of countries, including the U.K., France, Germany, Canada, and Australia. Japan and South Africa demonstrate significant future potential.

e Example Research Facilities

The following facilities have demonstrated expertise for providing cooperative opportunities in mechanical sciences:

- Korea—Pohang University of Science and Technology, Smart Structures Laboratory [<http://www.postech.ac.kr/e/research/centers.html>]
- Japan—Engineering Research Association for a Supersonic/Hypersonic Transport Propulsion System Project [<http://www.kansai-ri.co.jp/treid/mcp/>]
- Canada—Intelligent Sensing for Innovative Structures [<http://www.isisCanada.com>]
- United Kingdom—Association for Structural and Multidisciplinary Optimization in the United Kingdom [http://www.brad.ac.uk/staff/vtoropov/asmo_uk/index.html]

8 Atmospheric Sciences

Weather and climate are major factors that can affect any operation. A thorough knowledge of and ability to predict patterns and phenomena, and adapt to them are therefore of keen interest to the U.S. Army. To maintain superiority on the battlefield, an all-weather capability must exist and be exploited to eliminate environmental factors as an element. Prediction and foreknowledge of the environment thus improves chances for uninterrupted communication and transportation. Three major research areas are of interest to the Army in atmospheric sciences: atmospheric effects on sensors and systems, characterization of the atmospheric boundary layer at high resolution, and management of atmospheric information.

During this decade, information technology has exploded, increasing capabilities in remote sensing and other similar fields. This has made data sets available at a faster rate worldwide, spawning greater research in areas of meteorology and solar and terrestrial physics, for example. Remote sensing is of great importance to the Army as the detection of weather phenomena and objects, manmade or natural, is simplified. Most European and Asian countries that were not as actively involved beforehand now have their own programs and participate in international programs such as the World Meteorological Organization (WMO) [<http://www.wmo.ch>] and in numerous conferences. As a result, the base technical capability required to be a global contributor in the area of atmospheric sciences has risen.

A continual burden to Russia's technical capability is a lack of financial resources. Russia maintains high standards of scientific excellence through its large number of scientific institutions; however, aging equipment and the erosion of many programs are preventing them from leading

state-of-the-art programs. Japan represents the strongest Asian technical presence, with its Asian neighbors demonstrating competence and a growing desire for international collaboration. Several European countries have world-class programs, with the U.K., Germany, and France, regarded as the European leaders. Table E-19 depicts the international capabilities in atmospheric science research.

TABLE E-19. BASIC RESEARCH—ATMOSPHERIC SCIENCES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
ATMOSPHERIC EFFECTS ON SENSORS & SYSTEMS						
◆◆◆◆ Dynamic processes	◆◆◆◆ ISTP	◆◆◆◆ Acoustic propagation	Japan ◆◆◆◆ ISTP China, Taiwan ◆	◆◆◆◆ Dynamic processes	◆◆◆◆ Adaptive optics	Australia, Israel, Norway ◆ Denmark, Italy Finland, Netherlands ◆◆
CHARACTERIZATION OF THE ATMOSPHERIC BOUNDARY LAYER AT HIGH RESOLUTION						
◆◆◆◆ Remote sensing	◆◆◆◆ All	◆◆◆◆◆ Aerosols	Japan ◆◆◆◆◆ Remote Sensing	◆◆◆◆	◆◆◆◆◆	Australia, Israel, Norway, Spain ◆ Denmark, Finland, Netherlands ◆◆ Italy ◆◆◆
MANAGEMENT OF ATMOSPHERIC INFORMATION						
◆◆◆◆◆ Visualization	◆◆◆◆ Modeling	◆◆◆◆ Modeling	Japan ◆◆◆◆◆ HPC	◆	◆◆◆◆	Australia, Denmark, Finland, Norway ◆ Israel, Sweden, Netherlands ◆◆

Note: See page E-6 for legend.

a Atmospheric Effects on Sensors and Systems

The propagation of signals is subject to scattering and attenuation because of varying indices of refraction and an abundance of charged particles in the environment. From source to target, acoustic and EM transmissions can be scattered from changes in the medium, where propagation behavior is path dependent. Further, small-scale atmospheric turbulence and scintillation can cause significant attenuation and scattering of a transmitted signal. Transmission of not only signals, but aerosols or other agents, is of crucial importance due to the CB weapons threat. Modeling and prediction of these events are therefore of interest to the Army to achieve its mission with maximum effectiveness. Several groups are performing research in the area of propagation research.

Sampling of small-scale atmospheric turbulence has been used in ground-based astronomy through adaptive optics. Here, a laser is used to excite a “guide star” in the thin sodium layer about the atmosphere. The guide star, fluoresced adjacent to the intended star, samples local turbulence and deforms a focusing mirror to counter its effects on the incoming star’s visible light. The result is an image taken without the effects of atmospheric turbulence. This technique, used

in the airborne laser, can be used in other Army applications. Adaptive optics are found on many ground-based telescopes and in other optical devices.

Many atmospheric studies focus on the propagation of pollutants and various environmentally damaging particles. The International Solar-Terrestrial Physics (ISTP) program, however, is a major international collaboration of ground- and space-based measurements led by NASA, the European Space Agency, and the Institute of Space and Astronautical Science (Japan). One of the goals of the ISTP is to develop the first solar-terrestrial model that predicts atmospheric events as they are influenced by solar disturbances. The ionosphere (and magnetosphere) plays a big role because of the susceptibility of EM fields and sensors to extremes in solar weather.

b *Characterization of the Atmospheric Boundary Layer at High Resolution*

The atmospheric boundary layer, an interface of approximately 1 km between the Earth's surface and the troposphere, is subject to daytime heating and nighttime cooling. These thermal changes taking place over heterogeneous terrain can cause of considerable weather variations over small temporal and spatial scales. How these variations couple the boundary layer over land to that over water is a mechanism for study as well. Real-world simulations of wind vectors, temperature, and moisture are key to weather prediction and tracking the dispersion of aerosols and other agents.

