# Defense Technology Plan



DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

# DEFENSE

# TECHNOLOGY

# PLAN



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Department of Defense

Director, Defense Research and Engineering

## ACKNOWLEDGEMENTS

The publication of the Defense Technology Plan culminates six months of intensive effort to report on the latest Department of Defense Science and Technology efforts and to chart a course for the future. I want to thank all the members of the Science and Technology community who contributed to the creation of this document. The richness of the Defense Technology Plan is rooted in the experience and diversity of this outstanding group of individuals.

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The Science and Technology Strategy has been issued, by the Director of Defense Research and Engineering (DDR&E), to document the vision that guides Science and Technology investment decisions, the capabilities that we hope to achieve, and how these factors affect the structure, content and execution of our Science and Technology program.

This Technology Plan, which has been prepared by DDR&E, Service and Defense Agency teams, is responsive to the Strategy. It is a compilation of individual plans - each covering one of the 19 technology areas comprising everything but basic research - that collectively describe the total Department of Defense Science and Technology effort. The primary purpose of this plan is to document the objectives that we are trying to achieve and the Science and Technology efforts that are being pursued in order to reach these objectives. The Plan also identifies the funding that has been allocated for these objectives and the timeframes in which these technologies will be available to be transitioned to new warfighting capabilities.

The Plan provides a means to communicate our objectives and work with the development community, the warfighters, and others who can help us to structure an efficient and effective program. Its use will ensure that the Department's investment in Science and Technology is properly focused and executed.

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# CONTENTS

TECHNOLOGY AREA PLANS

1. Aerospace Propulsion and Power
2a. Air Vehicles
2b. Space Vehicles
3. Battlespace Environments
4. Biomedical
5. Chemical and Biological Defense
6. Clothing, Textiles and Food
7. Command, Control and Communications (C3)
8. Computing and Software
9. Conventional Weapons
10. Electronics
11a. Electronic Warfare
11b. Directed Energy Weapons
12a. Environmental Quality
12b. Civil Engineering
13. Human Systems Interface
14. Manpower, Personnel, and Training
15. Materials, Processes, and Structures
16. Sensors
17a. Surface/Under Surface Vehicles - Ships and Watercraft -
17b. Ground Vehicles
18. Manufacturing Science & Technology (MS&T)
19. Modeling and Simulation (M&S)

ACRONYMS....................A-1

# 1. AEROSPACE PROPULSION AND POWER

## A. SCOPE

This technology area includes those efforts directed toward propulsion and power systems for aircraft, missiles, and space vehicles. There are four major sub-areas: (1) the Integrated High Performance Turbine Engine Technology (IHPTET) program, focused on gas-turbine propulsion systems for aircraft and cruise missiles; (2) the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) program, focused on propulsion systems for space and missile systems; (3) high-speed propulsion and fuels, focused on ramjet, scramjet, combined-cycle propulsion systems for missiles and space-launch systems, and fuels; and (4) aerospace power, focused on non-propulsive power generation systems for aircraft, missiles, and space vehicles.

Funding for this area is $305 million in FY 1994.

## B. VISION

Maintain U.S. world leadership in usable technology for superior, affordable aerospace propulsion and power systems.

## C. RATIONALE FOR INVESTMENT

Aircraft, missiles, and space vehicles constitute a major portion of the force structure—total expenditures related to aircraft alone are about 1/3 of the DoD budget. Increased cost-effectiveness of these systems is essential to support all of the top five JCS future warfighting capabilities. Since propulsion and power systems (including fuel) for these vehicles typically account for 50-90 percent of their overall weight and a significant fraction of their supportability requirements, increases in propulsion and power system performance—reductions in weight, volume, and fuel—and decreases in cost and supportability requirements will have a large impact on the affordability and capability of these vehicles.

Significant improvements in performance and cost of propulsion and power systems—e.g., a 100 percent increase in the thrust/weight ratio of fighter engines, a 100 percent increase in thrust/weight ratio and a 20 second increase in specific impulse of rocket engines, a 100 percent increase in effective impulse in a ducted rocket engine, and a 200 percent increase in the specific power of satellite power systems—are attainable through foreseeable technological advances in: aerothermodynamic design, lightweight/high-temperature materials, innovative structural arrangements, improved propellants and fuels, tribology, controls, and direct energy conversion phenomena. These improvements in propulsion and power system characteristics will have a large impact on reducing the cost and increasing the capability of aerospace vehicle systems. Typical examples include: a 100 percent increase in mission radius or a 35 percent reduction in take-off gross weight of a strike aircraft; a 45 percent reduction in space launch costs using existing space launch vehicles; a 100 percent increase in the air/air missile no-escape zone; and a 20 percent reduction in the number of C-141 loads required to support the deployment of combat aircraft.

Aerospace power and propulsion technologies, when developed and demonstrated, have both an excellent historical record of transition and many future transition opportunities. Examples of the latter include: systems currently under development (F-18E/F, F-22, RAH-66); potential upgrades to existing systems (F-15/F-16, AH-64, C-130, Delta, Atlas, Titan IV, AMRAAM, DMSP); and potential new systems (JAST/ASTOVL, SOA, ACA, new space launch system). These technologies are also largely dual-use in nature, and will enhance U.S. economic security by further strengthening the aerospace sector—over a $100 billion/year industry with the largest positive balance of trade.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Integrated High Performance Turbine Engine Technology (IHPTET)

**a.** *Goals and Timeframes.* The IHPTET program was initiated in FY 1988 to achieve the following with reference to the 1987 state-of-the-art for turbofan/turbojet(TF/TJ), turboshaft/turboprop (TS/TP), and expendable (EXP) engines, while maintaining current levels of reliability, durability, and cost:

| | | |
|---|---|---|
| 1991: | TF/TJ: | +30% thrust/weight,+100 F combustor inlet temperature(-20% fuel burned) |
| | TS/TP: | +40% power/weight,-20% specific fuel consumption |
| | EXP: | +35% thrust/airflow,-20% specific fuel consumption, -30% cost |
| 1997: | TF/TJ: | +60% thrust/weight,+200 F combustor inlet temperature (-30% fuel burned) |
| | TS/TP: | +80% power/weight,-30% specific fuel consumption |
| | EXP: | +70% thrust/airflow,-30% specific fuel consumption, -45% cost |
| 2003: | TF/TJ: | +100% thrust/weight,+400 F combustor inlet temperature(-40% fuel burned) |
| | TS/TP: | +120% power/weight,-40% specific fuel consumption |
| | EXP: | +100% thrust/airflow,-40% specific fuel consumption, -60% cost |

The current status of the program is that 90 percent of the 1991 goals have been achieved, and achievement of the 1997 goals is anticipated in 1997.

**b.** *Potential Payoffs and Transition Opportunities.* Given that aircraft-related expenditures are 1/3 of the DoD budget, the potential payoffs are large; illustrative examples include a 115 percent increase in radius for an upgraded F-18; a 35 percent reduction in gross weight for a new strike aircraft; and an F-18 size STOVL aircraft with greater range/payload capability. IHPTET technology is currently being transitioned to the F414 engine for the F-18E/F and the F119 engine for the F-22; future opportunities include engine upgrades for the F-15, F-16, AH-64, and new systems such as JAST/ASTOVL and ACA. IHPTET also provides the basis for continued preeminence in civil aircraft engines, as the technology is largely dual-use in nature—approximately 75 percent of the planned FY 1995 funding is devoted to technology with significant dual-use applications.

**c.** *Major Technical Challenges.* Higher maximum cycle temperatures, higher combustion initiation temperatures, higher component efficiencies, and lead-efficient structures are required. These require improvements in: aerothermodynamic design through 3D viscous codes and swept-blade aerodynamics; cooling; sealing; lubrication; magnetic bearings; controls; stall/surge control; innovative structures such as substituting rings for solid rotors; and effective use of high temperature/lightweight materials (titanium aluminides, titanium composites, ceramic composites).

**d.** *Performing Organizations.* All Military Departments and ARPA participate in IHPTET, and the majority of the technology is generated by the seven U.S. aircraft engine manufacturers and their subcontractors. Approximately 85 percent of DoD IHPTET funds are contracted to industry.

**e.** *Related Federal and Private Sector Efforts.* Both NASA and industry participate in IHPTET. NASA investment is approximately $20 million in FY 1994, and industry discretionary funding is estimated at approximately $100 million in FY 1994. NASA also has two efforts directed specifically at civil engines that use IHPTET outputs as the foundations.

**f.** *Funding*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 127 | 130 | 134 | 138 | 143 | 149 |

(then-year dollars in millions)

## 2. Integrated High Payoff Rocket Propulsion Technology (IHPRPT)

**a.** *Goals and Timeframes.* The IHPRPT program is being initiated in FY 1994 to achieve the following with reference to the current state-of-the-art for boost and orbit transfer propulsion systems (B/T), satellite/divert control propulsion systems (SD), and tactical missile propulsion systems (TM):

| | | |
|---|---|---|
| 2000: | B/T: | +5 sec Isp,+0.02 mass fraction,+30% thrust/weight,-10% cost,-25% fail. rate |
| | SD: | +10% Isp,+15% mass fraction |
| | TM: | +10% mass fraction, +3% delivered energy |
| 2005: | B/T: | +10 sec Isp,+0.03 mass fraction,+60% thrust/weight,-15% cost,-50% fail. rate |
| | SD: | +15% Isp,+25% mass fraction |
| | TM: | +20% mass fraction, +7% delivered energy |
| 2010: | B/T: | +20 sec Isp,+0.04 mass fraction,+100% thrust/weight,-20% cost,-75% fail. rate |
| | SD: | +20% Isp,+35% mass fraction |
| | TM: | +30% mass fraction,+15% delivered energy |

These goals are to be achieved with no compromise in operability and safety characteristics.

**b.** *Potential Payoffs and Transition Opportunities.* Rocket propulsion systems typically account for the vast majority of the weight of the total vehicle, and hence the payoffs are significant. Illustrative examples include a 40 percent increase in payload capability of existing launch vehicles, as well as a 45 percent reduction in launch costs using existing vehicles; an 80 percent reduction in launch costs with a new family of launch vehicles; and a 100 percent increase in payload or a 50 percent decrease in size for tactical missiles. Transition opportunities include upgrades to Sidewinder, ATACMS, AMRAAM, Titan, and Delta; and potential new systems such as ESSM, Javelin, and a single-stage-to-orbit launch system. A significant fraction of IHPRPT output will be directly applicable to civil space operations as well—approximately 80 percent of the planned FY 1995 funding is devoted to technology with significant dual-use applications.

**c.** *Major Technical Challenges.* Higher chamber pressures, higher maximum temperatures, more energetic propellants, compact thrust management, and lightweight structures are required. These require improvements in: heat transfer control; gelled fuels; innovative solid propellant formulations; environmentally safe propellants; combustion characteristics; platelet technology; aerothermodynamic and mechanical design; hydrostatic bearings; higher temperature metal alloys; and organic, metal matrix, and ceramic composite materials.

**d.** *Performing Organizations.* All Military Departments will participate in IHPRPT, and the majority of the technology is generated by the ten rocket engine contractors and their subcontractors. Approximately 65 percent of the DoD IHPRPT funds will be contracted to industry.

**e.** *Related Federal and Private Sector Efforts.* Both NASA and industry will participate in IHPRPT. Industry discretionary funding of IHPRPT efforts remains to be determined, but is expected to be significant.

**f.** *Funding*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 55 | 55 | 57 | 57 | 57 | 57 |

(then-year dollars in millions)

## 3. High Speed Propulsion and Fuels

**a.** *Goals and Timeframes.* The major goals for high speed propulsion are:

| | |
|---|---|
| 1996 | +100% effective impulse for air/air missiles via a variable-flow ducted rocket (VFDR) |
| 1998 | Flight demonstration of hydrogen-fueled scramjet to Mach>12 |
| 1999 | Mach 0-6 operation of combined cycle engine with hydrocarbon fuels |
| 2005 | Flight demonstration of Mach 8 hydrocarbon-fueled scramjet; |

The major goals for fuels are:

| | |
|---|---|
| 1998 | +50% fuel cooling capacity with JP-8+100 |
| 2005 | 5X increase in fuel cooling capacity with JP-900 |
| 2005 | 5-10X increase in fuel cooling capacity with endothermic fuels |

**b.** *Potential Payoffs and Transition Opportunities.* In high-speed propulsion, the VFDR will double the no-escape zone in air/air combat, and is initially targeted for AMRAAM P3I; the demonstration of a scramjet to M>12 may lay the foundation for single-stage-to-orbit space launch; and the demonstration of combined cycle and scramjet propulsion systems will enable defense against time urgent targets at long ranges, as in air defense and boost-phase intercept of ballistic missiles. In the fuels area, JP-8+100 will eliminate the need to carry excess fuel for heat-sink purposes on some aircraft, and is immediately transitionable when demonstrated; higher heat capacity fuels enable high-speed vehicle operation. The hydrogen-fueled scramjet is also directly applicable to civil space launch—approximately 50 percent of the planned FY 1995 funding in this sub-area is devoted to technology with significant dual-use potential.

**c.** *Major Technical Challenges.* In high-speed propulsion, the major requirements are: understanding and accommodating mode change dynamics (transition from turbine engine to ramjet, or transition from ramjet to scramjet); efficient combustion in reasonable lengths through improved injection and mixing; efficient inlet and exhaust nozzle operation, including expanding the operating range of fixed-geometry scramjet systems; thermal management through fuel-cooled structures and materials protection; and lightweight and/or high temperature materials, including composites. In fuels, the major requirements are: overcoming the base-stock limitation of hydrocarbon fuels by the development of suitable additives that increase the thermal capability of fuels; test methods to adequately assess additives; and high-temperature, low-weight heat exchangers for endothermic fuels.

**d.** *Performing Organizations.* All Military Departments participate in this area, with the Air Force being the principal investor, and a significant amount of the technology is generated by industry. Approximately 80 percent of the DoD funds in this area are contracted to industry.

**e.** *Related Federal and Private Sector Efforts.* NASA has research efforts in both fuels and combined cycle engines that are closely coordinated with DoD. NASA and DoD participate jointly in the Hypersonic Technology Program aimed at scramjet operation at M>12.

**f.** *Funding*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 73 | 71 | 72 | 70 | 70 | 71 |

(then-year dollars in millions)

## 4. Aerospace Power

**a.** *Goals and Timeframes.* For aircraft power, the goals of the More Electric Aircraft (MEA) initiative are:

| | |
|---|---|
| 1998 | Eliminate need for central hydraulic system, through electric distribution and actuation; 2.5X increase in reliability; -50% in engine bleed air requirements |
| 2005 | Eliminate need for engine gearbox through integral starter generator; 4X increase in reliability; eliminate engine bleed air |

In space power, the major goals are:

| | |
|---|---|
| 1998 | +200% in specific power of satellite power systems |
| 2000 | -50% in cost of satellite power systems |

**b.** *Potential Payoffs and Transition Opportunities.* Payoffs for MEA include a 20 percent reduction in C-141 loads required to support the deployment of combat aircraft, due to reduction in required ground support equipment; a 15 percent reduction in maintenance manpower; and a 15 percent increase in sortie generation rate. Transition opportunities include selective retrofit to existing aircraft and to potential new systems such as JAST/ASTOVL. MEA technology is also largely applicable to civil aircraft. For space power, payoffs include a 50 percent increase in satellite payload capability or a reduction in deployment cost of $5-$25 million per satellite. Transition opportunities include DMSP Block 6, NAVSTAR GPS 2F, and others. DoD space power technology efforts are also directly applicable to civil systems. Approximately 75 percent of the planned FY 1995 funding in this sub-area is devoted to technology with significant dual-use applications.

**c.** *Major Technical Challenges.* In the MEA initiative, the major requirements are: an integral starter/generator imbedded in a turbine engine (effort shared between MEA and IHPTET); a highly reliable, fault tolerant electrical distribution system; a single electric auxiliary power system that eliminates the need for external power; and electrically driven flight control actuation systems. In space power, the major requirements are: practical concentrator solar cell arrays, through the use of refractive optics and/or optical reflector concentrators; lightweight, long life batteries through the use of sodium sulfur or lithium batteries; high efficiency thin film solar cells; and, in the longer term, thermionic systems for nuclear power conversion.