The European Experiment on Transport and Transformation of Environmentally Relevant Trace Constituents in the Troposphere Over Europe (EUROTRAC-2) comprises 250 research groups in approximately 30 countries. In particular, the Global and Regional Atmospheric Modeling (GLOREAM) experiment could be of significant interest to the Army. Much work is going into atmospheric modeling and tropospheric chemistry. For example, the High-Resolution Limited Area Model (HIRLAM) project is an international effort to develop a numerical, short-range weather forecasting system that analyzes surface pressure, atmospheric temperature, wind velocity, and humidity. Meteorological institutes in Denmark, Finland, Iceland, Ireland, the Netherlands, Norway, Spain, and Sweden are participants and cooperate with Météo-France. A great majority of work is being driven by environmental concerns and the effects on weather of air pollution and smog, ozone depletion, ocean circulation, and global warming.

c *Management of Atmospheric Information*

Information is meaningless unless it can be presented efficiently and interpreted by the user. Visualization and display of information, as well as delivery to the soldier and decisionmaker, are critical to all aspects of the atmospheric sciences effort. An additional top priority is capability in high-performance computational techniques that combine direct and indirect measurements into a forecast model or real-world battlefield visualization. Because weather prediction is a probabilistic science, error assessment can substantially influence the decisionmaking process. Areas of interest include imaging techniques, signal processing, and modeling for multivariate data.

Management of atmospheric information can generally be as sophisticated as the meteorological programs themselves. In other words, with larger and increased numbers of datasets comes the need for more efficient ways of storing, delivering, and displaying the data. The majority of visualization research is performed at the university level with significant international collaboration and visitor exchange.

d Example Research Facilities

The following facilities have demonstrated expertise for providing cooperative opportunities in atmospheric sciences:

- Switzerland—WMO, Geneva [<http://www.wmo.ch/>]
- EUROTRAC [<http://www.gsf.de/eurotrac/et-2.htm>]
- United Kingdom—Applied Optics Group, Blackett Lab, Imperial College [<http://op.ph.ic.ac.uk/>]

9 Terrestrial Sciences

Basic research in terrestrial sciences studies terrain characteristics and processes, including topography, climatology, and hydrology. This research critically affects all aspects of mission planning, logistics, unit effectiveness, and system performance. Knowledge of the topographical, geological, climatological, and hydrological characteristics of the landscape is critical to mobility/counter mobility, logistics, communications, survivability, and troop and weapon effectiveness. The digital battlefield also requires detailed and sophisticated information about topography, as well as terrain and environmental features and conditions. Of particular importance to Army goals is terrestrial science research in three broad areas: terrain characterization and analyses, hydrodynamic and surficial processes, and geotechnical engineering. Table E-20 highlights international research capabilities in terrestrial sciences.

TABLE E-20. BASIC RESEARCH—TERRESTRIAL SCIENCES

Technology	United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
TERRAIN PROPERTIES & CHARACTERIZATION							
	◆◆◆◆	◆◆◆◆+ Remote sensing	◆◆◆◆ Remote sensing GIS	Japan ◆◆◆ China ◆◆	◆◆	◆◆◆	Netherlands ◆◆◆+ Sweden, Australia ◆◆◆
TERRESTRIAL PROCESSES & LANDSCAPE DYNAMICS							
	◆◆◆◆	◆◆◆	◆◆◆	Japan ◆◆◆ India, China ◆◆	◆◆	◆◆◆◆	Netherlands ◆◆◆+ Australia, Israel ◆◆◆
TERRESTRIAL SYSTEM MODELING & MODEL INTEGRATION							
	◆◆◆◆	◆◆◆	◆◆◆+	Japan ◆◆◆ China ◆◆	◆◆—	◆◆◆+	Sweden, Norway ◆◆◆

Note: See page E-6 for legend.

International capabilities in these areas of research related to Army goals include studies of hydrogeology in Israel and Canada and magnetohydrodynamics and hydrology work in France and the U.K. Other countries with active basic research programs include Japan, Australia, India, China, Russia, and the Netherlands.

a *Terrain Properties and Characterization*

This field contributes to the characterization of the surface geometry and terrain features needed for enhanced planning and tactical decisionmaking, as well as designing equipment adaptable to the varied natural environment. Research on topography and terrain seeks to develop new remote sensing data acquisition capabilities and data synthesis and analysis techniques to develop topography and terrain database information. This work is supported by studies of the dynamical physical processes involved in the interactions between surface features and materials and the atmospheric boundary layer and weather systems in order to produce highly sophisticated models of dynamic environmental effects on mission performance. Countries with active research in this area include Australia, Sweden, France, Germany, China, and the Netherlands.

b *Terrestrial Processes and Landscape Dynamics*

Basic research in hydrodynamics relates to the hydrologic cycle and focuses on hydrometeorology, rainfall/runoff dynamics, and fluvial hydraulics, as well as the relationship between surface and groundwater hydrology. Research in surficial processes relates to the geomorphological character of the surficial environment, primarily the physical processes operating in arid/semi-arid, tropical, and coastal environments. This work contributes to the ability to estimate hydrologic/physical response and therefore to the ability to accomplish specific activities within a range of expected environmental conditions.

c *Terrestrial System Modeling and Model Integration*

Research in this field focuses on the strength and behavior of materials under a variety of external forces, both natural and manmade. This includes studies of the properties of snow, ice, and frozen ground, as well as soil dynamics and structural mechanics. International capabilities in areas related to Army goals include research on retrofit material systems in the U.K., geotechnical materials research in France, and precision experiments in structural response in Germany. The Scandinavian countries, most notably Norway and Sweden, have made advances in soil mechanics and land use planning, respectively. Many other countries have significant capabilities in niche areas of geotechnical engineering, including Japan (earthquake engineering), India, Canada, and China.

d *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in terrestrial sciences:

- Australia—Australian Geodynamics Cooperative Research Center [<http://www.agcrc.csiro.au/>]
- Austria—International Symposium on Acoustic Remote Sensing [<http://www.boku.ac.at/imp/isars/>]
- The Netherlands—Vrije Universiteit Amsterdam [<http://www.geo.vu.nl/users/hydro/index.html>]
- Canada—National Hydrology Research Institute [<http://ecsask65.innovplace.saskatoon.sk.ca/>]
- Russia—Hydrometeorological Centre of Russia

10 Biomedical Research

Basic research efforts in the biomedical sciences related to military missions address four areas: infectious diseases of military significance, combat casualty care, Army operational medicine, and medical CBD (MCBD). The first relates to protection/prophylaxis of personnel deployed to

a mission area from indigenous organisms or to biological agents; the second, to care of personnel following acute injury; the third, to enhancers/sustainers of performance in the field; and the fourth, to treatment and care of persons following exposure to biological agents. These areas of investigation are dual use and affect general health care delivery, although military aspects often differ from civil concerns in several critical instances. For example, deployed military personnel may be more susceptible than indigenous populations to infectious agents because of a lack of prior exposure. Also, developing novel means useful in delaying onset of clinical disease in the face of the physically and mentally demanding nature of combat is of critical importance, because incapacitating military forces for short periods may have profound effects on the outcome of operations. Table E-21 summarizes international capabilities in medical research.

a *Infectious Diseases of Military Importance*

Basic research in infectious diseases of military significance concentrates on the prevention, diagnosis, and treatment of infectious diseases affecting readiness and deployment. The human genome effort will identify those gene profiles that render specific populations more susceptible to disease than other populations. The entire human genome is anticipated to be characterized in 2003, and perhaps sooner.

The human genome project is a multinational effort spearheaded by the United States, the EC, and Japan; the information is freely available on the Internet. Novel combinatorial chemistry strategies have allowed the synthesis of nonpeptide molecules that bind gene fragments, receptors, or cell proteins and thereby offer the potential of protection against threat agents. These same materials also may provide utility in multiarray sensors used for the detection of biological agents. Combinatorial chemistry strategies are being pursued in many developed nations through the pharmaceutical sector. Switzerland, Sweden, and Israel have expertise in these areas, as do the above-mentioned nations. Although China does have a capability in production of several antibiotics, much of the technology is obtained through license of foreign technologies. There are innovative joint research efforts between China and several U.S. firms; however, current Chinese capability in antibiotic and vaccine development and production more closely approximates that of developing nations with extensive foreign investment.

b *Medical Chemical and Biological Defense*

Foreign efforts in medical chemical defense closely parallel those in medical biological defense. For the most part, countries that are engaged in one are also active in the other. The one exception to the countries listed is the Netherlands. The Dutch effort in medical chemical defense is not as extensive as in medical biological defense. All countries listed have world-leading capabilities and none is expected to pull ahead of the others.

Normally occurring biomolecules that enhance or degrade the immune response of persons to infectious materials or to toxins have now been identified. These materials are called biological response modifiers. Treatment with novel biological response modifiers of military forces who may have been exposed to pathogenic agents as a consequence of deployment or through biological agent attack may enhance the survival or sustain the performance of the affected personnel. In the past few years, it has been shown that transport of infectious materials across cell membranes is a critical element in viral replication and maturation. Chemical treatment that interferes with the ability of a virus to bind to a target cell or with intracellular transport can impede viral multiplication and infectivity. Such treatments may sustain performance of

TABLE E-21. BASIC RESEARCH—BIOMEDICAL RESEARCH

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
INFECTIOUS DISEASES OF MILITARY IMPORTANCE						
◆◆◆◆ Human genome & disease susceptibility Vaccines & vaccine delivery post-exposure Rapid diagnosis Antibiotics Biological response modifier Tissue growth & transplant	◆◆◆◆ Human genome & disease susceptibility Vaccines & vaccine delivery post-exposure Rapid diagnosis Antibiotics Biological response modifier Pathogenicity islands Block viral/bacterial disease	◆◆◆◆ Human genome & disease susceptibility Vaccines & vaccine delivery post-exposure Rapid diagnosis; tissue growth & transplant Block viral/bacterial disease Telemedicine	<i>Japan</i> ◆◆◆◆ Human genome & disease susceptibility Vaccines & vaccine delivery post-exposure Rapid diagnosis Antibiotics Tissue growth & transplant Pathogenicity islands Antivirals <i>China</i> ◆◆◆◆ Antibiotics	◆◆◆◆ Vaccines & vaccine delivery post-exposure Rapid diagnosis	◆◆◆◆ Vaccines	<i>Switzerland</i> ◆◆◆◆ Vaccines & vaccine delivery post-exposure Rapid diagnosis Antivirals <i>Sweden</i> ◆◆◆◆ Antibiotics <i>Israel, Italy, Netherlands</i> ◆◆◆◆
MEDICAL CHEMICAL & BIOLOGICAL DEFENSE						
◆◆◆◆ Vaccines & vaccine delivery post-exposure; acute trauma shock; lightweight face masks for BW protection			<i>Japan</i> ◆◆◆◆ Vaccines & vaccine delivery post-exposure Acute trauma shock <i>China</i> ◆◆◆◆ Acute trauma shock <i>ROK</i> ◆◆◆◆	◆◆◆◆ Vaccines & vaccine delivery post-exposure Acute trauma shock Lightweight face masks for BW protection		<i>Switzerland, Netherlands, Israel</i> ◆◆◆◆ Vaccines & vaccine delivery post-exposure Acute trauma shock Lightweight face masks for BW protection
MILITARY OPERATIONAL MEDICINE						
◆◆◆◆ Biological response modifier; biomarkers for toxicant exposure; nutrient additives			<i>Japan</i> ◆◆◆◆ Biological response modifier Biomarkers for toxicant exposure Nutrient additives	◆◆ Biomarkers for toxicant exposure Nutrient additives Personnel containment following CB attack		<i>Switzerland, Sweden, Israel</i> ◆◆◆◆ Biological response modifier Nutrient additives
COMBAT CASUALTY CARE						
◆◆◆◆ Telemedicine; wound healing & nervous system repair; blood replacement			<i>Japan</i> ◆◆◆◆ Telemedicine Wound healing & nervous system repair Blood replacement <i>Korea</i> ◆◆◆◆ Blood replacement <i>China</i> ◆◆◆◆	◆◆ Telemedicine Wound healing & nervous system repair	◆◆ Artificial blood substitutes	<i>Switzerland, Israel, Netherlands, Sweden</i> ◆◆◆◆ Telemedicine Wound healing & nervous system repair Blood replacement