**d.** *Performing Organizations.* All Military Departments and BMDO participate in this area, and a significant amount of technology is generated by industry. Approximately 65 percent of the DoD funds in this area are contracted to industry.

**e.** *Related Federal and Private Sector Efforts.* NASA participates in the MEA initiative, and also conducts research efforts in space power that are closely coordinated with those of DoD. Industry discretionary investment in this area is estimated at approximately $30 million in FY94.

**f.** *Funding*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 50 | 46 | 37 | 38 | 38 | 38 |

(then-year dollars in millions)

## 5. Roadmap of Technology Objectives

See Table 1-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

This technology area has significant interfaces four other technology areas: (1) Materials, Processes, and Structures, which provides advances in generic materials; (2) Aerospace Vehicles, concerning various technology integration aspects (e.g., thrust vector control, integrated flight/propulsion control) with vehicles; (3) Conventional Weapons, concerning technology integration aspects associated with weapons; and (4) Election Devices, which provides enabling device technology for the control of both propulsion and power systems. Aerospace Propulsion and Power technology also relies upon generic advances made in the areas of Computers and Software.

**Table 1-1. Roadmap of Technology Objectives for Aerospace Propulsion and Power Goals**

| Sub-Area | By 1995 | By 2000 | By 2005 | Transition Opportunities |
|---|---|---|---|---|
| IHPTET - Turbofan/ jet engines | +30% thrust/weight<br>+100$^{O}$F combustor inlet temperature<br>-20% fuel burned (typical) | +60% thrust/weight<br>+200$^{O}$F combustor inlet temperature<br>-30% fuel burned (typical) | +100% thrust/weight<br>+400$^{O}$F combustor inlet temperature<br>-40% fuel burned (typical) | F-18E/F<br>F-22<br>RAH-66<br>AH-64<br>JAST<br>ASTOVL |
| IHPTET - Turboshaft/ prop engines | -20% SFC<br>+40% power/weight | -30% SFC<br>+80% power/weight | -40% SFC<br>+120% power/weight | ACA<br>F-15 upgrade<br>F-16 upgrade<br>C-130 upgrade |
| IHPTET - Expendable engines | -20% SFC<br>+35% thrust/airflow<br>-30% cost | -30% SFC<br>+70% thrust/airflow<br>-45% cost | -40% SFC<br>+100% thrust/airflow<br>-60% cost | Tomahawk<br>Supersonic Standoff Weapon |
| IHPRPT - Boost/Orbit Transfer | | -25% failure rate<br>-10% cost<br>+30% thrust/weight<br>+ 5 sec Isp<br>+0.02 mass fraction | -50% failure rate<br>-15% cost<br>+60% thrust/weight<br>+10 sec Isp<br>+0.03 mass fraction | Delta<br>Titan<br>New Launch System<br>Sidewinder<br>ATACMS<br>ESSM |
| IHPRPT - Satellite/ Divert Control | | +10% Isp<br>+15% mass fraction | +15% Isp<br>+25% mass fraction | Javelin<br>TACAWS<br>AMRAAM |
| IHPRPT - Tactical | | +10% mass fraction<br>+3% delivered energy | +20% mass fraction<br>+7% delivered energy | |
| High-Speed Propulsion and Fuels<br>- High-Speed Propulsion | | +100% effective impulse for air/air missiles<br>Flight demo of hydrogen fueled scramjet to M>12<br>Mach 0-6 operation of combined cycle engine with hydrocarbon fuels | Flight demonstration of Mach-8 hydro-carbon fueled scramjet | AMRAAM<br>Air Defense/ Missile Defense Weapons<br>Stand-off weapons |
| - Fuels | | +50% fuel cooling capacity with JP-8+100 | 5X increase in fuel cooling capacity with JP-900<br>5-10X increase in fuel cooling capacity with endothermic fuels | All aircraft<br>New high-speed vehicles |
| Aerospace Power<br>-Aircraft Power | | Eliminate hydraulic system<br>2.5X increase in reliability<br>-50% in engine bleed air | Eliminate engine gearbox<br>4X increase in reliability<br>Eliminate engine bleed air | F-15<br>F-16<br>F-18E/F<br>RAH-66<br>F-22<br>JAST |
| -Space Power | | +200% in specific power | -50% cost of satellite power systems | DMSP Blck 6<br>NAVSTAR GPS 2F |

# 2a. AIR VEHICLES

## A. SCOPE

Air vehicles, which provides affordable, global delivery of people, supplies, weapons and sensors, is divided into fixed wing vehicles, rotary wing vehicles, unmanned air vehicles and system integration technology. Technology efforts are aeromechanics, flight controls, subsystem, air vehicle structures. Funding for this area is $169M in FY94.

## B. VISION

Maintain US world leadership in superior, affordable air vehicle systems by aggressively pursing the design, development and demonstration of timely, cost-effective air vehicle product and process technologies.

## C. RATIONALE

Air vehicles form the backbone for both our national defense and power projection abroad—supporting four of five (not "Control Use of Space") of Joint Chiefs' of Staff (JCS) top future warfighting capabilities (Section II). Air vehicles are critical to air superiority, strike, military airlift, early warning, reconnaissance, command and control, ground attack, and sea control. Since one-third of DoD's annual budget ($85B/yr) supports aircraft expenditures, improvements in air vehicle cost and capability offer significant potential for reducing defense expenditures.

Air vehicle technology advances in lift/control augmentation, fly-by-light controls, weapons/avionics/propulsion integration, and helicopter active control offer the opportunity by 2010 for major improvements in warfighting capability, including: a 100% increase in range/payload for fighter/attack aircraft; a 50% reduction in system acquisition cost for airlift/patrol/bomber aircraft; a 400% increase in global mission range, and a 50% reduction in global reaction time for high speed aircraft; a 50% increase in survivability for attack/recon/utility helicopters; and a 35% increase in payload/gross weight ratio for cargo helicopters.

Technologies have transition potential to a wide variety of military aircraft systems, i.e., F-15/F-16/F-18/AH-64 upgrades; RAH-66/V-22/F-22 growth; F-18/F-22 derivatives; and new strike fighter developments. Air vehicle technologies have strong dual-use application to the civil sector, thus strengthening U.S. competitiveness in this $95B/yr industry and significantly enhance our economic security. Dual-use technologies being addressed are aerodynamics, power-by-wire flight controls, electrically-actuated brakes, extended-life tires, transparencies, and aging aircraft life extension.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Fixed Wing

**a.** *Goals and Timeframes.* Fixed wing subsystem level goals have been established to improve combat effectiveness of DoD Fixed-Wing aircraft and assure U.S.

preeminence in the aircraft industry for five families of aircraft (fighter/attack, airlift/patrol, special operations/assault, bombers, and high speed). The goals are derived from component level improvements, including their integration in aerodynamics, airframe structures, flight control, and subsystems. Percentage improvements for fighter/attack from the current F-22, F/A-18 E/F technology baselines are:

| Fighter/Attack | YEAR | | |
|---|---|---|---|
| | 2000 | 2005 | 2010 |
| Lift/Drag Increase | 10% | 20% | 30% |
| Signature Reduction | 30% | 40% | 50% |
| Development Cost | 20% | 30% | 40% |

**b.** *Potential Payoffs and Transition Opportunities.* Attainment of the above subsystem level goals will yield the following fighter/attack system level payoffs (percentage payoffs are compared to current F-15 capability):

| Fighter/Attack | YEAR | | |
|---|---|---|---|
| | 2000 | 2005 | 2010 |
| Missio/Range Payload Increase | 20% | 25% | 33% |
| Life Cycle | 8% | 18% | 25% |

The other four aircraft families and more detail are discussed in the expanded DoD Technology Area Plan for Air Vehicles.

**c.** *Major Technical Challenges.* Major technical challenges are in non-linear dynamics/aerodynamics, hypersonic aerothermodynamics/aeroelasticity unsteady separated flows, high temperature fatigue/fracture, smart skins, and aging systems.

**d.** *Performing Organizations.* AF/Navy Labs 20%, Industry 79%, Academia 1%.

**e.** *Related Federal and Private Sector Efforts.* Efforts include cooperative programs with a) Canada in nonlinear aerodynamics and air cargo handling, b) UK MOD on STOVL/CTOL and c) JAST investments which are continually coordinated with ongoing Air Force and Navy Programs to avoid duplication of effort. NASA participates in cooperative programs plus conducts research in commuter, subsonic transport and high speed/hypersonic vehicles—i.e., advanced subsonic technology (AST), high speed research (HSR) programs at approximately $300M per year—which have application to military aircraft.

**f.** *Funding.*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| **Funding ($M):** | 70 | 94 | 88 | 87 | 74 | 96 |

- Excludes JAST funds

## 2. Rotary-Wing

**a.** *Goals and Timeframes.* Aggressive goals have been established to both increase the combat effectiveness of DoD rotorcraft and maintain the nation's preeminence in the rotorcraft industry. The four technology efforts (Aeromechanics, Flight Control, Structures and Subsystems) are clearly focused on overcoming the barriers with the highest potential for improving overall system affordability and performance.

| | YEAR | |
|---|---|---|
| | 2003 | 2010 |
| Reduction in vibration, interior noise | 50% | 75% |
| Improved handling qualities | 20%* | 35%* |
| Reduction in manufacturing costs | 30% | 50% |
| Reduction in vulnerability | 40% | 50% |

**b.** *Potential Payoffs and Transition Opportunities.* Operational capability improvements to both military and civil fleets will tremendously impact both the overall "cost of ownership" and acceptance of rotorcraft by passengers and community. Reducing acquisition/operating costs, diminishing vibration and noise levels, and improving the night adverse-weather operation, all highlight the vast dual-use potential of rotary-wing technology advancements. Specific payoffs are:

| | YEAR | |
|---|---|---|
| | 2003 | 2010 |
| Reduce Life Cycle Cost | 18-23% | 29-36% |
| Improve operational availability | 5% | 15-20% |
| Increase in mission range | 53-100% | 94-172% |

**c.** *Major Technical Challenges.* The major technology challenges are the accurate prediction and control of stall and compressibility characteristics which will lead to overall rotorcraft performance improvement; determination of optimal rotorcraft response types, necessary for improving handling qualities; non-intrusive monitoring components and techniques, sensors, algorithms and methods to improve design and manufacturing processes and to permit real-time monitoring of flight loads and damage; and actuators constructed using smart materials for primary control and vibration control of rotorcraft rotor blades.

**d.** *Performing Organizations.* DoD Laboratories: 45%; Contractors: 54%; Academia: 1%.

**e.** *Related Federal and Private Sector Efforts.* Independent R&D (IR&D) efforts are conducted by the nation's four helicopter manufacturers. NASA has related rotary wing technology development.

**f.** *Funding.*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| **Funding ($M):** | 16 | 22 | 26 | 20 | 21 | 30 |

### 3. Unmanned Air Vehicle (UAV)

**a.** *Goals and Timeframes.* The High Altitude Endurance (HAE) UAV S&T program is to demonstrate an unmanned aerial vehicle system that is capable of affordable, continuous, all weather, wide-area surveillance in support of military operations. The design to cost goal is $10M (FY94 dollars) unit flyaway cost with sensor for the 10th unit.

**b.** *Potential Payoffs and Transition Opportunities.* The HAE UAV system will provide demonstration of technologies for affordable, all weather continuous wide area reconnaissance support to warfighting combatant forces. The concept will support pre-deployment, regional crisis/limited deployment, and forward deployed wartime scenarios. The system will be compatible with existing exploitation assets and will permit dissemination to other facilities for more intensive exploitation.

**c.** *Major Technical Challenges.* The processor, a major cost driver, will be the biggest technical challenge. Wide area surveillance performance can only be achieved with a high data rate communications link.

**d.** *Performing Organizations.* DoD laboratories: 5%; contractors: 95%.

**e.** *Related Federal and Private Sector Efforts.* NASA is performing research on high altitude, long endurance vehicles, and the Lawrence Livermore National Laboratory is considering use of the CONDOR vehicle for high altitude environmental research.

**f.** *Funding.*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| **Funding ($M):** | 30 | 75 | 140 | 150 | 150 | 150 |

### 4. Systems Integration Technologies

Systems Integration technologies is the integration of the air vehicle technologies with other DoD Technology Areas, e.g., sensors, propulsion, wepaons, and human systems, to provide improved or new operational capability.

**a.** *Goals and Timeframes.* The technology goals are those required to design, develop, test, and demonstrate technologies for Fixed Wing, Rotary Wing, and UAVs.

| | | YEAR | |
|---|---|---|---|
| **Goals** | **2000** | **2005** | **2010** |
| Design Time Reduction Factor | 2 | 4 | 10 |
| Test Time/Cost Reduction Factor | 2 | 3 | 10 |

**b.** *Potential Payoffs and Transition Opportunities.* The key to operational capability for Air Vehicles in the integration technologies. The payoffs of the integration technologies are a result of the synergistic benefits of the individual technologies and can be applied to a) upgrades and extended capability for existing systems: i.e., A-6, A-7, AV-8, AH-64, B-1, B-2, C-130, C-131, C-141, F-15, F-16, F-18 and F-117, and b) Developmental/Future air vehicles: i.e., C-17, F-22, RAH-66, V-22, and new strike fighter. The payoffs for Fighter/Attack compared to F-22 baseline for 2000, 2005, and 2010 are presented below:

| Fighter/Attack | | YEAR | |
|---|---|---|---|
| | 2000 | 2005 | 2010 |
| Increase mission range | 25% | 30% | 50% |
| Improve dumb bomb delivery accuracy | 20% | 30% | 50% |

**c.** *Major Technical Challenges.* The major technical challenges require indepth understanding of multidisciplmary technologies, the development of a) analysis/design tools, b) validated models of integration complexities, c) criteria for general application, and d) integrated testing techniques.

**d.** *Performing Organizatio.is.* DoD Laboratories: 10%; Contractors: 89%; Academia: 1%.

**e.** *Related Federal and Privaie Sector Efforts.* NASA has significant investment in specific integration areas of modeling/simulation, design codes, subscale/fullscale testing and propulsion/flight control demonstration.

**f.** *Funding.*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Funding ($M): | 53 | 69 | 38 | 33 | 37 | 44 |

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

Air Vehicle technologies interface with all DoD Technology Areas involved in the design, development, test and operation of air vehicles in DoD, i.e., aerospace propulsion and power; command, control, communications; computers; conventional munitions, electron devices; electronic warfare; environmental quality; human system interfaces; materials and structures; sensors; software; manufacturing S&T; modeling and simulation technology.

# 2b. SPACE VEHICLES

## A. SCOPE

The technologies assembled under the Space Technology Area are those oriented toward the spacecraft bus, as opposed to payload; technologies unique to space and the military; and their implementation thru flight experiments. The Space Technology Area encompasses eight sub-areas:

(1) propulsion focused on thrust producing engines and devices for space launch, orbit transfer, and maneuver.

(2) power focused on the generation and distribution of electrical power on-board spacecraft.

(3) thermal management focused on cryocooler and heat transfer/dissipation technologies for all satellite applications.

(4) structures focused on adapting advanced materials and structures produced in basic research for space applications.

(5) survivability focused on two sub-areas, "environments", both natural and hostile; and "techniques", including active and passive approaches to survivability.

(6) guidance, navigation and control focused on advanced science and technologies for the launch from earth, earth orbit and free space. GN&C encompasses both missile guidance to the unique gravity free/gravity controlled space environment. GN&C also involves the precise timing and time transfer technologies enabling the Global Positioning System (GPS), and advancing the technologies in GPS applications.

(7) technology integration focused on adapting products of other technology areas to space systems.