Note: See page E-6 for legend.

affected personnel for long periods after exposure to such agents. The U.K., Japan, France, Germany, Sweden, and the Netherlands are leaders in this area.

c *Military Operational Medicine*

Basic research within the Army operational medicine area provides a basic understanding of the pathophysiology of environmental and occupational threats affecting soldier health and performance. In addition to the risks to health and performance from operations in extreme and climatic environments and from the rigors imposed by military operations in and of themselves (e.g., sleep deprivation, jet lag, stress), operation of Army systems may present additional health hazards (e.g., EM radiation, noise, vibration, blast, toxic chemical byproducts).

Biomarkers for toxicant exposure in humans and animals have been identified as materials that are body catalysts and enzymes, which serve to detoxify chemicals. The absence of some of these normally occurring enzymes in specific persons has been shown to increase susceptibility to disease. It is now possible to screen blood and urine samples and determine the concentration of these biomarkers in selected persons. It is likely that biomarker profiles will have utility in selection of persons resistant to toxicants (for special operations) and for reviewing fitness for duty. The human genome project is likely to increase the number of biomolecules that can serve as biomarkers for exposure. The U.S., Canada, the EC, and Japan have expertise in this area.

d *Combat Casualty Care*

The critical areas of care for combat casualties in the next decade include treatment for fluid loss and accompanying shock; management of impact injury on the nervous system, including the spinal cord; increased susceptibility to infection at points of projectile entry because of stress-related events; and prevention of biological agent dissemination by friendly forces exposed to agents. Biocompatible materials that bind oxygen and have utility as blood-expanding agents are in development in the United States, the EC, and Japan. Cellular growth factors, acting on neural tissues, have been found to stimulate the repair of transected spinal cord and other central nervous system regions. Macromolecular growth factors, acting on tissues other than the nervous system, have been shown to enhance the rate of wound healing and to increase resistance to disease. This research is actively explored in the U.S., Canada, Germany, the U.K., France, Japan, Israel, Italy, and Sweden.

e *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in biomedical research:

- Canada—Defence and Civil Institute of Environmental Medicine [http://www.dciem.dnd.ca/DCIEM/welcome_e.html]
- Belgium—Center for the Evaluation of Vaccination, University of Antwerp [<http://esoc-www.uia.ac.be/esoc/CEV/>]
- Czech Republic—Department of Military Epidemiology, Purkyně Military Medical Academy [<http://www.pmfhk.cz/rEnglish/index.htm>]
- Switzerland—Neuroscience Center, Swiss Federal Institute of Technology [<http://www.neuroscience.unizh.ch/>]

11 Biological Sciences

Basic research in the biosciences increases the understanding of and ability to (1) manipulate those aspects of the biological world that affect soldier sustainment and survival, and (2) identify and characterize biological materials and processes for future exploitation in materiel systems. Specifically, biological sciences research contributes directly to a knowledge of food production in deployed areas; production of potable water; protection of military personnel from infectious agents in a deployed region; production of sensors for CB agents; reduction of signatures to increase stealth; and production of materials useful in communications, sensing, and self-assembly. Table E-22 summarizes international research capabilities in biological sciences.

TABLE E-22. BASIC RESEARCH—BIOLOGICAL SCIENCES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
BIOMOLECULAR & CELLULAR MATERIALS & PROCESSES						
◆◆◆◆ Combinatorial chemistry, human genome, pathogenicity islands Characterization of receptors for biological agents, toxins, and neurotransmitters Functional MRI, PET, and systems			<i>Japan</i> ◆◆◆◆ Combinatorial chemistry Human genome, pathogenicity islands Characterization of receptors for biological agents, toxins, and neurotransmitters Functional MRI, PET, and systems ◆◆◆◆ Biomimetic optical information processing Biomimetics for lightweight protective clothing <i>China</i> ◆◆◆◆+ Combinatorial chemistry Characterization of receptors for biological agents, toxins, and neurotransmitters <i>India</i> ◆◆	◆◆— Combinatorial chemistry Human genome, pathogenicity islands Characterization of receptors for biological agents, toxins, and neurotransmitters Functional MRI, PET, and systems ◆◆◆ Biomimetic optical information processing Biomimetics for lightweight protective clothing	◆◆◆ Targeted delivery	<i>Netherlands, Israel, Switzerland, Sweden, Australia</i> ◆◆◆◆ <i>Italy</i> ◆◆◆—
MICROBIOLOGY & BIODEGRADATION						
◆◆◆◆ Bioremediation Signature reduction			<i>Japan</i> ◆◆ Bioremediation <i>China</i> ◆◆◆◆+ Biomimetic optical information processing	◆◆ Bioremediation Signature reduction		<i>Netherlands, Switzerland, Finland, Israel, Sweden</i> ◆◆◆◆

TABLE E-22. BASIC RESEARCH—BIOLOGICAL SCIENCES (CONT'D)

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
PHYSIOLOGY, SURVIVABILITY, & PERFORMANCE						
◆◆◆◆ Rations to enhance/sustain performance Biological response molecules Nutritional additives from microbiological or sea plant sources Encapsulation			<i>Japan</i> ◆◆◆◆ Rations to enhance/sustain performance Biological response molecules Nutritional additives from microbiological or sea plant sources Encapsulation <i>China</i> ◆◆◆◆ Rations to enhance/sustain performance Biological response molecules Nutritional additives from microbiological or sea plant sources Encapsulation	◆◆◆◆ Rations to enhance/sustain performance Biological response molecules Nutritional additives from microbiological or sea plant sources		<i>Netherlands, Italy, Sweden, Israel</i> ◆◆◆◆ Rations to enhance/sustain performance Biological response molecules Nutritional additives from microbiological or sea plant sources

Note: See page E-6 for legend.

a Biomolecular and Cellular Materials and Processes

Research in this area seeks to define structure function relationships and biochemical interactions for enzymes, receptors, and other macromolecules exhibiting mechanisms and properties relevant to Army interests. These include biocatalysis, ribosomal and nonribosomal biosynthesis, and metabolic engineering.

The Human Genome Project utilizes biochemistry (combinatorial chemistry), biophysics, and molecular biology to explore questions of intrinsic disease susceptibility in humans, animals, and crops. These technologies also reveal the nature of molecules that allow bacteria to infect humans, allow viruses to infect cells, and allow cells to communicate with each other (i.e., receptors). The insights gained from the Human Genome Project have resulted in the identification of gene sequences (pathogenicity islands) in biological agents that increase pathogenicity in humans and target animals. Since the effect of toxins on cells is a result of their action on specific cell receptors, these technologies reveal how we can neutralize toxins. Russia had developed expertise in the use of biological toxins to deliver molecules to specific cells. The Russian capability has decreased in many of these areas during the past 5 years, but still remains strong in targeted delivery (associated with Ministry of Defense laboratories). The U.K., Canada, Japan, Taiwan, Russia, Sweden, China, Korea, Brazil, and Israel have capabilities in these areas. A number of nations have strong programs in the characterization of biomolecules, for example, surface characterization work in China and nuclear magnetic resonance studies in Japan, the Netherlands, and the U.K.

The use of biomaterials as structural elements or as models to construct nonbiological materials that function as biomimetics has grown, as has the demand for system miniaturization. Polyhydroxybutyrate and silks are two examples of biomaterials with good tensile properties. The

U.K., France, Germany, Israel, the Netherlands, and Australia are developing advanced biomaterials for energy transduction applications. New materials emerging from nanotube technology, ceramics based on marine shell structures, and isolated bacterial rhodopsin have applications in signature reduction and information storage. Russia, in collaboration with the former DDR, utilized bacterial rhodopsin to construct a read/write device called Biochrome. The reduction in financial resources in the FSU has caused a decline in this capability. A Biochrome material is currently available from Germany. The U.K., Japan, France, the Netherlands, and Israel also have strong capabilities in this area.

Biotechnology applications can contribute to Army efforts. Large-scale production of biomaterials and products is necessary to capitalize on emerging biotechnology developments. The techniques for providing these large quantities of biomaterials (bioprocess engineering), of significant interest to the U.S. Army, include production of the material (including cell culture and fermentation), downstream product processing, and packaging.

Compared to other rapidly advancing technologies, biotechnology at the research level is relatively open. The most concerted challenges may be expected from Japan, Germany, France, the U.K., the Netherlands, Switzerland, Italy, Sweden, Russia, and certain of the other FSU and Eastern European states. Canada, Brazil, Singapore, Israel, and China are other examples of countries with strong capabilities in the basics of biotechnology upon which to build, as well as strong (in some cases world leading) capabilities in niche technologies.

Japan's well-coordinated government and industry cooperative effort provides guidance, avoiding duplicate efforts while increasing support and sharing throughout different companies. Government sponsors in biotechnology include the Council for Science and Technology; the Science and Technology Agency; MITI; the Ministry of Health and Welfare; the Ministry of Education, Science, and Culture; and the Ministry of Agriculture, Forestry, and Fisheries. Large companies (e.g., Kirin Brewery, Suntory Limited, Mitsubishi Kasei Corporation, Sumitomo Chemical Company, Takeda Chemical Industries, Tanabe Seiyaku Company, Ltd., Toray Industries, Yamanouchi Pharmaceutical Company) are important participants in Japanese biotechnology activities. These companies—traditionally strong in chemicals, pharmaceuticals, food and beverage, and textiles—now see the possibilities for additional diversification to high-value-added health care products. A Japanese consortium of Fuji and Seiko is examining the human genome. In Japan there is a close, strong relationship between industry and the university community. The relationship includes company financial support of biotechnology activities and industry personnel performing onsite research at universities.

Strong government influence is also evident in Japan's research centers. Some of the better known are the Fermentation Research Institute, the National Institute of Basic Biology, Institute of Physical and Chemical Research (RIKEN), and the New Energy and Industrial Development Organization. These centers encourage and support basic and applied research in virtually all of the key areas of biotechnology identified in this Advanced Technology Assessment Report. They also help the larger governmental agencies identify key directions that Japanese biotechnology R&D efforts should take.

Several institutes are essentially dedicated to biotechnology: Osaka Bioscience Institute, National Institute of Agrobiological Resources, National Institute of Sericultural and Entomological Science, Fermentation Research Institute, and Nippon Institute for Biological Science. Molecular biology, cell biology, and enzymes are the main research activities at the Osaka Bioscience Institute. Major areas of research at the National Institute of Agrobiological Resources

include molecular and cellular biology, genetic engineering (such as recombinant DNA), and bioprocessing (cell fusion). The National Institute of Sericultural and Entomological Science is studying silk culture. This has mainly been restricted to silkworm silk for commercial purposes and is only generically related to spider silk. However, they are currently collecting information on other insects. The Fermentation Research Institute conducts a broad range of activities in bioprocessing. These include recombinant DNA, bioreactors using immobilized enzymes, and cell growth. The Nippon Institute for Biological Science' research projects cover a wide area of genetic engineering.