(8) flight experiments which is the culmination of space related S&T and focuses on space qualification and transfer of the technology to the military and civilian space communities. The flight experiments sub-area also caters to the science community and enables the scientific examination of the sun, the space environment, the earth's surface from space, as well as the earth's weather and atmosphere.

For this S&T Master Plan, space propulsion and space power are covered under Aerospace Propulsion and Power section.

## B. VISION

The fundamental goal of space related S&T is to make future DoD space systems more cost effective while retaining U.S. technological superiority.

## C. RATIONALE FOR INVESTMENT

If the fundamental goal of space related S&T is to make future DoD space systems more cost effective while retaining U.S. technological superiority, then there must be three thrusts. The first is to reduce the direct costs of space systems. Currently the total cost associated with a space system are 30% for the actual satellite, 20% for launch, 25% for ground control, and 25% for user equipment. Great savings can be achieved in the satellite and launcher through weight reduction and increased component life. Weight reduction in the satellite and booster reduces the size of the booster needed, the amount of fuel consumed, and the over all complexity of the effort. Advanced composite materials, smart structures, high temperature superconductivity, integrated structural and electrical systems all have great promise for weight reduction. New materials, durable coatings, radiation hard electronics promise increased component life if adapted to space systems. Increased component life also includes reusable components. Reusable, less complex boosters have great promise for cost reduction. Single stage to orbit and recoverable boosters being examples. Not only can the cost of the booster be amortized over more usage but these less complex launchers will be cheaper to built and require less infrastructure. The second thrust is a rapid insertion of new technologies into operational space system. This means the application/adaptation of COTS technology wherever possible and the demonstration and space qualification of new technologies through flight experiments. Selective use of small experimental satellites and technology test beds with operational capabilities can demonstrate that technology and operating concepts are mature enough for insertion directly in planned operational systems. The third thrust must be capabilities which push the edge of technology to ensure that the space systems available to U.S. forces are more advanced than those of any potential foe. In a global environment where high technology, low cost space systems are commercially available, technological surprise must be guarded against. These three thrusts can be described as cheaper, faster, better. The recent success of the BMDO/Navy Clementine satellite demonstrate that these thrust work for space vehicles.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Thermal Management

**a.** *Goals and Timeframes.* The sub-area of thermal management explores cryocooler and heat transfer/dissipation technologies.

| | | |
|---|---|---|
| 1995: | Cryo:<br>Heat: | 60K cryocooler for MWIR applications<br>NaS battery thermal control |
| 2000: | Cryo:<br>Heat: | 35K cryocooler for LWIR applications<br>Next generation, thermal bus demonstration |
| 2005: | Cryo:<br>Heat: | 10K cryocooler for VLWIR applications<br>Composite materials for spacecraft thermal management |

**b.** *Potential Payoffs and Transition Opportunities.* Cryocoolers are an enabling technology for long life IR systems, superconducting devices, and long term storage of cryogen's. Heat management technologies such as capillary pump loops and composite radiators will provide for light weight thermal busses. This sub-area has strong interest to the civil and commercial space industries, since they are the direct beneficiaries from almost any military technological advance with commercial application. Several opportunities for dual use are being pursued. These opportunities range from high efficiency home heating and air conditioning to cooling of commercial communications equipment.

**c.** *Major Technical Challenges.* Demonstration of long life, low vibration cryogenic coolers and the zero gravity performance of two phase fluid systems are the major obstacles which must be overcome.

**d.** *Performing Organizations.* The Phillips Laboratory performs most of the S&T work in this sub-area with BMDO supplementing Air Force funding. The Naval Research Laboratory is doing some structural work in composites with thermal implications.

**e.** *Related Federal and Private Sector Efforts.* NASA is leveraging from the Phillips Laboratory work in the development of cryocoolers for the Earth Observing System.

**f.** *Funding.*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 7 | 12 | 13 | 15 | 16 | 17 |

## 2. Structures

**a.** *Goals and Timeframes.* The sub-area of structures has two thrusts: Control & Damping (C&D) and Advanced Material Applications (AMA)

| | | |
|---|---|---|
| 1995: | C&D: | Conduct in-space demonstration of smart structures to provide 100x vibration reduction capability |
| | AMA: | Complete development of composite joining techniques that reduce structures part count by a factor of three and improve antenna pointing accuracy 40% |
| 2000: | C&D: | Demonstrate replacement for Pyrotechnic Release Devices that lower shock to payloads by at least two orders of magnitude |
| | AMA: | Complete demonstration of all composite spacecraft bus to reduce satellite structure weight 50% |
| 2005: | C&D: | Demonstrate spacecraft vibration suppression hardware that costs less than $1000 per application |
| | AMA: | Reduce launch vehicle structure cost and weight by 40% |

**b.** *Potential Payoffs and Transition Opportunities.* Advances in structures will produce reductions in weight and cost. For example, weight reductions in Milsatcoms will permit transition from Titan class launch vehicles to a Medium Launch Class vehicle saving $100M per launch. Reduced weight will enable higher performance from Defense Meteorological Satellite, Landsat, and the next generation of missile warning satellites. Structures are an enabling technology for Single Stage to Orbit vehicles.

**c.** *Major Technical Challenges.* It will be necessary to reduce the cost of spacecraft composite structures below that of aluminum. The cost of spacecraft vibration suppression hardware must be reduced to less than $1000 per application. Integration of the spacecraft electrical system into the structure offers the opportunity to eliminate weight associated with electrical wiring.

**d.** *Performing Organizations.* All three services have separate agreements with BMDO covering work that each is performing as BMDO's agent. Generally, each service is conducting technology demonstrations for BMDO to support the BMD systems for which it is the developer. The lead DoD organization for this work is Phillips Laboratory with the Naval Research Laboratory performing some Navy system specific work.

e. *Related Federal and Private Sector Efforts.* NASA and the Department of Energy also funds work in advance structures. Coordination with them is provided through the Space Technology Interdependency Group. Industry also funds IR&D work in space structures

f. *Funding.*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| ? | ? | ? | ? | ? | ? |

### 3. Survivability

a. *Goals and Timeframes.* The sub-area survivability focuses on two sub-sub-areas, "environments", both natural and hostile; and "techniques", including active and passive approaches to survivability.

| | | |
|---|---|---|
| 1995: | ENV: | Complete new modules for SNRTACS Code for radiation belts<br>Integrate and evaluate DEBRA/KIDD for space debris<br>Establish predictions for space debris growth |
| | TEC: | Space Object Identification technology<br>Design Handbook for radiation tolerance of satellite components<br>Critical Ionization Velocity Experiment for signature generation<br>Space element passive RF survivability criteria developed |
| 2000: | ENV: | Establish international policy on space debris<br>Complete upgrades on near earth radiation environments |
| | TEC: | Develop guidelines for commercial satellite susceptibilities<br>Complete sensor hardening design guidelines for directed energy<br>Tie the survivability directly to the space control mission |
| 2005: | ENV: | All hostile environments characterized and included in simulation code |
| | TEC: | Simulation of interaction scenarios complete and design trade-offs |

b. *Potential Payoffs and Transition Opportunities.* Potential payoffs and transition opportunities for survivability technologies in the new political environment will be associated with making commercial and military satellites more robust to the threats posed by third world countries such as jamming, masking, spoofing that can cause limited damage but can be a nuisance. Simulation can increase realism at tremendous cost savings.

c. *Major Technical Challenges.* Major challenges in the next few years will be to develop more capable computer simulations that will provide the capability for evaluation of the technologies and improvements at low cost, while considering the very complex interactions that usually are impossible to predict without a real test. Additional technical challenges will be to reduce the jamming potential and increase the robustness of sensor and communications signals and processing hardware.

d. *Performing Organizations.* The Naval Research Laboratory, Phillips Laboratory, and the Harry Diamond Laboratory all perform technology development research for the Navy, Air Force and Army respectively. BMDO funds much of this work.

**e.** *Related Federal and Private Sector Efforts.* The Phillips Laboratory is leveraging the BMDO investments in space technologies and, in particular, the investment in hardening for laser effects and in development of hardened sensors. NASA is leveraging from the Air Force, and Army Work in space debris and is combining the joint work into an international policy proposal for minimizing future space debris. The Army developed intercept end game scenario modeling, the Navy NPB and natural environment assessments and the Air Force space environmental effects on orbital operations are working together to characterize the threats to space systems and evaluate RV discrimination and kill assessments.

**f.** *Funding.*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 22 | 22 | 24 | 23 | 22 | 22 |

## 4. Guidance, Navigation, and Control

**a.** *Goals and Timeframes.* The GN&C sub-area has two thrusts: Navigation and Attitude. Four methods are viable options for GN&C improvements: the Global Positioning System (GPS), Inertial Fiber Optic Gyros and Ring Laser Gyros, Autonomous Navigation Systems (AN), and Star Trackers (ST).

| | | |
|---|---|---|
| 1995: | GPS: | 200 Cu In, 21 Watts, 8 Lbs |
| | Gyro: | 140 Cu In, 10 Watts, 1.1 Lbs |
| | AN: | Testing on Clementine and TAOS spacecraft |
| | STs | 120 Cu In, 7 Watts, 0.8 Lbs |
| 2000: | GPS: | 40 Cu In, 10 Watts, 5 Lbs |
| | RLG: | 120 Cu In, 8 Watts, 1 Lbs |
| | AN: | AutoNav used for 5% of satellites |
| | STs | 100 Cu In, 6 Watts, 0.6 Lbs |
| 2005: | GPS: | 30 Cu In, 10 Watts, 3.5 Lbs |
| | RLG: | 100 Cu In, 8 Watts, 0.9 Lbs |
| | AN: | AutoNav used for 20% of satellites |
| | STs | 80 Cu In, 5 Watts, 0.5 Lbs |

**b.** *Potential Payoffs and Transition Opportunities.* The Government has multi-agency interest in the development of GPS systems, attitude sensors such as star trackers, and attitude control systems related to a spacecraft or missile. GPS navigation systems for reentry vehicles can provide a precision strike mission using conventional munitions. GPS related projects and advanced gyro development have dual use potential as is evident by the widespread commercial use of GPS and the use of RLGs in commercial aviation. Lightweight navigation and attitude sensors are directly applicable to commercial satellites. Transfer of this technology to third world countries is of concern because the technology can be used for ballistic missile development.

**c.** *Major Technical Challenges.* Major technical challenges include obtaining sufficient accuracy from miniaturized navigation and attitude sensors, obtaining payloads and associated flight software with which top test autonomous navigation concepts, and obtaining GPS sensors that can handle the high dynamic motion of a spacecraft or missile.

Other technical challenges include reducing the power and thermal output of new miniaturized devices.

**d.** *Performing Organizations.* The Navy and the Air Force both conduct technology development in GN&C. The Naval Research Laboratory; Naval Command, Control, and Ocean Surveillance Center; Phillips Laboratory; and Wright Laboratory perform the work. ARPA is active as a sponsor of GN&C technology funding development of the GPS Guidance Package for a low cost precision guidance system. ARPA and Phillips Laboratory have a MOU for development of a new generation guidance system for non-nuclear ballistic missiles.

**e.** *Related Federal and Private Sector Efforts.* The Tactical High Anti-jam GPS Guidance package designed by Wright Laboratory is related.

**f.** *Funding.*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 31 | 10 | 12 | 14 | 14 | 12 |

## 5. Technology Integration (Astronics)

**a.** *Goals and Timeframes.* The Astronics sub-area has four thrusts: space electronics (Elec), space sensors (Sens), space communications (Comm), and computer science (CS).

| | | |
|---|---|---|
| 1995: | Elec | Bulk CMOS families of 32-bit processors with high fault tolerance<br>Include Rad-hard computer in MISTI |
| | Sens | Manufacture Low Wave Low Background HgCdTe Detectors<br>Include LWIR hybrids in Brilliant Eyes demonstration |
| | Comm | Design development of 60 GHz antenna development<br>Test EHF technologies |
| | CS | Deliver a Telementry, Tracking, and Commanding (TT&C) generic ground architecture based on a sample subdomain and two sample constellations |
| 2000: | Elec | Demo 200 million instructions per second computer |
| | Sens | Manufacture Low Background Quantum well detector for space |
| | Comm | 60 GHz receiver<br>C3 demo for high data rate technology |
| | CS | TT&C ground station with satellite health and status assistant<br>Distributed processing for AI<br>Standards for ground station components/interfaces |
| 2005: | Elec | Demo 800 million instructions per second computer |
| | Sens | Demo Quantum well detectors in space<br>Manufacture Low Background Quantum well detector with superconducting electronics |
| | Comm | Demo giga byte laser comms and advanced SHF<br>Space qualified 60 GHz receiver |
| | CS | Flight demonstration of onboard health and status automation<br>RTS elimination via satellite relay |

**b.** *Potential Payoffs and Transition Opportunities.* The reduced size, weight, power consumption and increased onboard processing technology will provide lighter, more capable busses which are cheaper to launch and operate. The technologies will transition to the mission payloads and commercial space industries.

**c.** *Major Technical Challenges.* The major technical challenges for the astronics sub-area are a space qualified multiplexer foundry, producing low background long wavelength mercury cadmium telluride, an extremely large space qualified radar antenna; demonstration of radiation hardened 60 GHz RF components, and demonstration of very high data rate heterodyne laser optical communication links.

**d.** *Performing Organizations.* The Navy and the Air Force conduct astronics technology development. Most of the Navy work is performed at the Naval Research Laboratory with some related work be done at Naval Command, Control, and Ocean Surveillance Center. Phillips Laboratory is the lead lab for the Air Force.

**e.** *Related Federal and Private Sector Efforts.*

**f.** *Funding.*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 45 | 60 | 66 | 70 | 73 | 75 |

## 6. Flight Experiments

**a.** *Goals and Timeframes.* Flight Experiments encompasses four separate but highly interconnected efforts: the development of the experiment, placing the experiment in earth orbit, operation of the experiment in orbit, and utilization of the data produced by the experiment. Experiment development is performed by individual projects in the sub-areas of Propulsion, Power, Thermal Management, Structures, Survivability, GN&C, and Astronics. Experiment development is also the result of individual projects in other technology areas such as Environmental Sciences, C3, Electronic Warfare, Materials, Sensors, and even Medical. Data use takes place within the technology area or sub-area which developed the experiment. Placing the experiment in orbit and operation of the experiment varies with the size and financial resources of the experiment. Large, expensive experiments are usually placed in orbit and operated within the originating technology. Small, lower cost experiments are usually flown through the DoD Space Test Program. Efforts in any of these areas may enhance the overall capability to conduct flight experiments, though.

Flight Experiments seeks to improve the opportunities for all experimenters to validate their technologies or conduct science in earth orbit or the upper atmosphere. This is the continuing goal. Specific objectives include: reducing the cost of access to space, annual launch of a dedicated experiments satellite by DoD Space Test Program, a permanent platform for space experiments, increasing the use of supper atmospheric experiments as a low cost alternative to on-orbit experiments where suitable, and to increase the number of experiments conducted each year both in support of technology development and science experimentation.

**b.** *Potential Payoffs and Transition Opportunities.* Flight Experiments validate new technologies at both the component and system level prior to their operational use and conduct scientific research. The validated technology provides enhanced operational capability to the war fighting forces and further expands the capability to conduct Flight Experiments. The knowledge gained in scientific research is applied to the development of new technologies, systems, and capabilities. New scientific knowledge and technological capabilities rapidly disseminate through both government and industry. The increased capability to conduct space based scientific research and validate technology achieves a multiplier effect for space systems.

**c.** *Major Technical Challenges.* The fundamental and single biggest challenge for flight experiments is to reduce the cost of access to space and the upper atmosphere as cost and availability are directly related.

**d.** *Performing Organizations.* DoD space flight experiments originate in all three military services with the Air Force and Navy also contributing the majority each year. In addition, ARPA and BMDO both contribute experiments of their own and sponsor many of the experiments contributed by the military services and other organizations. The DoD Space Test Program provides access to NASA flights, dedicated satellites to carry experiments, integration of experiments onto operational satellites, launch services, on-orbit operations, and data handling for small experiments from all DoD. The DoD Space Test Program by far provides most DoD space experiments their access to space.

**e.** *Related Federal and Private Sector Efforts.* Almost all space flight experiments are executed by the Government although increasing commercialization of flight opportunities is evident. NASA, NOAA, DoE, DoD DoC, DoT and NSF are just a few of the many agencies that either conduct or sponsor flight experiments. Whether sharing an experiment platform or transferring the scientific results of an experiment, leverage between agencies is an ongoing and significant process. Coordination and cooperation between agencies is achieved through several organizations including the Joint Directors of Laboratories (JDL), the Space Technology Interdependency Group (STIG) and many less formal working groups. Both industry and the academic community are also actively involved in these activities, either providing services or conducting experiments.

**f.** *Funding.* As space experiments originate in all the various technology areas and are reported under those sections, a separate report of Flight Experiment funding would generally constitute dual accounting and possibly be confusing as many experiments do not directly book the cost of the "flight".

The DoD Space Test Program is funded to provide access to space for experiments which cannot provide their own launch and on-orbit operations. As funding for the DoD Space Test Program is not otherwise reported, **DoD Space Test Program ONLY** funding is provided here.

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 72 | 62 | 69 | 65 | 67 | 69 |

## 7. Roadmap of Technology Objectives

See Table 2b-1.

## Table 2b-1. Roadmap of Technology Objectives for Aerospace Vehicles—Space Vehicles

| Sub-Area | By 1995 | By 2000 | By 2005 | Transition Opportunity |
|---|---|---|---|---|
| Thermal-Cryo:<br>Heat: | • 60K cryocooler for MWIR applications<br>• Thermal control of NaS batteries | • 35K cryocooler for LWIR applications<br>• Next generation, thermal bus demonstration | • 10K cryocooler for VLWIR applications<br>• Composite materials for spacecraft thermal management | • Ballistic Missile Defense<br>• MilSatCom |
| Structure-C&D:<br>AMA: | • Conduct in-space demonstration of smart structures to provide 100x vibration reduction capability<br>• Complete development of composite joining techniques that reduce structures part count by a factor of three and improve antenna pointing accuracy 40% | • Demonstrate replacement for Pyrotechnic Release Devices that lower shock to payloads by at least two orders of magnitude<br>• Complete demonstration of all composite spacecraft bus to reduce satellite structures weight 50% | • Demonstrate spacecraft vibration suppression hardware that costs less than $1000 per application<br>• Reduce launch vehicle structure cost and weight by 40% | |
| Survival-ENV:<br>TEC: | • Complete new modules for SNRTACS Code for radiation belts<br>• Integrate and evaluate DEBRA/KIDD for space debris<br>• Establish predictions for space debris growth<br>• Space Object<br>• Identification technology<br>• Design Handbook for radiation tolerance of satellite components<br>• Critical Ionization Velocity<br>• Experiment for signature generation<br>• Space element passive RF survivability criteria developed | • Establish international policy on space debris<br>• Complete upgrades on near earth radiation environments<br>• Develop guidelines for commercial satellite susceptibilities<br>• Complete sensor hardening design guidelines for directed energy<br>• Tie the survivability directly to the space control mission | • All hostile environments characterized and included in simulation code<br>• Simulation of interaction scenarios complete and design trade-offs | |
| GN&C-GPS:<br>Gyro:<br>AN:<br>STs | • 200 Cu In, 21 Watts, 8 Lbs<br>• 140 Cu In, 10 Watts, 1.1 Lbs<br>• Testing on Clementine and TAOS spacecraft<br>• 120 Cu In, 7 Watts 0.8 Lbs | • 40 Cu In, 10 Watts, 5 Lbs<br>• 120 Cu In, [illegible] Watts, 1 Lbs<br>• AutoNav used for 5% of satellites<br>• 100 Cu In, 6 Watts, 0.6 Lbs | • 30 Cu In, 10 Watts, 3.5 Lbs<br>• 100 Cu In, 8 Watts, 0.9 Lbs<br>• AutoNav used for 20% of satellites<br>• 80 Cu In, 5 Watts, 0.5 Lbs | |
| Astronics-Elec:<br>Sens:<br>Comm:<br>CS: | • Bulk CMOS families of 32-bit processors with high fault tolerance Include Rad-hard computer in MISTI<br>• Manufacture Low Wave Low Background HgCdTe Detectors Include LWIR hybrids in Brilliant Eyes demonstration<br>• Design development of 60 GHz antenna development Test EHF technologies<br>• Deliver a TT&C generic ground architecture based on a sample subdomain and two sample constellations | • Demo 200 million instructions per second computer<br>• Manufacture Low Background Quantum well detector for space 60 GHz receiver<br>• C3 demo for high data rate technology<br>• TT&C ground station with satellite health and status assistant Distributed processing for AI Standards for ground station components/ interfaces | • Demo 800 million instructions per second computer<br>• Demo Quantum well detectors in space Manufacture Low Background Quantum well detector with superconducting electronics<br>• Demo giga byte laser comms and advanced SHF Space qualified 60 GHz receiver<br>• Flight demo of onboard health and status automation RTS elimination via satellite relay | ALARM<br>MILSATCOM<br>Brilliant Eyes<br>Brilliant Eyes<br>DMSP<br>ALARM<br>BMD C3<br>Advanced EHF<br>Advanced Satcom<br>MILSATCOM<br>ALARM |

# 3. BATTLESPACE ENVIRONMENTS

## A. SCOPE

The Battlespace Environments technology area encompasses the study, characterization, prediction, modeling, and simulation of the terrestrial, ocean, lower atmosphere, and space/upper atmosphere environments to understand their impact on personnel, platforms, sensors, and systems; enable the development of tactics and doctrine to exploit that understanding; and optimize the design of new systems. Funding for this area is $271 million in FY94.

## B. VISION

Maintain U.S. lead in technology to provide commanders timely and effective knowledge of the battlespace and a capability to exploit that knowledge as a force multiplier.

## C. RATIONALE FOR INVESTMENT

Commanders at all levels must know how the environment will impact their operations as well as the operations of their adversary and use this knowledge for military advantage. Sensor and weapon system developers must also understand the environment's effects on system performance to optimize design effectiveness. This investment will provide:

- A 10 time improvement in providing digital topographic data needed by the commander for optimized deployment, mobility, planning, and logistics support.
- High resolution weather and sea state forecasts for incisive decision making and enhanced operational capability in adverse weather with reduced weather related damage and fuel costs.
- Realistic representation of dynamic environment and terrain in simulations to permit effective mission rehearsal and training, and more cost effective materiel acquisition.
- Detection and precise location of nuclear weapons tests to support counterproliferation and treaty verification.
- A 90% improvement in capability to predict magnetic storm induced outages of C3, surveillance, and navigation systems to maintain control of the battlespace.
- Realistic portrayal of the effects of the battlespace environments to reduce operational costs and reduce casualties.

## D. TECHNOLOGY SUBAREAS AND INVESTMENT STRATEGIES

### 1. Terrestrial Environment

**a.** *Goals and Timeframes.* Emphasis is on study, characterization, and modeling of the physical phenomena, processes, interactions, and effects associated with terrain, its surface features, and the overlying atmosphere at scales of interest to ground combat forces.

| | |
|---|---|
| BY 1995 | Field capability to update DMA digital topographic data from imagery and produce image map substitutes<br>Baseline capability for dynamic environment and terrain (DET) simulation<br>Baseline seismic monitoring capability |
| BY 2000 | Unified weather decision aid (WDA) packages using AI technology<br>Automated generation/update of topographic data for mission rehearsal and battlespace visualization<br>Validated seismic signal extraction techniques |
| BY 2005 | Comprehensive WDA support including 3-D sound level capability<br>Battlespace fly-through and automated terrain analysis at Brigade and Battalion<br>DET implementation in computer generated forces<br>Global seismic monitoring capability |

**b.** *Potential Payoffs and Transition Opportunities.* This S&T is needed to provide technology for maps and terrain background displays, realistic mission rehearsal, and training; to develop effective weather decision aids (WDA) for ground forces; to improve design of combat equipment; to optimize operations in cold regions; and for detection and identification of nuclear weapons tests to support the DoD initiative in counterproliferation and nuclear test ban treaty verification.

**c.** *Major Technical Opportunities/Challenges.* The challenges are to: develop WDA (emphasizes weather effects near the surface) for implementation on automated C3 systems; integrate rapid digital terrain database construction methods with data from DMA and field topographic units; advance technology for the representation of dynamic environmental effects in combat simulation and mission planning and rehearsal systems; and detect/precisely locate underground nuclear explosions in realistic geological media.

**d.** *Performing Organizations.* This S&T is performed by the Army's Research Laboratory, Cold Regions Research and Engineering Laboratory, and Topographic Engineering Center; Naval Research Laboratory; Air Force Phillips Laboratory; and universities.

**e.** *Related Federal and Private Sector Efforts.* Other federal and private sector investment in this research is relatively low due to the focus on warfighting needs. WDAs are focused on warfighting enhancements, not weather effects; hence, no directly related investment is identified outside of DoD.

**f.** *Funding*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 49 | 28 | 24 | 26 | 28 | 30 |

(then year dollars in millions)

## 2. Ocean Environment

**a.** *Goals and Timeframes.* Increasing emphasis is on the coastal, shallow, and semi-enclosed sea areas where the ability to predict and simulate the spatial and temporal variability of the environment is a formidable challenge.

| | |
|---|---|
| By 1995 | >4 optical depth mine countermeasures (MCM) Lidar performance upgrade<br>Sediment transport/mine burial models<br>Shallow water acoustic daylight measurements<br>Prototype 3-D subbottom swath mapping system<br>Littoral remote sensing simulator |
| By 2000 | Range dependent weapons frequency acoustic propagation models<br>4-D coastal currents prediction model<br>MCM Tactical Environmental Data System (MTEDS)<br>Regional air-ocean coupled prediction system<br>Acoustic/optical sensor fusion technology |
| By 2005 | Remote in situ autonomous smart coastal sensing system<br>Rapid remote sediment classification<br>Distributed simulation with data fused forecasts of full acoustic spectrum littoral environment |

**b.** *Potential Payoffs and Transition Opportunities.* The payoffs are to: provide commanders with real-time knowledge and effective now/forecasts of the Ocean Environment at tactically relevant scales; demonstrate rapid data inversion and acoustic simulations critical to the delivery of mine hunting systems, as well as models and databases of nearshore/beach response to physical forcing that impacts mine countermeasures; mine, anti-submarine, and amphibious warfare; and special operations.

**c.** *Major Technical Opportunities/Challenges.* The challenges are to develop: surf models for shallow water reconnaissance; models of physical and biological processes which impact acoustic propagation at weapons frequencies; specialized sensing systems for shallow water processes; capabilities for measurement/forecast of coastal optics; remote seafloor mapping capabilities; models of range dependent wave guide propagation; and signal processing to enhance clutter rejection and improve target detection.

**d.** *Performing Organizations.* This S&T is performed by the Navy's Research Laboratory; Surface Warfare Center; Undersea Warfare Center; Command, Control, and Ocean Surveillance Center, and Postgraduate School; the Army Waterways Experiment Station; and universities.

**e.** *Related Federal and Private Sector Efforts.* With the exception of coastal engineering, industry investments are small. Federal S&T is also supported by NOAA, NSF, NASA, DoE, and MMS. Major foreign investments are the European Community's MAST program and Japanese investments in deep submersibles.

**f.** *Funding*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 101 | 97 | 101 | 101 | 100 | 101 |

(then year dollars in millions)

## 3. Lower Atmosphere Environment

**a.** *Goals and Timeframes.* Lower Atmosphere Environment emphasis is on providing tactical scale atmospheric nowcasts and forecasts; real-time tools to assess the environment and its effects on performance; and quantitative measurement, analysis, and prediction with seamless, global, continuous coverage.

| | |
|---|---|
| BY 1995 | Ocean and continental aerosols EM/E-O propagation model<br>Prototype battlefield forecast model<br>Initial coupled global ocean/atmosphere model<br>Capability to model location of hazardous chemical clouds |
| BY 2000 | Advanced aerosol and EM/E-O propagation model<br>Strike warfare atmospheric environment decision aid<br>Tactical targeting E-O simulator<br>Coupled global troposphere/stratosphere model |
| BY 2005 | 3-5 day operational forecast<br>On scene, slowly degrading weather forecasts<br>On scene atmospheric environment decision aids<br>Real-time, on scene satellite and local data assimilation |

**b.** *Potential Payoffs and Transition Opportunities.* Lower Atmosphere Environment S&T ensures that operations occur successfully with reduced casualties and decrease costs in asset utilization and system development. The dual-use potential of this area helps ensure continued U.S. leadership in atmospheric environment technologies particularly with NOAA, USDA, and FAA.

**c.** *Major Technical Opportunities/Challenges.* The challenges are to develop: improved and new on-scene and remote sensors, data acquisition and quality control, battlescale analysis and prediction, and artificial intelligence technology for atmospheric product management; an ability to adequately address turbulence and aerosols in field experiments; and, improved transport and diffusion models for chemical and biological agents, battlefield smokes/obscurants, and dust.

**d.** *Performing Organizations.* The majority of Lower Atmosphere Environments S&T is performed in the individual service laboratories. These laboratories combine in-house science and technology base development with supporting basic research performed both at the service labs and through university grant programs. Industry is not a major performer.

**e.** *Related Federal and Private Sector Efforts.* NSF, NOAA, USDA, and FAA participate in lower atmosphere environment S&T. There is only a small industrial base in this area.

**f.** *Funding*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 44 | 39 | 35 | 38 | 36 | 37 |

(then year dollars in millions)

## 4. Space/Upper Atmosphere Environment

**a.** *Goals and Timeframes.* DoD Space assets ($600B) provide a tremendous force multiplier when they perform reliably. This S&T leverages these assets by maximizing their on-call availability.

| | |
|---|---|
| By 1995 | 50% improvement in accuracy of C3 outage prediction<br>50% decrease in lost space objects and prediction errors of solar flare induced outages<br>50% increase in sensor sensitivity and clutter processing accuracy |
| By 2000 | 75% improvement in accuracy of C3 outage prediction<br>75% decrease in lost space objects and prediction errors of solar flare induced outages<br>75% increase in sensor sensitivity and clutter processing accuracy |
| By 2005 | 95% improvement in accuracy of C3 outage prediction<br>90% decrease in lost space objects and prediction errors of solar flare induced outages<br>100% increase in sensor sensitivity and clutter processing accuracy |

**b.** *Potential Payoffs and Transition Opportunities.* The payoff is a 10 time decrease in surprise loss of C3; a 100% increase in target detection range; a 30% reduction in number of surveillance satellites needed; a 95% decrease in false alarms; and a 7 time decrease in lost space debris. There is dual-use potential in the communications, power, and civil satellite industry.

**c.** *Major Technical Opportunities/Challenges.* The challenges are to: improve characterization of radiation belt dynamics, anticipate solar flares; determine the physical processes that dominate coupling of the global ionosphere and upper atmosphere; consolidate a unified physical instability model to predict C3 outages; and develop new space-hardened sensor technology.

**d.** *Performing Organizations.* The majority of Space/Upper Atmosphere Environment S&T is performed in the individual service laboratories. These laboratories integrate in-house science and technology base development with supporting basic research performed both at the service labs and through university grant programs which receive about 50% of the S&T funds. Industry is not a major performer.

**e.** *Related Federal and Private Sector Efforts.* NASA, NSF, and NOAA participate in Space/Upper Atmosphere Environment S&T. The industrial base in this area is small, even though there is significant leverage on DoD system performance.

**f.** *Funding*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 77 | 71 | 68 | 65 | 66 | 64 |

(then year dollars in millions)

### 5. Roadmap of Technology Goals

See Table 3-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

Battlespace Environments is a cross cutting technology impacting most technology areas. The environment affects system performance; design considerations; command, control and communications; electronic devices; electronic warfare; etc. Battlespace Environments science and technologies are directly applicable to the Environmental Quality and Civil Engineering, C3, Modeling and Simulation, Sensors, and Chemical/Biological Defense technology areas.