Germany, because of its strong industrial base and major presence in pharmaceutical and brewing areas, is generally considered to have the strongest capability for biotechnology within the EC. They are well positioned to challenge the United States and Japan, and to become a world leader in biotechnology. The Bundesministerium für Forschung und Technologie Federal Ministry for Research and Technology, the DECHEMA Chemical Plant Association, and the GBF Institute for Biotechnology Research are important biotechnology development centers. Ger-

enzyme-based systems for decontamination of CW agents. This effort is coordinated through the Defense Science Agency for NBC Protection.

The GBF Institute has achieved worldwide fame for its work in fermentation processes and technology. Areas of research interest at GBF are separation, sequencing, and purification of products; enzyme and microbial transformation; genetic engineering; bioreactor design and process control; protein engineering and modeling; and biosensor technology. In addition, the Biotechnology Information Knot for Europe, a database/information base of biotechnology, is maintained at GBF. The Institute for Biotechnology, another German organization devoted to biotechnology, is instrumental in microbial degradation of polymers and use of enzymes (cellulose and hemicellulose, etc.).

The Max Planck Institute and other government-funded organizations are primarily research-related and provide a solid basis for further advances in German biotechnology. Germany's university structure—University of Technical Chemistry at the University of Hannover, the Institute of Biochemistry and Molecular Biology at the Technical University of Berlin, the Institute for Biochemistry at Free University of Berlin, as well as others—provides strong capabilities in most biotechnology-related research areas. The industrial sector has numerous large, multinational corporations founded in Germany, such as Bayer and Hoechst. Many smaller German firms are making significant advances in biotechnology, especially in areas like enzyme production, biological pesticides/insecticides, fertilizers, and pharmaceuticals. The German chemical firm Degussa has shown considerable interest in amino acids. However, no European firm has the capability exhibited by the Japanese in this area.

The U.K. is generally cited as having a strong biotechnology capability within the EC, only slightly trailing Germany. The U.K.'s initial biotechnology emphasis was focused on genetic engineering; however, fermentation, bioreactors, and chemical engineering areas are now receiving considerable interest and support from government, academia, and industry. The U.K. is one of the participating nations in ITF24, which deals with emerging technologies for the detection and identification of biological agents. This effort falls under a memorandum of agreement on CB defensive material. Government agencies providing support and resources to promote biotechnology advances in the U.K. are MRC, SERC, and the Biotechnology Division of the Department of Trade and Industry. These agencies provide funding, develop and implement

policy, encourage research, and provide guidance and oversight to academia, industry, associations, and any collaboration among these participants. Many universities and industries are closely associated through cooperative ventures. This synergy promotes university research efforts and graduate education while providing industry with promising projects.

Biotechnology projects in the U.K. will continue to improve and grow because of the strong foundation provided by academia/industry. The U.K. university system is one of the best in the world in biotechnology. Numerous colleges and universities have ongoing research programs in many different biotechnology areas. Some major areas of emphasis are fermentation mixing, scale-up, and pilot plant development of bioreactors; immunoaffinity materials for downstream processing; monoclonal antibody production and hybridoma cell growth; genetic engineering; biosensors; thermal stable enzymes; chemically sensitive fiber-optic sensors; biodegradation techniques; and bioelectronics.

Genetic engineering

CNRS [<http://www.cnrs.fr>]

Institut National de la Recherche Agronomique

Institut Pasteur

Institut National de la Sante et de la Recherche Medicale

Photosynthesis and radioisotopic metabolism

Commissariat a l'Energie Atomique

Hybridoma technology, virology, and immunology

Institut Pasteur [<http://www.pasteur.fr>]

Biological reactors; catalysis, production, and purification of enzymes; immobilization of enzymes; and fermentation techniques:

Laboratory of Chemical Genetics (division of CNRS)

National Polytechnic Institute of Lorraine

Laboratory of Biopharmacology—CNRS, Tours

National Institute for Applied Chemical Research (also production of synthetic peptide intermediate compounds (amino acids, oligopeptides, phosphorylated derivatives)).

Bioinformatics (algorithms, software, and hardware tools) to monitor and control bioreactors, biotechnological processes optimizing yield and quality, and related M&S techniques:

National Polytechnic Institute of Grenoble

Industrial biotechnology:

Rhone-Poulenc

Roche

Roussel-Uclaf

Ciba-Geigy

Sanofi

Shering-Plough

Merck

I'Oreal

France participates in a number of joint projects with the EC. However, they have strong national aspirations as well. In the 1980s, the French government initiated an aggressive biotechnology development program designed to make them the European leader by 2000. Their aim is to capture 10 percent of the world's market in biologically derived substances. The French Committee for Strategic Industrial Development committed millions of dollars with matching industry funds to numerous biotechnology projects. France is also a member of NATO PG 31 for developing enzyme-based decontaminants. The primary research facility involved is the CEB, Vert-le-Petit.

Because France perceives itself as lagging behind its major European counterparts—Germany and the U.K.—it decided to place particular emphasis on long-term means (e.g., education, training) to achieve its goal. The leading research institutes and university centers

identify candidate biotechnology areas for establishing and developing products. One of the major handicaps of the French biotechnology program is the lack of cooperation between industry (applied uses) and the university (academic research). To facilitate better exchange of ideas and promote commercial application of research, a number of joint technology centers were established (Compiègne, Toulouse, Institut Pasteur, and Paris-Grignon University).

The success of recent collaboration between industry and academia has promoted projects sponsored by industry and government. One major public-private sector collaborative initiative—the Intergene Program—is leading France's research efforts in immunoenzymology, bacterial

immunology, parasitic and viral immunology, monoclonal antibodies, and enzyme purification. The government participants of this effort are CNRS, the Institut National de la Sante et de la Recherche Medicale, and the Ministry of Research and Technology; Transgene, Immunotech, and Bio-Merieux are the private sector players.

Before the dissolution of the FSU, the Soviet Union led a strong biotechnology effort, linked cooperatively with its Eastern European allies by the Council for Mutual Economic Assistance. Different countries emphasized different points of biophysical research. Primary emphases of biotechnology efforts within the FSU, as in other nations, include drugs, vaccines, and agricultural applications. Russian work includes virtually all of the basic elements of generic biotechnology. The theoretical and analytical work done is strong and of high quality. Specific sub-technologies include recombinant DNA and protein engineering, self assembly, enzyme immobilization, and Langmuir–Blodgett films. Their discoveries and achievements—their understanding of the molecular mechanisms whereby neurons process information, their development of Biochrome bacteriorhodopsin-based film, and the use of dynamic chemical reactions for image processing—indicate a substantial capability. The development of Biochrome film (a highly stable and fast-response (picoseconds) membrane capable of bistable switching) is particularly significant. First, it demonstrates a strong level of understanding and capability in basic biotechnology that could lead to protein engineering techniques to produce materials with optimized functional capabilities. Equally important, successful demonstration of bistable materials opens possibilities for application of biomaterials to important information storage, processing, and computational applications.

b Microbiology and Biodegradation

Microbiology is an essential science in the production of fermented and processed foods (bread, yogurt, beer, wine), of pharmaceuticals and human hormones (the latter using genetic engineering), and in evaluating human performance (neural function, vital signs). The U.K., Japan, Germany, France, and Russia have a long tradition of expertise in this areas. Hungary has an established capability in the production of fermenters. China has a developing capability in nutrient additives and biological response modifiers.

Remediation of soils and water using biological organisms to metabolize contaminants has been an area of extensive research in the past decade. The U.K., France, Germany, the Netherlands, Sweden, Finland, Japan, Russia, and Israel have expertise in this area, with the U.K. and Israel particularly active in water purification.

c Physiology, Survivability, and Performance

This area includes research on how organisms respond and adapt to environmental signals and the strategies they employ to survive adverse environmental conditions. Other research of interest includes work in nutrient additives, protein stabilizers, sugar modification, and synthesis of biopolymers for use as elastomers in food containers. Encapsulation and irradiation technologies have been used to increase shelf life, and encapsulation also increases palatability. Most EC nations and Japan have advanced food technology programs. Strong capability in the use of biopolymers as packaging primarily resides in the EC.

d Example Research Facilities

The following facilities have demonstrated expertise for providing cooperative opportunities in biological sciences:

- France—Center for Molecular Biophysics, CNRS—University of Orléans [<http://www.cnrs.fr>]
- Netherlands—Graduate School of Food Technology, Agrobiotechnology, Nutrition, and Health Sciences, Wageningen Agricultural University
- United Kingdom—Center for Biomimetics, University of Reading [<http://www.reading.ac.uk/AcaDepts/cb/home.htm>]

12 Behavioral, Cognitive, and Neural Sciences

Basic research in the Army Behavioral, Cognitive, and Neural Sciences (BCNS) program seeks the scientific understanding of factors that enhance or diminish performance of soldiers in units. Table E-23 summarizes the research capabilities of the international research community in BCNS.

TABLE E-23. BASIC RESEARCH—BEHAVIORAL, COGNITIVE, AND NEURAL SCIENCES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
TRAINING						
◆◆◆◆—	◆◆◆	◆◆◆◆	Japan ◆◆◆◆+	◆◆◆—	◆◆◆◆	Israel ◆◆◆
PERSONNEL						
◆◆◆	◆◆	◆◆	Japan ◆◆ Philippines, Singapore ◆◆+	◆	◆◆◆	Israel, Australia ◆◆◆ Eastern Europe ◆◆
LEADERSHIP						
◆◆◆◆	◆◆◆	◆◆◆	Japan ◆◆◆◆	◆	◆◆◆◆	Israel ◆◆◆ Australia ◆◆
VISUAL & AUDITORY PROCESSES						
◆◆◆◆	◆◆◆	◆◆◆◆	Japan ◆◆◆	◆◆◆	◆◆◆◆	Netherlands, Israel ◆◆◆ Australia ◆◆
STRESS & COGNITIVE PROCESSES						
◆◆◆◆	◆◆	◆◆	Japan ◆◆	◆◆		Israel ◆◆◆◆
SOLDIER INTERFACE						
◆◆◆	◆◆◆	◆◆◆◆	Japan ◆◆◆	◆◆◆		Israel, Australia ◆◆◆

Note: See page E-6 for legend.

a Training

Training research concerns how individual soldiers acquire, process, store, and use information. Traditional issues include speed of learning, rate of forgetting, and the transfer of skills from one set of conditions (e.g., a simulator) to another set (e.g., performance on the actual equipment). Training research is also expanding to development of mental models that underlie complex task performance. Results from this research are used to develop effective technologies for training soldiers.

Wide-ranging programs of basic research on skill acquisition, retention, and transfer are supported by many major universities and research institutions in Northern Europe (particularly in the U.K. and Germany) and in Canada. These countries routinely collaborate with U.S. scientists on issues relating to learning, memory, and cognition. Israel and Japan also maintain significant research infrastructures for most topics in this area, though not as broadly based as the former mentioned countries. The FSU had significant basic research programs in learning and memory, but their capabilities are in decline. Asia and Pacific Rim countries have relatively small programs, but they are perceived as growing in capabilities.

b Personnel

The goal of personnel research is to provide a scientific and technical basis for methods related to recruiting, selecting, assigning, and retaining the best personnel possible. For selection and assignment methods, the fundamental issues relate to the theory and practice of assessing job aptitudes and abilities. Recruitment and retention methods are founded on theories relating to attitude formation and stability. Other relevant issues in personnel research include personal opinions and behaviors toward diversity and other societal issues. Results from research in this area often have direct implications for military personnel acquisition and retention policies.