**Table 3-1. Roadmap of Technology Objectives for Battlespace Environments Objectives to Support Goals**

| Sub-Area | BY 1995 | BY 2000 | BY 2005 | Transition Opportunities |
|---|---|---|---|---|
| Terrestrial Environment | · Capability to update DMA digital topographic data from imagery<br>· Baseline capability for dynamic environment and terrain (DET) simulation<br>· Baseline seismic monitoring capability<br>· Demonstrate hybrid personal navigator<br>· Demonstrate procedures for MC&G software module integration<br>· Demonstrate correltaions of hyperspectral data signatures to library signatures | · Automated generation and update of topographic data<br>· Objective capability for DET including cold regions (CR)<br>· Validated seismic signal extraction techniques<br>· Proof-of-concept demosntartion of Personal Navigation and Reporting System<br>· Populate MC&G domain with standard software modules<br>· Capability to identify man-made materials using hyperspectral data | · Automated topographic support for Division and Brigade<br>· DET implementation in computer generated forces including CR<br>· Global seismic monitoring capability | DTSS<br>ATCSS<br>AVCATT<br>ENCATT<br>BDS-D<br>SOF-PARS |
| Ocean Environment | · Shallow water acoustic daylight measurement<br>· Prototype 3-D subbottom swath mapping system<br>· Upgrade capability for surf mine detection using lidar<br>· Sediment transport/mine burial models<br>· Littoral remote sensing simulator | · Range-dependent acoustic propagation models<br>· Subbottom swath mapping inversion<br>· MCM Tactical Environmental Data System (MTEDS)<br>· Multilayer pore water/sediment response model<br>· Acoustic/optical sensor fusion technology<br>· Regional air/ocean coupled prediction system<br>· 4-D coastal currents prediction model | · Remote in situ autonomous, smart coastal sensing system<br>· Rapid remote sediment classification<br>· Distributed simulation w/data-fused forecasts of littoral environment | TESS<br>Magic Lantern<br>SQR-19<br>SQR-23<br>AN-UYQ-25B<br>ADS<br>AEAS<br>FDS<br>SQQ-891 |

| | | | | |
|---|---|---|---|---|
| Lower Atmosphere Environment | · Automated 12-hr tactical weather forecasting capability<br>· Ocean and continental aerosols EM/E-O propagation model<br>· Environmental simulation modules<br>· Prototype battlefield forecast model<br>· Initial coupled global ocean/atmosphere model<br>· Capability to model location of hazardous chemical clouds | · Automated 48-hr battlefield weather forecasting capability<br>· Advanced aerosol and EM/E-O propagation model<br>· Strike warfare environmental decision aid<br>· Tactical targeting E-O simulator<br>· Coupled global troposphere/ stratosphere model<br>· Data fusion for global cloud analysis<br>· AI data assimilation and data processing | · Automated, high resolution battle scale, weather forecasting model<br>· 3-5 day operational forecast<br>· On scene environmental decision aids<br>· On scene, slowly degrading weather forecasts<br>· Detailed atmospheric models for intelligence and battle damage assessment<br>· Real-time, on scene satellite and local data assimilation | TESS<br>IMETS<br>CWS<br>TAMPS<br>OPAR<br>OPSR |
| Space/Upper Atmosphere Environment | · Improved space environment specifications for satellite design<br>· Operational magnetospheric specification model<br>· Integrated all-altitude atmospheric optical background simulation code<br>· Quiescent atmospheric structured radiance model | · Space environment model for spacecraft solar cell operations<br>· New space sensors for DMSP<br>· New sensor technology for ionosphere<br>· All-altitude, all wavelength 2-D atmospheric radiance scene image simulator<br>· Atmospheric radiance variability model incorporating satellite data | · Automatic systems to relieve charge build-up on satellites<br>· Environmental anomaly sensors to detect electronic upsets on satellites<br>· Integrated target-in-background 3-D scene visualization simulator<br>· Optimized IR clutter rejection for surveillance, tracking and interceptor systems<br>· Operational ionospheric and neutral density forecast models<br>· Reliable, long term, space debris hazard assessment model<br>· C3 disruption forecast model | DMSP<br>BMDO |

# 4. BIOMEDICAL

## A. SCOPE

Biomedical S&T (BST) programs are focused to yield superior technology in support of the DoD mission to provide health support to U.S. military forces. Unlike non-defense medical S&T investments, BST is concerned with preserving the combatant's optimal mission capabilities and health despite battle and non-battle threats rising from the distinctive nature of military operations. By international treaty and convention, military medical research programs must be conducted for the benefit of mankind. Also, many programmatic activities are regulated by the U.S. Food and Drug Administration.

Defense BST programs are coordinated through the Armed Services Biomedical Research, Evaluation and Management Committee with direction and oversight exercised through Joint Technology Coordinating Groups aligned to the following seven functional areas: 1) Infectious Diseases of Military Importance, 2) Combat Casualty Care, 3) Medical Biological Defense, 4) Medical Chemical Defense, 5) Military Operational Medicine, 6) Military Dentistry, 7) Ionizing Radiation Bioeffects.

Each area, except Combat Casualty Care, emphasizes prevention of injury or disease through the provision of medical materiel (e.g., vaccines, drugs, and applied medical systems) and biomedical information (e.g., health risk and performance criteria). Combat Casualty Care provides capabilities for resuscitation, stabilization, evacuation, and treatment of all casualties.

Appropriated funding for these functional areas is $326 million in FY 1994.

## B. VISION

Provide U.S. Armed Forces with the superior medical technology required to enable the full spectrum of military operations for crisis and conflict resolution, protecting and sustaining service men and women from battle and non-battle threats to health, enabling optimal military performance supported by the world's best combat casualty care.

## C. RATIONALE FOR INVESTMENT

Individual service men and women are the most important, yet most vulnerable, components of military systems and mission capabilities. Life-threatening or incapacitating regional disease epidemics both limit and constrain military deployment alternatives for conflict resolution and peacekeeping operations. The declining force structure—confronted by the potential for large-scale regional conflicts, proliferation of weapons of mass destruction, diverse and highly complex missions, the enduring threats of disease, harsh climates, operational stress and injury—mandates sustained, robust investment in BST programs.

Superior BST technologies contributed substantially to our Gulf War victory; e.g., forward diagnostic labs; protective vaccines, drugs and practices; and fluid intake discipline. This translated into reduced casualties and sustained military operational superiority despite the harsh environment and continuous high-tempo operations.

The Gulf War also emphasized the need for medical countermeasures to biological and chemical weapons, since demonstrably superior countermeasures deter and constrain proliferation and use of such weapons. Finally, our nation's concern about causes and treatment of the Gulf War Syndrome exemplifies DoD's need for robust BST investment.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Infectious Diseases of Military Importance

a. *Goals and Timeframes*

- Prevent infectious disease casualties with vaccines and pretreatment drugs;
- Identify and diagnose endemic diseases and vectors;
- Minimize illness with therapeutic drugs.

b. *Potential Payoffs and Transition Opportunities.* Potential payoffs and transition opportunities include new vaccines and drugs to prevent leishmaniasis, enterotoxic *E. coli* (ETEC) diarrhea, hemorrhagic fever with renal syndrome, and human immunodeficiency virus (HIV) infections; new drugs for treating malaria and dengue; single step field assays for malaria diagnosis; and sound DoD policies for controlling infections.

c. *Major Technical Challenges.* Major technical challenges include vaccines for diseases that have no animal model, mechanisms of parasite resistance to antimalarial drugs and insecticides, risk assessment of new diseases, and simplified methodology for diagnosing diseases.

d. *Performing Organizations.* Program execution is distributed as 50 percent in-house DoD labs, 2 percent other Federal labs, 5 percent academia, and 43 percent commercial with 68 Cooperative Research and Development Agreements (CRDAs) executed and 46 CRDAs under negotiation.

e. *Related Federal and Private Sector Efforts.* See above.

f. *Funding*

| Funding ($000) | FY94 PBR[1] | FY94 Appr[2] | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|---|
| DoD | 49,249 | 94,609 | 50,194 | 44,593 | 45,344 | 46,508 | 47,723 |

1 PBR = President's Budget Request

2 Appr = Appropriation

### 2. Combat Casualty Care

a. *Goals and Timeframes.*

- Enhance diagnostic methods and battlefield treatment, including resolving trauma management problems peculiar to battlefield environments;
- Exploit intelligent systems and virtual reality technologies to extend advanced casualty diagnostics and treatment far-forward;

- Minimize lost duty time from minor injuries and combat stress;
- Decrease the resupply requirements for all forward echelons of care.

**b.** *Potential Payoffs and Transition Opportunities.* Potential payoffs and transition opportunities include blood substitutes, enzymatic conversion of blood products to "universal donor", telesurgical-mentoring and remote, telepresence surgery; these technologies will contribute to preservation of the fighting force by improved duty retention, decreased mortality and reduced long-term morbidity rates. Virtual reality training will greatly enhance medical and surgical readiness.

**c.** *Major Technical Challenges.* Major technical challenges include: oxygen carrying blood substitutes; small volume resuscitation solutions; and non-invasive, diagnostic sensors.

**d.** *Performing Organizations.* Program execution is distributed as 47 percent in-house DoD, 18 percent other Federal laboratories (e.g., VA hospitals), 17 percent academia, and 18 percent commercial with 14 CRDAs.

**e.** *Related Federal and Private Sector Efforts.* See above.

**f.** *Funding*

| Funding ($000) | FY94 PBR[1] | FY94 Appr[2] | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|---|
| DoD | 38,825 | 43,594 | 67,773 | 65,509 | 66,111 | 64,313 | 41,945 |

[1] PBR = President's Budget Request

[2] Appr = Appropriation

## 3. Medical Biological Defense

**a.** *Goals and Timeframes*

- Prevent casualties with medical countermeasures such as vaccines, toxoids, and/or pretreatment drugs;
- Diagnose disease with forward deployable kits and confirmation assays;
- Treat casualties to prevent lethality and to maximize return-to-duty using antitoxins and/or therapeutic drugs.

**b.** *Potential Payoffs and Transition Opportunities.* Potential payoffs and transition opportunities for expanded force protection include Botulinum toxoid, Type F; Q fever CMR-extract vaccine; cell culture-derived smallpox vaccine; and Botulism F(ab)2 antitoxin, heptavalent, equine-derived.

**c.** *Major Technical Challenges.* Major technical challenges include appropriate model systems for investigational purposes, generation of immune responses to small molecules, and expression vectors for recombinant products.

**d.** *Performing Organizations.* Program execution is distributed as 77 percent in-house DoD, 1 percent other Federal laboratories, 9 percent academia, 11 percent commercial, 2 percent overseas. Related Federal and private sector efforts are characterized by little commercial interest, as reflected by a single CRDA for vaccine adjuvants.

**e.** *Related Federal and Private Sector Efforts.* See above.

**f.** *Funding*

| Funding ($000) | FY94 PBR[1] | FY94 Appr[2] | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|---|
| DoD | 47,905 | 46,906 | 45,828 | 40,551 | 41,412 | 43,581 | 45,757 |

[1] PBR = President's Budget Request

[2] Appr = Appropriation

## 4. Medical Chemical Defense

**a.** *Goals and Timeframes*

- Preserve combat effectiveness by timely provision of medical countermeasures to meet chemical agent threats;
- Provide medical management of chemical casualties, enhancing survival, and expediting return-to-duty.

**b.** *Potential Payoffs and Transition Opportunities.* Potential payoffs and transition opportunities include a reactive topical skin protectant/decontaminant, with broad-spectrum effectiveness against chemical agents, specific drugs to prevent vesicant agent effects, methemoglobin-forming drugs to increase resistance to cyanide, and an advanced anticonvulsant.

**c.** *Major Technical Challenges.* Major technical challenges include developing effective pretreatments completely devoid of side effects, developing suitable animal models, extrapolating efficacy test results from animals to man, and generating immune responses to small molecules.

**d.** *Performing Organization.* Program execution is distributed as 60 percent in-house DoD, 3 percent other Federal laboratories, 10 percent academia, and 27 percent commercial with 42 active CRDAs.

**e.** *Related Federal and Private Sector Efforts.* See above.

**f.** *Funding*

| Funding ($000) | FY94PBR[1] | FY94 Appr[2] | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|---|
| DoD | 36,440 | 35,802 | 36,044 | 30,447 | 31,043 | 32,783 | 34,562 |

[1] PBR = President's Budget Request

[2] Appr = Appropriation

## 5. Military Operational Medicine

**a.** *Goals and Timeframes*

- Protect military personnel from operational and materiel hazards;
- Enhance individual, and unit performance under all operational conditions;
- Develop performance models and realistic system safety/design criteria;

- Apply performance criteria to improve operational concepts and doctrine.

**b.** *Potential Payoffs and Transition Opportunities.* Potential Payoffs and transition opportunities include: enhancement of performance through ration components and resynchronization of biological rhythms; predictive models and health risk criteria to protect against materiel and environmental threats, such as halon replacements, blast, decompression sickness, diver oxygen toxicity, and electromagnetic radiation; and casualty prevention and frequency agile laser eye protection, enhanced impact protection, and battle stress management.

**c.** *Major Technical Challenges.* Major technical challenges include pharmacological control of sleep and alertness without impairment of motor or cognitive abilities; cochlear hair cell regeneration; neurophysiological control of spatial disorientation and motion sickness; stress-induced immune suppression; enhanced cognitive function during intense stress; and psychophysical adaptions for man-machine interface of electro-optical displays.

**d.** *Performing Organizations.* Program execution is distributed as 60 percent in-House DoD labs, 5 percent other Federal laboratories, 14 percent academia, and 21 percent commercial with 26 active CRDAs.

**e.** *Related Federal and Private Sector Efforts.* See above.

**f.** *Funding*

| Funding ($000) | FY94PBR[3] | FY94 Appr[2] | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|---|
| DoD | | 84,066 | 85,112 | 84,033 | 86,296 | 88,567 | 92,203 |

[3] PBR = Request is integrated among other programs

## 6. Military Dentistry

**a.** *Goals and Timeframes*

- Reduce evacuations due to dental emergencies and oral diseases;
- Decrease morbidity and mortality following maxillofacial trauma.

**b.** *Potential Payoffs and Transition Opportunities.* Potential payoffs and transition opportunities include ultralong duration anesthetics, a fiberoptic periodontal probe for rapid dental diagnostics, and oral delivery systems using histidine-rich proteins to minimize dental casualties. Maxillofacial trauma will be addressed with filmless imaging, visualization of non-metal shrapnel, improved tissue viability assessment, microencapsulated antibiotics and antimicrobial dermal dressings.

**c.** *Major Technical Challenges.* Major technical challenges include biomaterials compatibility; fast-acting, long-duration anesthetics with localized effects that do not impair motor and cognitive capabilities; and easily transportable dental emergency diagnostic and prognostic methods.

**d.** *Performing Organizations.* Program execution is distributed as 75 percent in-House DoD, 8 percent other Federal laboratories, 5 percent academia, 12 percent commercial with 9 active CRDAs and 8 CRDAs under negotiation.

**e.** *Related Federal and Private Sector Efforts.* See above.

**f.** *Funding*

| Funding ($000) | FY94PBR[4] | FY94 Appr | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|---|
| DoD | | 2,719 | 2,755 | 2,950 | 3,173 | 3,329 | 3,462 |

[4] PBR = Request is integrated among other programs

## 7. Ionizing Radiation Bioeffects

**a.** *Goals and Timeframes*

- Develop Biomedical strategies to minimize performance-degrading and life-threatening health effects of radiation;
- Assess radiation injury on the battlefield with biological indicators;
- Develop advanced treatments to prevent lethality and long-term effects of radiation alone or in combination with battle injuries.

**b.** *Potential Payoffs and Transition Opportunities.* Potential payoffs and transition opportunities include drugs to prevent radiation-induced lethality, genotoxicity, and performance-degrading gastrointestinal effects; treatments based on simulation of natural repair processes; radiation damage assessment based on analysis of chromosome; and models for projection of casualties in wartime and risk assessment in peacetime.