The United States is the clear leader in personnel research, but English-speaking countries (in particular, the U.K., Canada, and Australia) have significant capabilities. Israel also has a few academic programs in personnel research. Other countries lesser capabilities are the Philippines and Singapore. Also, some academic programs in personnel research are implemented in Israel. It is interesting to note that some Central European countries (Hungary and Slovakia) and Turkey have small but growing capabilities for conducting personnel research.

c Leadership

Leadership research is concerned with identifying characteristics of effective military leaders with direct implications for designing programs for (1) developing leadership competencies in junior commissioned and noncommissioned officers, and (2) broadening and strengthening these competencies in senior military leaders. Such competencies include the ability to manage others, coordinate activities, inspire groups, train individuals and teams, and make decisions. This research also assumes that leadership is conditioned and constrained by important social context factors, such as the communications infrastructure. The goal of leadership research is to develop and promote leadership skills that enhance the effectiveness of Army units.

Leadership is a traditional area of study within social psychology and, as such, is a staple teaching and research topic in most academic psychology and sociology programs in developed countries. However, research in leadership has not been as active as in previous decades. This is partly because some of the traditional issues in leadership (e.g., decisionmaking) have been subsumed by other topics (e.g., training). Furthermore, in leadership, more than in any other

research area, cultural differences may limit collaborative efforts to countries that share our basic concepts. Specifically, the highly individualistic and aggressive leadership style admired in the United States and other English-speaking countries may not be as relevant to other countries that do not share the same cultural background. An exception to this generalization, however, is the activity in leadership research in Japan. For example, Jyuji Misumi's Performance–Maintenance theory of leadership has had a significant impact on research in the United States and other countries.

d *Visual and Auditory Processes*

The goal of research in this area is to understand the visual system, the primary stimulus input channel for human information processing. Specific issues of interest to the Army include divided attention (particularly as it influences the use of HMDs), night operations, and tele-operations. Research on visual processes intersects with training research on the issue of instruction on C² tasks in the context of VR and DIS technologies.

Visual processing and perception are central topics in experimental psychology, as well as in clinical research in ophthalmology and optometry. Many universities in most developed countries conduct some form of research in these areas. A high level of active research is maintained in Northern Europe and is particularly strong in Germany, reflecting its long history of research in psychophysics. Japan has an interest in the psychophysics of vision, particularly as it applies to the engineering of visual displays. A substantial vision research infrastructure is also maintained in the U.K. and in the Netherlands. Active research is also ongoing in Russia and the rest of the FSU. Research on the physiology of vision is ongoing in Australia.

The goal of auditory process research is to develop a better understanding of audition from both the biological and the information processing points of view. The challenge is to protect a soldier's hearing on the noisy battlefield while enhancing the soldier's capability to detect important sources of auditory information. An important topic is how auditory signal processing interacts with other sensory modalities, the most important being vision.

Auditory processes are studied by a variety of disciplines, including the clinical field of otology, physics, psychology, and (recently) computer science. Germany continues its long history of research in psychophysical research on auditory processing. Research is also strong in the rest of Northern Europe, Japan, and Canada. Research on the physiology of audition is underway in Australia.

e *Stress and Cognitive Processes*

An important and unique consideration for human performance research in the Army is that soldiers must be able to perform combat tasks under stressful conditions brought on by high rates of physical or mental effort, physical exhaustion, or emotional responses to threat. Goals for research in this area are to identify and describe human responses to such stressful conditions and to develop interventions for ameliorating its negative effects.

Israel has a comparatively long history of authoritative research on combat stress, as conducted by the Israeli Institute for Military Studies and at other universities. Considerable work is performed on combat stress within the military research establishments of other countries as well, such as research on post-traumatic stress syndrome being performed by the U.K.'s Ministry of Defence. Some research on work-related stress is being performed in Northern European coun-

tries. For example, the National Institute for Working Life in Sweden is primarily focused on civilian jobs, but selected areas of expertise (e.g., effects of environmental stresses) are also applicable to military jobs.

f *Soldier Interface*

Research in soldier interfaces concerns the intersection of human and machine, particularly in the developing context of the digital battlefield. The advanced sensors and improved communications afforded by digitization of the Army dramatically increase the amount of information impinging on soldiers. The goal of research in this area is to design interfaces and procedures that allow soldiers to benefit from the advantages of these new technologies and to avoid the potentially negative effects of information overload.

High-technology firms in many developed countries are developing computer technologies that will provide the infrastructure for the digital battlefield. In particular, industries in the U.K. and Israel are active in developing portable, soldier-friendly technologies to aid tactical decision-making. With respect to the more academic issues related to the soldier-machine interface, scientists in Germany are conducting multidisciplinary research incorporating cognitive science, ergonomics, systems engineering, and software/information engineering. In addition, the U.K. is particularly active in task analyses used to support development of appropriate HCIs.

g *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in behavioral, cognitive, and neural sciences:

- United Kingdom—MRC Interdisciplinary Research Centre for Cognitive Neuroscience [<http://www.cogneuro.ox.ac.uk>]
- Israel—Institute of Information Processing and Decision Making, Program in Cognitive Psychology and Human Factors, University of Haifa [<http://psy.haifa.ac.il/~iipdm/>]
- Canada—Auditory Research Laboratory, McGill University [<http://www.psych.mcgill.ca/labs/auditory/laboratory.html>]
- Federation of European Psychophysiological Societies [<http://www.psychol.uni-giessen.de/abteil/klinisch/fmri.htm>]
- European Computer Vision Network (ECV Net).

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13. ABSTRACT (Maximum 180 words) Requirements to cooperate internationally in defense matters are highlighted in the globalization of technology and in ongoing forecasts that many future military operations will be conducted with coalitions of cooperating forces. These conditions mandate that the Services and other DoD agencies use the best available technologies for system procurement and upgrade. They also point out multiple benefits of procuring best technologies across the world, especially when this can be accomplished with coalition partners. This document provides a consolidated statement of selected Army acquisition principals designed to accommodate these future conditions. It also presents a rank-ordered selection of screened and validated opportunities available from foreign entities. These opportunities have been nominated from both foreign and U.S. sources, and have had their suitability validated by technical experts qualified in the areas nominated. Technologies are representative, but not exhaustive. Others are possible. The document does provide program officers and other officials with sufficient materials to consider which areas are suitable for cooperation, and contact points for officials knowledgeable in each technology identified.				
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