**c.** *Major Technical Challenges.* Major technical challenges include toxicity of known radioprotectant compounds, development of protective drugs without performance-impairing side effects, enhancement of DNA repair, and extrapolation of model results to humans.

**d.** *Performing Organizations.* Program execution is 95 percent in-House DoD, 1 percent academia, and 4 percent commercial with 19 active CRDAs.

**e.** *Related Federal and Private Sector Efforts.* See above.

**f.** *Funding*

| Funding ($000) | FY94PBR | FY94 Appr | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|---|
| DoD | 18,097 | 17,981 | 15,698 | 14,594 | 10,000 | 8,500 | 6,900 |

## 8. Roadmap of Technology Objectives

See Table 4-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

Although BST is vital to the human capability dimension of all joint War-fighting Capabilities and supporting technologies, DoD technology areas most closely related to BST include Chemical and Biological Defense; Clothing, Textiles and Food; Environmental Quality and Civil Engineering; Human Systems Interfaces; and Manpower, Personnel and Training.

## F. TECHNOLOGY TRANSFER AND DUAL USE

*Blood Substitutes and Resuscitation Fluids Technologies.* Maintaining an adequate battlefield supply of blood, blood products and resuscitative fluids is an enduring combat casualty care problem. Defense technology advances in blood substitutes, enzymatic conversion of red blood cells to "universal donor" status, and low volume resuscitative fluids will greatly benefit civilian blood banking, rural provision of emergency life support, and reduce national health care delivery costs while improving patient safety.

*Vaccine Technologies.* Since the DoD vaccine program targets militarily important diseases, with few exceptions these vaccines have little demand in the U.S. They are in high demand in third world markets. The International Childhood Vaccine Initiative will benefit from DoD-developed vaccines as well as vaccine development, scale-up production, and immunization technologies. Defense laboratories serve as international reference standard laboratories for disease-causing organisms and play an important role in worldwide disease epidemiology and natural history.

*Tele-Medicine and Medical Information Technologies.* Conflicting requirements of preserving medical and surgical capabilities and having them immediately available at the side of the wounded are being addressed through exploitation of virtual reality and intelligent systems technologies. While focused on forward care of the combat casualty, technological advancements in medical devices for enhanced diagnostics, medical and surgical intervention, and medical simulation, education and training, and intelligent health care information systems have direct and obvious applications in civilian health care delivery, improved quality and reduced health care costs.

*Hazardous Environments-Occupational Health Technologies.* Since medical chemical defense pretreatment drugs must be devoid of adverse behavioral effects, this program produced microcomputer-based human performance assessment tools that are national and international standards for assessing impacts of drugs and environmental stressors on human performance. More directly, research on blast overpressure models, sleep and performance is being applied by the Department of Transportation (DOT) to motor vehicle crash injury and accident prevention.

**Table 4-1. Roadmap of Technology Objectives for Biomedical Science and Technology Roadmap**

| Sub-Area | By 1995 | By 2000 | By 2005 |
|---|---|---|---|
| Infectious Diseases of Military Importance | • Liposome delivery of antieishmanial drug<br>• Synthesized drugs for malaria treatment<br>• Genetically engineered Vaccines for hantavirus<br>• Monoclonal antibodies for forward diagnosis of insect-borne viruses | • Peptide synthesis of HIV vaccine<br>• Countermeasures for malaria drug resistance<br>• Proteosome delivery of oral vaccine for ETEC diarrhea<br>• Single step field assays for malaria diagnosis | • Combined oral vaccines for bacterial diarrhea<br>• Topical antiparasitic drugs<br>• Gene therapy to protect against HIV |
| Combat Casualty Care | • Improve far-forward treatment techniques<br>• Reduce blood requirements by 10 percent | • Improve blood storage by 100 percent<br>• Reduce far-forward IV fluid requirements by 50 percent<br>• Improve airway management far-forward by 30 percent | • Reduce secondary effects of trauma 10 percent with free-radical scavenger<br>• Reduce battlefield mortality 20 percent with casualty life support<br>• Field blood substitute |
| Medical Biological Defense | • Microencapsulated vaccines for SEB<br>• Genetically engineered vaccines for VEE<br>• Monoclonal antibodies for botulinum toxins | • Mouse-human antibodies<br>• Bioengineered scavengers for ricin an botulinum toxins<br>• Peptide synthesis for ricin protection | • Nucleic acid therapy |
| Medical Chemical Defense | • Cyanide pretreatment drug<br>• Adsorptive topical skin protectant | • Catalytic pretreatment for nerve agents<br>• Advanced anticonvulsant<br>• Reactive topical skin protectant | • Catalytic scavengers for broad range of CW agents<br>• Monoclonal antibodies nerve agent protection |
| Military Operational Medicine | • Ankle brace reduction of musculoskeletal injury<br>• Blast standards<br>• Aviation spatial awareness<br>• Vestibular test battery | • Performance enhancing nutrients<br>• Water quality monitor<br>• Vigilance/alertness monitor<br>• Electromagnetic radiation standards<br>• Improve aviator training and selection | • Physiological status monitor<br>• Sleep/alertness enhancers<br>• Treatments for retinal laser injury<br>• Spatial awareness incorporation into trainers |
| Military Dentistry | • Microencapsulated antibiotics<br>• Antimicrobial dermal dressing<br>• Filmless dental imager<br>• Rapid chairside dental diagnostics | • Ultralong duration anesthetics<br>• Fiberoptic dental periodontal probe<br>• Safe mercury waste disposal process | • Oral delivery systems using histidine-rich proteins<br>• Improved tissue flap and tissue viability assessment<br>• Non-metal shrapnel visualization in maxillofacial injury |
| Ionizing Radiation Bioeffects | • First generation immuno-modulator therapy<br>• Anti-emetic compounds<br>• BW/CW neutralization | • New generation immuno-modulators for multi-organ injury<br>• Pharmacological approach to synapse deficits<br>• Depleted uranium injury risk assessment | • Molecular strategies to reduce radiation-induced cancer/mutation |

# 5. CHEMICAL AND BIOLOGICAL DEFENSE

## A. SCOPE

The danger posed by the proliferation of weapons of mass destruction is highlighted by the Joint Chiefs of Staff as one of the top five Future Joint Warfighting Capabilities. U.S. forces must be prepared for conflict in a chemical and biological (CB) environment in a Global Reach concept. The CB defense technology area includes four major subareas: detection, protection, decontamination, and information processing and dissemination. Medical CB defense issues are addressed in chapter 15. Funding for CB Defense is $53M in fiscal year 1994.

## B. VISION

Ensure an overmatching defensive posture which protects our forces and makes CB warfare a high risk, low payoff alternative.

## C. RATIONALE

The purpose of CB defense research is to develop equipment that will protect our forces, sustain combat operations and maintain system effectiveness in a CB contaminated environment. The cornerstone of CB defense strategy is early detection and warning to provide situational awareness and permit forces to avoid the threat. Detection systems, including both point and standoff sensors, will enable commanders to detect CB warfare agents below incapacitating levels and immediately activate protective/avoidance measures.

The complement to detection is protection, both active and passive. The goal of active protection is to intercept and destroy CB warhead payloads. The goal of passive protection is to insulate forces from CB agents using clothing ensembles and respirators as well as collective filtration systems and shelters. Carefully balancing performance requirements with human physiological and psychological parameters, protection technologies will enable the forces to sustain their mission with minimal casualties when a CB threat is encountered.

When CB contamination cannot be avoided, decontamination systems quickly reconstitute personnel and equipment with minimal logistics burden and impact on mission effectiveness. Decontamination technologies will be used during operations or in preparation for return to CONUS.

Finally, information processing and dissemination technologies, including modeling and simulation, will aid in the assessment of Joint Service doctrine, training and materiel for operating in a CB environment, provide equipment design parameters, and enable field commanders to integrate and interpret real-time data.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Detection

**a.** *Goals and Timeframes.* The goal of the detection subarea is to provide a real-time capability to detect, identify, locate and quantify all CB warfare agent threats below incapacitating levels. Current emphasis is on multiagent sensors for biological agent detection and standoff CB detection. To meet the needs of the next 3 to 5 years, a number of individual sensors are being developed while detection technology matures. Far term objective technologies will allow integration of chemical and biological point and standoff detection into a single system. The technology focus is on detection sensitivity and specificity across the evolving spectrum of CB agents, system size/weight, range, signature and false alarm rate as well as on integration of CB detectors into various platforms, individual clothing and the C3I network.

**b.** *Potential Payoffs and Transition Opportunities.* The future CB detection system will provide the capability to detect, identify, map and track all CB contamination in the theatre of operations. This will enable commanders to avoid CB contamination or to assume the minimum appropriate protection required to continue fighting and sustain their mission with minimal performance degradation and casualties. Small, lightweight CB detectors can be incorporated into clothing ensembles to provide an individual CB detection capability. CB detection technologies have dual use potential in monitoring air pollution, noxious fumes inside enclosed areas and municipal water supplies.

**c.** *Major Technical Challenges.* The major technical challenges are in the areas of biological detection and identification, including remote sensing, improved agent discrimination and quantification, sampling efficiency, interferant rejection and antibody/probe development. Size reduction of CB detectors, development of integrated biological and chemical detection systems, and the fusion of sensor data with mapping, imagery and other data for real-time display of events are also challenges. Finally, detector technologies based on olfactory-like chemical sensing and molecular approaches to optical sensors offer long term opportunities.

**d.** *Performing Organizations.* Edgewood RDE Center, Army Research Laboratory, Space and Strategic Defense Command, Naval Surface Warfare Center, Naval Research Laboratory, Wright Laboratory, Armstrong Laboratory, Marine Corps Systems Command, Defense Nuclear Agency

**e.** *Related Federal and Private Sector Efforts.* Other related efforts include medical and food testing sensors for use in detecting biological organisms indicative of disease. International cooperative efforts include development of a biodetector with the U.K. and Canada, a standoff chemical detector with France and mass spectrometry for the field with Germany.

**f.** *Funding.* Industry 25 percent, Academia 10 percent, OGA 15percent

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| DoD | 21 | 20 | 21 | 22 | 26 | 28 |

## 2. Protection

**a.** *Goals and Timeframes.* The goals of the protection subarea are to maintain a high level of protection against CB warfare agents while reducing the physiological burden associated with wearing protective equipment; to integrate CB protection with protection from environmental, ballistic and other threats; and to provide a protective environment for personnel operating in aircraft, armored vehicles, ships, shelters and other large-area enclosures. To achieve these goals, physiological performance requirements key to the design and evaluation of clothing and respirators are being established. New barrier and filtration materials, and permeable fabrics to accommodate these performance requirements, are being developed and evaluated. Regenerative filtration materials and techniques that would virtually eliminate the need to replace collective filters are being explored.

**b.** *Potential Payoffs and Transition Opportunities.* Individual protection investments will result in improved respiratory and percutaneous protection with reduced physiological and psychological burden to the individual warrior. Improved air purification systems for collective protection applications will allow for extended operations in enclosures in a CB contaminated environment and reduce the logistics burden of filter exchange. Filtration technology has commercial application to the chemical industry and for automotive applications.

**c.** *Major Technical Challenges.* Integrating CB protection into future warrior systems necessitates tradeoffs between performance requirements and limitations of materials and designs. Integral respiratory protection requires tradeoffs between physiological performance parameters such as pulmonary function, field of view, speech intelligibility and anthropometric sizing against cost, size/weight, agent life and interfacing with other equipment. Integral CB protective clothing requires tradeoffs between minimizing thermal stress and moisture buildup against agent resistance, weight/bulk and power requirements of cooling systems. Air purification systems require tradeoffs with respect to size, weight and power requirements, as well as longer life and minimal environmental impact.

**d.** *Performing Organizations.* Edgewood RDE Center, Natick RDE Center, Naval Surface Warfare Center, Naval Air Warfare Center, Navy Textile Research Facility, Naval Health Research Center

**e.** *Related Federal and Private Sector Efforts.* Contractual and cooperative efforts between industrial suppliers and the National Institute of Occupational Safety and Health (NIOSH) are commonplace.

**f.** *Funding.* Industry 15 percent, Academia 6 percent, OGA 7 percent

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| DoD | 17 | 12 | 10 | 10 | 11 | 13 |

### 3. Decontamination

**a.** *Goals and Timeframes.* The goal of the decontamination sub-area is to develop CB technologies that will clean-up toxic materials without performance degradation to the contaminated object while being environmentally safe. This area includes decontamination of personnel, individual equipment, tactical combat vehicles, and military bases. The current decontamination technologies being pursued include enzymes, catalysts that improve reactivity, decontaminants that are effective in both fresh and brackish water, reactive coatings and improved reactive sorbents. Contamination control involves investigating procedures that minimize the extent of contamination pickup and transfer, and maximize the ability to eliminate the contamination pickup on-the-move as well as during decontamination operations.

**b.** *Potential Payoffs and Transition Opportunities.* The payoff from enhanced decontamination materials and systems will be new non-corrosive, non-toxic, non-flammable, and environmental safe decontamination systems suitable for a timely clean-up of CB agents on all materials and surfaces. This ability will allow the forces to reconstitute personnel and equipment in a timely fashion to increase combat efficiency and lessen the logistic burdens. Reactive coatings may, in the future, allow the continuation of combat operations without the need to disengage for decontamination. Dual use potential for environmental remediation, especially pesticide contamination, is being exploited.

**c.** *Major Technical Challenges.* The technical difficulties associated with this effort have been in the areas of increasing the activity of the decontaminants and developing systems that effectively clean all surfaces and materials, and are environmentally safe. Reduction of the manpower and logistics burdens of decontamination also remains a significant challenge.

**d.** *Performing Organizations.* Edgewood RDE Center, Naval Surface Warfare Center, Naval Research Laboratory, Office of Naval Research

**e.** *Related Federal and Private Sector Efforts.* Decontamination research is being done cooperatively with the U.S. Army Chemical Materiel Destruction Agency on alternative methods of destroying the U.S. chemical weapons stockpile, in consonance with recommendations from the National Research Council.

**f.** *Funding.* Industry 5 percent, Academia 5 percent, OGA 2 percent

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| DoD | 4 | 3 | 2 | 2 | 2 | 3 |

## 4. Information Processing and Dissemination

**a.** *Goals and Timeframes.* The goal of the information processing and dissemination subarea is to provide systems which will enhance command evaluations, integrate sensor data, and permit realistic training and simulation of the CB battlefield. Key to this effort is the development of mathematical models for the dispersion, transport, diffusion, deposition, evaporation and decay of CB warfare agents; the use of these models to estimate the exposure and subsequent effect of CB warfare agents on personnel and materiel; and the integration of CB warfare models into new and existing combat simulations and wargames.

A current thrust is to take advantage of the rapidly increasing computational power in personal computers by incorporating terrain, mesoscale meteorology and objects such as tanks, ships or buildings into CB effects models. Steps are also being taken to add a realistic CB warfare capability to wargames such as JANUS. The development of hazard assessment models for use by operational forces is another area of emphasis based on experience during Operation Desert Storm.

**b.** *Potential Payoffs and Transition Opportunities.* This subarea will provide the ability to provide information and decision aides to commanders to allow tradeoffs among tactical options as well as assessment of Joint Services doctrine, tiring, leadership, organization, materiel and soldier performance during and after a CB agent attack. Modeling and threat assessment efforts offer value-added evaluations and design optimization of CB defense equipment during its development. Modeling and simulations offer a rapid, less expensive alternative to field trials and allow for evaluations under a wide variety of meteorological conditions and terrains. These technologies have dual use potential to model the dispersion of air pollutants from normal industrial operations for municipal environmental monitoring or toxic or noxious fumes from burning industrial facilities, railroad tank car spills or other accidents.

**c.** *Major Technical Challenges.* The primary technical challenges in this sub-area are data generation for evaluation and validation of the models, manipulation of large data bases for real-time simulations to reduce computer running time, and providing a simplified output and decision aides for easier interpretation of results. Other technical challenges include incorporation of a 3-dimensional Navier-Stokes flow code for more realistic profiles, developing high resolution models for the Distributed Interactive Simulations (DIS), and establishing threat/toxicity levels for CB agents with the models under various scenarios.

**d.** *Performing Organizations.* Edgewood RD&B Center, Army Research Laboratory, Office of Naval Research, Naval Surface Warfare Center, Armstrong Laboratory, Defense Nuclear Agency, Ballistic Missile Defense Organization, Advanced Research Projects Agency

**e.** *Related Federal and Private Sector Efforts.* An international data center concept being planned by ARPA, will display meteorological, atmospheric radionuclide and seismic data as part of verification of a comprehensive nuclear test ban treaty. Later efforts could include CB monitoring components on the stations for worldwide environmental monitoring purposes.

**f.** *Funding.* Industry 15 percent, Academia 6 percent, OGA 6 percent

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| DoD | 11 | 8 | 8 | 6 | 6 | 7 |

### 5. Roadmap of Technology Objectives

See Table 5-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

Survivability and sustainment in a chemically or biologically contaminated environment is a significant problem for all weapons platforms, including the soldier as a system. The CB defense area provides technology for integration with all platform and component technology areas. Decontamination technology is applicable to and leverages remediation efforts in the Environmental Quality area. The technology areas of Clothing, Textiles and Food and Materials, Processes and Structures investigate CB protective textiles and materials of construction, respectively. The Biomedical area addresses medical aspects of CB defense and shares antibody technologies with this area. Advances in the Sensors and Electronics areas are integrated into the CB detection program.

**Table 5-1. Roadmap of Technology Objectives for Chemical and Biological Defense S&T Goals**

| Sub-Area | By 1995 | By 2000 | By 2005 |
|---|---|---|---|
| CB Detection | • Field limited NDI systems for Bio Agent point and standoff detection<br>• Demo standoff detection from mobile platforms with range to 3 KM<br>• Aircraft interior vapor detection<br>• Personal Chemical Monitor<br>• Demo sensor deployment application framework tool prototype<br>• Demo micro-EM bio-agent detector prototype<br>• Demo miniaturized CB surveillance detector | • Demonstrate integrated point/standoff Biodetection capability (ATD)<br>• Complete R&D of tunable, eyesafe laser for standoff detection<br>• Demo Individual Soldier Chemical Detector weighing <8 oz and measuring 2"x1"x1"<br>• Equipment contamination scanner, handheld<br>• In-line water CB monitor<br>• Biological Air Particle counter<br>• Biological Identifier | • Demonstrate integration of chemical and biological agent detection in one system<br>• Wild Area CB Scanner with 5 to 10 KM hemispherical radius and agent discrimination |
| Protection | • Demo mask with 50% reduction in breathing resistance and 50% improvement in field of vision<br>• Demo Joint Service Battle Dress Overgarment | • Demonstrate regenerative filter prototype<br>• New chemical protective clothing, handwear and footwear materials transition to 21 CLW<br>• Personal air conditioner backpack weighing less than 10 pounds | • Continuous Operations filter technology<br>• Personal Dosimeter |
| Decontamination | • Demo improved sorbents<br>• Aircraft Interior Decon procedures (non-system) | • Aircraft Interior Decon system<br>• Improved decon material to replace DS 2 | • Demonstrate sensitive equipment and environment safe decon materials<br>• Demonstrate enzymatic decon<br>• New self-decontaminating materials technology |
| Information Processing and Dissemination | • Incorporation of CB effects into 2-D wargame/combat simulations (JANUS-A)<br>• Demo user friendly software for downwind hazard prediction of WMD<br>• Equipment design standards (challenge levels) | • Incorporation of CB effects into 3-D DIS<br>• New code for prediction of high altitude CB warhead intercept, breakup and dispersion<br>• Regional/urban modeling and simulations<br>• Demonstrate integrated sensor data, decision aids and contamination mapping of CB agents into C4I digitized battlefield | • Incorporation of CBDE into 3-D DIS<br>• Global modeling and simulation<br>• Field integrated sensor data, decision aid, and CB contamination mapping system |

# 6. CLOTHING, TEXTILES AND FOOD

## A. SCOPE

The DoD Clothing, Textiles, and Food technology area focuses on protecting and sustaining soldiers, sailors, airmen and marines, individually and collectively. Food, clothing, and shelter are essential to performance, survival, enhancing quality of life, boosting morale, and maintaining readiness. At first glance, providing for the basic needs (food and clothing) for service personnel appears to be deceptively simple. In truth, it is a highly complex challenge - protecting and sustaining hundreds of thousands of military personnel for every operational mission in every environment at any time presents a unique spectrum of challenges for which there is no civilian comparison.

This technology area is comprised of two sub-areas: 1) Clothing and Textiles, and 2) Food, The clothing and textiles sub-area includes all textile-related polymer, fiber, yarn, fabric, film, dye, pigment, coating, and clothing systems and their packaging that enhance survivability, performance, and mobility - both on the battlefield and in operations other than war. These efforts provide technology advancements in the areas of individual ballistic protection, percutaneous chemical/biological protection, countermeasures to sensors, integrated protection (to include flame/incendiary protection and anthropometric/biomechanical concepts for clothing design), and bioengineered materials for protection. This sub-area also includes textile-based technologies for items such as tentage and parachutes.

The food sub-area includes science and technological efforts to sustain warriors and enhance their mental and physical acuity and performance on the battlefield. These efforts include nutritional performance enhancement, food preservation, food packaging, consumer acceptance, and equipment and energy technologies. They support the unique feeding requirements of the military services ranging from general purpose individual and group ration systems to rations designed for special operations or for extreme/remote environments, as well as the development of field food service equipment and systems essential for individual and group feeding during ground, air, and shipboard operations. The need to "fuel the fighter" - to deliver the right nutrients at the right levels at the right time in the right combination - requires breakthroughs in food related technologies, especially to meet the additional and unique demands that the "information/electronics age" will bring to bear on military personnel.

Funding for this technology area is $31.1M in FY94 (includes $2.7M of 6.1 funding) and $27.6M in FY95 (includes $2.0M of 6.1 funding).

## B. VISION

The vision is to maximize survivability and combat effectiveness of the individual combatant by exploiting emerging technologies to provide (1) integrated protection through multifunctional materials and modular suites of components, parachutes, shelters, and (2) nutritional sustainment and performance enhancement through scientifically-designed high quality rations and advanced, logistically efficient field feeding systems.

## C. RATIONALE FOR INVESTMENT

Individual protection, sustainment, and mobility are critically required military capabilities. The clothing, textiles, and food area is structured to develop the technologies necessary to provide these capabilities. Military personnel are the essence of our ability to achieve our national military strategy and are the primary means through which successful mission accomplishment is assured. The specialized abilities of our troops have been vital, nationally and internationally, not only for operational contingencies, but also for operations other than war (e.g., humanitarian, peacekeeping). Protection and sustainment of our soldiers is a must when the public demands few casualties, especially in operations other than war.

Through years of traditional approaches to clothing and textile-based protective materials, the military has fielded hundreds of high performance protective items. Now the military is at a juncture where the traditional approach is no longer sufficient to defeat the complex and ever-increasing battle theater challenges. An integrated approach to designing systems of protection and modular suites of components is more effective and affordable in providing new levels of protection to the individuals. This new approach allows incorporation of suites of modular chemical protective components, modular small arms bullet protection, and modular load carriage equipment.

Further, in the increasingly sophisticated battlefield of the future, it is the warfighter who assures mission success. Sustaining that fighter, the "man in the loop" in most weapons platforms, in peak condition is critical to that goal. Subsistence research efforts encompass support to ground combat, special operations, air and shipboard operations, and other specialized operations with emphasis on the standardization of rations, and of field feeding, equipment, and procedures among the Services while also providing cutting-edge solutions for sophisticated and unique military activities. The food provided to the fighter before and during his mission can provide the performance edge that makes him a true force multiplier.

Foreseeable advances in clothing and textile technology include: development of next generation high performance fibers, membranes, and fabrics for multiple threat protection textile-based systems; dyes and textile materials to prevent detection by multi-spectral sensor devices; increased understanding of chemical penetration mechanisms; and textile systems for clothing and soft shelters that provide thermal and environmental protection with minimum bulk and weight.

Foreseeable advances in food science and technology include: use of natural ingredients with glucose-modulating and neuroactive potential to enhance mental and physical performance; use of liposomal vesicles capable of surviving digestive stress and delivering special nutrients and bioactive constituents to specific physiological sites; use of edible plasticizers and antiplasticizers to manipulate food structure and viscosity to minimize deteriorative physical and chemical reactions during high temperature storage; development of aseptically and ohmically processed particulate foods with optimal textural properties that would enhance soldier acceptance; use of intrinsic chemical markers to validate sterility of thermally processed foods to avoid overprocessing and quality degradation; use of integral chemical heaters in self-activating package configurations to ensure hot meals "on-the-move"; use of predictive equations and time-temperature indicating labels for assessing remaining shelf life of foods stored in uncontrolled environments; development of integrated thermoelectric power generators to simplify food preparation equipment; development of non-powered refrigeration for storing perishables in the field; and development of nonpowered water heaters for remote site applications.

Payoffs are demonstrated in terms of greater system capability and reduced costs. These systems are: multi-functional combat uniforms, integrated protective equipment, lightweight airbeam-supported soft shelters, air deployment of personnel and large equipment/cargo, rations, and efficient, modular, highly mobile field feeding systems. As compared to other major DoD systems, a relatively small investment in clothing, textiles, and food science and technology significantly impacts the survivability, sustainability, effectiveness, performance, readiness, and morale of every DoD service member. For example, for the food technology sub-area, the research and development investment-to-procurement ratio is approximately $12.0M to $2.0B, which indicates that for a relatively small investment, even small enhancements achieved through research and development can result in substantial savings.

Although the DoD investment in clothing, textiles, and food technology is focused on military unique applications, many of the basic clothing and food technologies are inherently dual use. This results in decreased cost to DoD where industry is willing to invest their own resources, and creates a more stable manufacturing base for surge production during times of mobilization. It also plays a strong role in strengthening the commercial-military industrial base, allows DoD to exploit cutting-edge technologies, and results in faster development, transition, and insertion of superior technologies. Developing technological advancements that address advanced clothing/textiles and optimal foods/rations and the purchasing of these items through the use of best commercial practices and processes, results in a larger more reliable manufacturing base and a more affordable means of fielding advanced technology. Investment in manufacturing science and technology is one way to ensure improved, cost effective production and manufacturing processes.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Clothing and Textiles

**a.** *Goals and Timeframes.* The DoD clothing and textiles technology sub-area addresses the full range of combat, environmental, and special purpose protective materials to maximize combatant survivability, performance, mobility, and effectiveness. The primary goals of clothing and textile technology efforts are:

| | |
|---|---|
| By FY96 | Transfer technology to reduced weight ballistic protective vest, weighting 15% less than current technology while providing equivalent fragmentation protection.<br>Develop advanced semi-permeable membrane eliminating/reducing the use of carbon in chemical protective ensembles.<br>Develop fibers/fabrics containing embedded phase change materials had identify phase change circulating fluids for cooling purposes.<br>Produce advanced combat uniform fabric with durable integrated protection.<br>Produce bioengineered spider silk based fiber for improved ballistic protection.<br>Demonstrate advanced airbeam technology in a large area night maintenance shelter.<br>Conduct Advanced Airdrop for Land Combat ATD. |
| By FY00 | Demonstrate an improved material system for protection against combined fragmentation and small arms threats, to be measured by a 20% reduction in areal density.<br>Identify technology for self-detoxifying chemical/biological protective capability by integrating reactive and catalytic materials with semi-permeable membranes.<br>Conduct Gen II Soldier ATD demonstration as part of 21CLW Top Level Demonstration.<br>Demonstrate prototype boot reducing stress-related lower extremity injuries.<br>Demonstrate 40,000 lb high glide airdrop system and transition to full development.<br>Upgrade packaging system to reflect SOA logistical, ergonomic, and environmental standards.<br>Produce biodegradable flame resistant fabric for shipboard use.<br>Establish military wide anthropometric database and develop three dimensional computer aided design models. |

**b.** *Potential Payoffs and Transition Opportunities.* The most significant payoffs are those which increase battlefield survivability and performance. This includes fully integrated protective systems with reduced cost, weight, and heat stress. Development of lightweight ballistic protective materials results in reduced casualties for personnel which translates to an enhanced mission completion while minimizing the potential of incapacitation from ballistic threats and physiological heat stress. Providing the individual combatant with integrated, multipurpose protective clothing and individual equipment that is functional in all terrains and environments will provide the DoD with a broad military capability and technological edge required by smaller scale forces to rapidly respond on a global basis to a diverse variety of missions, whether actual conflict or operations other than war. Cooperative Research and Development Agreements (CRDAs) with industry and development programs with major universities, are aggressively being pursued to develop both new fabrics from advanced fibers and improved fabric and clothing manufacturing techniques. Improved ballistic protective personnel armor technology has widespread applicability to law enforcement communities such as the FBI. Secret Service, Drug Enforcement Agency as well as state and local police. Improved chemical protective clothing technology has potential for wide application in the chemical industry, in agricultural pesticide applications, and in hazardous waste removal cleanup. The apparel, footwear, and international protective clothing industries will all potentially benefit from dual use technologies that support the design, sizing, manufacture and performance of civilian clothing and individual equipment. In addition, independent testing organizations benefit from test method and material specifications generated from DoD development efforts.

Chemical protective materials will transition to the Land Warrior advanced development program and also to the Gen II Soldier ATD. Integrated fabrics will be utilized in Joint Service-Lightweight Integrated Suit Technology (JS-LIST), aircrew, and soft shelter programs. Improvements in flame resistant materials for biodegradable clothing, phase change materials for flame resistant fabrics, and fit adjustable boots for firefighter's applications will transition to development efforts at the Naval Sea System Command (NAVSEA) and the Naval Air Warfare Center (NAWC) within the next few years. The Soldier and Marine Enhancement Programs (SEP/MEP) have also provided an avenue to insert transition-ready technologies directly from Science and Technology efforts to non-developmental items and get them into the hands of the soldier/marine in a short period of time. Technologies being developed under the ballistics program will transfer to Land Warrior, Gen II Soldier ATD, and the Joint Technical Coordinating Group for Aircraft Survivability's Modular Aircrew Armor Program as well as to any future generations of individual ballistic protective systems. These technologies are also being developed for dual use and are expected to be transferred to other government agencies and to the private sector.

**c.** *Major Technical Challenges.* Finding the appropriate balance between protection and other considerations (such as, weight, bulk, cost, rigidity of materials, and producibility) is required. Solving one challenge with a material solution may create another problem within the material system. For example, increased protection usually translates into increased weight, and insulating the individual from the environment to decrease the thermal signature results in increased heat burden. Development of biodegradable materials for clothing used in marine environments requires that material properties be balanced with functionality of the item and prevention of premature degradation. Environmental considerations also provide technical challenges for processing and finishing many textile materials, as hazardous solvents and materials which often provide the most effective and durable processing methods and textile finishes must be replaced.

**d.** *Performing Organizations.*

| Organization* | FY94 | FY95 |
|---|---|---|
| Government | 51% | 49% |
| Industry | 39% | 37% |
| Academia | 10% | 14% |

*6.2 and 6.3a only

One location, Natick, Massachusetts, conducts all in-house DoD clothing and textile science and technology work, as the single DoD Center of Excellence for this technology. Only the Army and the Navy have in-house capability to perform the clothing and textile science and technology mission. Army Natick and Navy Natick are currently fully collocated with their administrative and laboratory facilities on the same installation. The installation is operated by the Army with the Navy as a tenant activity sharing all available science and technology resource facilities under a joint Memorandum of Understanding (MOC) between the two Services. Navy Natick also performs all clothing and textile laboratory functions for the Coast Guard. The Air Force and the Marine Corps do not have any facilities dedicated to conducting clothing and textile science and technology work. The Air Force has used Army and Navy Natick in the past for science and technology work and will do so in the future. The Marine Corps meets its science and technology requirements by consistently using both Army Natick and Navy Natick.

**e.** *Related Federal and Private Sector Efforts.* The Defense Logistics Agency (DLA) is working, through the MANTECH program, with industry, universities, and other government agencies to move clothing production toward an apparel on-demand capability. This and other CAD/CAM related efforts will ultimately result in three-dimensional full-body laser scanning, instant custom pattern sizing, and production of mission- and individual-specific combat uniform systems. The Advanced Concepts and Technology (ACT) II Program is funding two substantial research efforts in airdrop technology. The Small Business Innovation Research (SBIR) program has spawned new technology opportunities in both food science and textiles. Special Operations Forces and USMC have sponsored research on ballistic protection, thermal signature reduction, chemical protection, and lightweight shelters.

The National Science Foundation, NASA, and the Federal Emergency Management Agency are working programs with DoD on clothing technology. The Department of Justice and Advanced Research Projects Agency (ARPA) have initiated an MOU for ballistic protective technologies. The Army is very active in NATO working groups that relate to the soldier and chairs NATO Working Group #5 on Combat Clothing and Personal Equipment and #14 on performance issues for the 21st century individual combatants. Data Exchange Agreements (DEAs) for combat clothing and individual equipment exist with France, Germany, Korea, Sweden, and the Netherlands.

**f.** *Funding.*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Funding ($M): | 19.0 | 19.1 | 16.6 | 16.6 | 16.9 | 18.0 |

(Includes 6.1 funding as follows: FY94 $2.1M, FY95 $1.8M, FY96 $1.5M, FY97 $1.5M, FY98 $1.6M, FY99 $1.6M).

## 2. Food

**a.** *Goals and Timeframes.* The DoD Food and Nutrition Program addresses the unique feeding requirements of military operations; the functional capabilities associated with such operations are neither required nor available in the commercial civilian sector. Military field feeding is so challenging and so different from non-military food service because of its unique characteristics that include: the rugged, often hostile, field conditions; the temperature/environmental extremes; the rapid mobility tactical environments; the limited availability of power, food, ration and water supplies (and resupply); the lack of refrigeration; the limitations on lift and related logistics assets; the variability in "group" size; and time and manpower constraints. For instance, in the civilian sector, the easy accessibility of heating and cooking equipment, fuel and energy sources, food supplies and supermarkets, refrigeration and freezers, and water, contrasts immensely from that found in military field environments. These differences are even more pronounced in the post-Cold War era where demands for field operations and remote site feeding to support our combat forces in underdeveloped countries are always increasing.

The food technology sub-area encompasses three major aspects of providing sustainment: (1) the formulation/processing of rations and foods that not only provide energy and other essential macro- and micro-nutrients, but also enhance performance by increasing alertness and extending endurance in combat and in environmental extremes; (2) protective ration packaging, including biodegradable packaging, required to stabilize rations against microbial, physical and biochemical deterioration during long-term storage worldwide; and (3) field food service equipment and systems that provide hot, high quality sustainment/meals to all fighters with minimal logistical support/investment: equipment, fuel, water, manpower. Representative goals of the food technology efforts include:

| | |
|---|---|
| By FY96 | Identify complex carbohydrate optimization for energy release during periods of high demand. |
| | Optimize complex carbohydrate bread components for metabolic release during periods of high demand. |
| | Validate ohmic food preservation system. |
| | Identify intrinsic chemical markers necessary for optimizing thermal processing of rations. |
| | Develop fully integrated self-heating rations and group meals. |
| | Demonstrate modular appliance technology, based upon centralized heating and circulation of a fluid or field kitchens. |
| | Demonstrate advantages of fluid heat transfer in field kitchens. |
| | Complete development of multi-fuel burners for field kitchens. |
| By FY00 | Develop automated prediction and assessment of shelf-life of rations/food, particularly at elevated temperatures to minimize waste and ensure high quality foods reach the soldier. |
| | Develop shelf-stable solid muscle foods providing A-like ration quality using irradiation. |
| | Select neurotransmitter precursors for anti-stress benefits. |
| | Develop new family of mobility-enhancing ration components using combination preservation/stabilization processes. |
| | Integrate water-cooled cook top thermoelectric generators in field kitchens. |
| | Demonstrate capability for non-invasively measuring physiological indices. |
| | Validate nonthermal preservation techniques used to minimize nutritive loss. |
| | Develop a lipid-based approaches to deliver performance enhancing nutrients and bioactive constituents to specific physiological sites. |
| | Evaluate and exploit phosphatidyl choline utilization for enhanced neuromuscular activities and identify foundation approaches to supplement rations with this neurotransmitter. |

**b.** *Potential Payoffs and Transition Opportunities.* While true starvation will probably never be a primary problem, the threat of deterioration in the performance of complex tasks due to inadequate nutrition is a real possibility. The stresses of force projection and the demands of a non-linear, highly technical, digitized battlefield (that require very close attention to details and precise coordination in action and maneuver) cannot tolerate the slumps in performance we can more readily accept in a civilian environment. A lack of attention to "fueling the fighter" could potentially compromise the investment in mechanical or electronic warfighting capabilities. Conversely, optimizing the performance of the "man-in-the-loop" could multiply the returns on that investment.

In the food technology area, the most significant payoffs are advances in food preservation, packaging, and equipment technologies that will provide the rations and food service systems to sustain/enhance battlefield performance and mobility while lowering logistical burden/costs. This includes research and development efforts or technologies that; sustain and support highly mobile, forward deployed troops; optimize performance capabilities such as enhance cognitive skills and decision making, particularly under stressful battlefield conditions, extend mission endurance and increase alertness; ensure food safety/stability in all environments; increase the protective capability of primary/secondary food packaging through the use of lightweight, compact materials; increase use of multi-fuel/energy and labor efficiency of field, shipboard and airborne food service equipment and systems; simplify logistics, distribution, and resupply; ensure operational readiness and rapid deployability; and improve the soldier's quality of life.

Advances in food/nutrition sciences and technologies will be transitioned through technology insertions for the continuous improvement of fielded rations such as the MREs, T-Rations, assault rations, and cold weather rations and to new/improved rations such as the Unitized Group Ration and self-heating rations. Transitions involving packaging technology will be horizontally integrated with new food/nutrition advances to ensure appropriate compatibility, durability, and utility. In addition, since food grade packaging tends to be the most restrictive, advances made in the area of food packaging technology will be easily transferable to other packaging needs such as ammunition, medical, and other types of packaging. Initiatives in field food service operations will be transitioned, as appropriate, to fielded food service equipment/systems and to new, modular feeding components and food service systems that will take a fraction of the manpower, time, fuel, and water to serve a better quality hot meal to troops engaged globally in diverse missions.

In addition, food, nutrition, packaging, and food service technologies have an excellent historical record of transition to the industrial base; conservative estimates indicate that 30%-35% of food/food packaging products on supermarket shelves can be attributed to military subsistence Research and Development. Enhancements in both individual and group feeding have tremendous civilian applications for hurricane, flood, earthquake relief, recreational activities, hospital, school, and prison use. High quality, food products based on new technologies are applicable for civilian consumer use as well. Although there are major differences in requirements between military and civilian sectors, ample opportunities exist to pursue technology transfer and other leveraging initiatives. The extensive coordination, including cooperative Research and Development agreements with industry, early in the Research and Development program, helps to ensure commercialization of the processes/products, which lowers the cost of the products for military use.

c. *Major Technical Challenges.* Foods are naturally complex systems. In addition to chemical, physical and nutritional variations inherently present in raw food ingredients, the formulation, processing, preservation, packaging and preparation of rations can result in undesired chemical, physical and nutritional changes that are often further compounded by lengthy, uncontrolled storage. These variables can interfere with nutrient bioavailability, reduce the nutritional content, decrease the acceptability/ consumption and limit the safety of the products. Due to the high demands and stresses associated with the digitized battlefield, improved nutrient retention, bioavailability and optimization (achieved through the integration of food technologies and nutritional strategies) will not only minimize nutrient degradation but will ensure enhanced cognitive and physical performance. The need to provide and deliver the right nutrients at the appropriate levels at the right time in the right combination requires breakthroughs in food related technologies, especially to meet the additional and unique demands that the "information age" will bring to bear on military personnel. also, the operational challenges associated with rapid deployment, force projection, and remote site field environments require improvements in heat transfer, power generation, controls, materials, refrigeration and automation technologies for new/improve food service equipment and systems to enable effective and efficient field feeding in a global environment.

d. *Performing Organizations.*

| Organization* | FY94 | FY95 |
|---|---|---|
| Government | 52% | 50% |
| Industry | 34% | 35% |
| Academia | 14% | 15% |

*6.2 and 6.3a only

The U.S. Army Natick Research, Development and Engineering Center (Natick), as the responsible DoD Executive Agency for the Food Research, Development, Testing, Evaluation, and Engineering (RDTE&E) Program, conducts the coordinated program of applied research on food and food service systems for all the military Services and the Defense Logistics Agency (DLA). The priorities for the DoD Food Program are established by a Joint Service Food and Nutrition Research and Engineering Board and chaired by OSD. Representatives from the Services meet at least twice annually to review the program. Natick and the U.S. Army Research Institute of Environmental Medicine (USARIEM) are collocated in Natick, Massachusetts and, by working together, ensure that a single, responsive food and nutrition research, development and engineering program is conducted on the behalf of all the Services. While Natick has primary responsibility for operational ration development including food, packaging, and equipment, USARIEM performs human nutrition research on soldiers testing new rations and nutritional supplements developed by Natick.

e. *Related Federal and Private Sector Efforts.* Extensive leveraging with industry, academia, foreign organizations and other government agencies, takes place under the execution of the DoD Food Program. For example, as an active participant in the Center for Advanced Food Technology with Rutgers University (Consertia) the government leverages over $4M in basic research with a $40K investment. There are five

DEAs with Germany, Israel, Korea, Norway and Sweden. Numerous CRDAs - with an estimated leveraging value of $1.8M in FY94 - with industry are also part of this ongoing program. Numerous CRDAs—with an estimated leveraging value of $1.8M in FY94—with industry are also part of this ongoing program.

f. *Funding.*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| **Funding ($M):** | 12.1 | 8.5 | 7.6 | 6.4 | 7.1 | 7.7 |

(Includes 6.1 funding as follows: FY94 $0.6M, FY95 $0.4M, FY96 $0.5M, FY97 $0.5M, FY98 $0.5M, FY99 $0.5M).

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

A small portion of the clothing and textiles sub-area includes ground breaking work on composite and biotechnology materials for ballistic protection and ballistic/laser eye protection; this is appropriately tied to the Materials and Structures technology area. Individual percutaneous chemical protection included in the Clothing and Textiles sub-area efforts is properly tied to the Chemical and Biological Defense technology area; the funding is shown in that plan. Human nutrition research is performed by MRDE/OTSG; funding is included in The Medical S&T Master Plan. Since the Simulation and Modeling technology area only covers DoD computer architecture, the clothing, textiles, and food efforts were not included in that plan. However, simulation and modeling in support of clothing, textiles, and food remains a significant part of the overall science and technology program, although not shown as a separate technology effort. There is interface with four additional technology areas, Target Interaction, Lethality and Vulnerability, where reference to personnel protection in terms of penetration algorithms for vulnerability codes is made: Human System Interfaces where reference to personnel equipment, life support and protection relative to aircraft cockpits, and ship and land vehicle stations is made; Environmental Science where packaging issues are addressed and Manufacturing Science and Technology, where affordability, producibility, and manufacturability issues are addressed.

# 7. COMMAND, CONTROL AND COMMUNICATIONS (C3)

## A. SCOPE

This science and technology area encompasses C3 systems of all types; data processing hardware and software dedicated to operational planning, monitoring or assessment (including information fusion), distributed processing, distributed data storage, and distributed data management. Not included within C3 are those S&T efforts directed at general purpose computer hardware and high performance computers, general purpose software, languages, software engineering, environments, and communications and processing elements considered subsystems in vehicles.

Effective Command, Control and Communications is recognized as a pivotal element in modern warfighting, providing the means for accurate decision making and information distribution to permit the successful employment of weapons systems. The Joint Chiefs of Staff's list of top five Future Warfighting Capabilities all require significant advances in C3 to be achieved. The number one capability, "To maintain near perfect real-time knowledge of the enemy and communicate that to all forces in near real-time" is a canonical C3 goal. Achieving this capability will require significant effort and technological advances in a number of areas. Funding for this area is $157 million in FY 1994.

## B. VISION

The guiding vision for C3 technology can be stated simply: battle space dominance through availability and use of the right information, at the right place, at the right time, while denying the same to the enemy.

## C. RATIONALE

The means for implementing C3 are advancing at a rapid pace. In no other technical area is the means of implementation decreasing in cost while rapidly increasing in performance. Many of these advances are being driven by commercial developments and products. The results can be brought to bear on DoD problems through cooperative efforts and participation in standards-setting and policy-making bodies rather than through costly DoD-specific development. There are aspects of C3 that must be strongly influenced or directly supported by DoD. In particular, communications to and among numerous, widely dispersed mobile sites, operation in actively hostile environments, identification of friend and foe, aspects of information security, and military-unique processing and decision support systems will not be developed without DoD support. The C3 technology strategy is necessarily a pragmatic one: identify the pivotal issues, capitalize on commercial development whenever feasible, leverage development in areas with special military aspects, and sponsor programs in technologies with unique DoD interest that would otherwise not be avail able to meet DoD needs.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

C3 encompasses a large number of interrelated technologies and specialties. The research will be addressed along three major emphasis areas: seamless communications, information management and distribution, and decision making.

Seamless Communications connotes assured, operator transparent, secure connectivity from sanctuary positions in CONUS or OCONUS through the theater of operations to the lowest echelon foot soldier or marine, individual ship, and individual aircraft, including allied, US and foreign government and commercial infrastructures. This connectivity will be accomplished using commercial infrastructure, military radio frequency networks and a range of bandwidths, standards and protocols. All types of information including voice, data, graphics, imagery and video need to be handled within a uniform information infrastructure. DoD must participate in commercial standards-setting bodies and in some aspects of development to ensure that its needs will be met.

Information Management and Distribution provides commanders, staff and warfighters immediate access to information and processing from any location within a globally distributed information system. It comprises network-linked distributed computing resources, data bases, platforms and individual users operating as an integrated, interoperable information infrastructure. This sub-area provides software support for multi-media, multi-modal interaction, distributed data base management, automated network management and control , information retrieval, filtering and portrayal. A particular issue is provision for multilevel security including access control, integrity and assured service operating within commercial and dedicated networks and in hostile conditions.

Decision Making is the ultimate purpose of C3 systems. The term "decision aids" includes manual, semi-automated and automated systems for maintaining the tactical and strategic picture, aids to situation assessment, planning aids, and support for resource allocation. Decision systems that effectively acquire information, process it using conventional and artificial intelligence techniques, and interact efficiently with human decision-makers are required. Many of these decision aids will need performance characteristics and have features that have no direct analog in the commercial sector.

### 1. Seamless Communications.

**a.** *Goals and Timeframes.* Development is well underway for a global, survivable DoD communications system integrated with commercial worldwide communications. Within five years commercial fiber-optic networks, equipment and protocols will be integratable with DoD satellite and radio transmission links to provide end-to-end communications. In the same time-frame fully integrated (multimedia) services, multilevel security (MLS) and distributed secure databases will become available to mobile platforms and command centers. Within ten years these services will become available to individual users. Full integration of tactical networks, simulation, and training systems will also be accomplished within this time-frame.

**b.** *Potential Payoffs and Transition Opportunities.* The major payoff will be the realization of a seamless communications grid from the National information highway to any tactical commander operating anywhere in the world. Communications will be available while forces are in transit and upon first arrival in the theater of operations. Within five years bandwidths of a few hundred megabits/second will be available. Within ten years gigabit rates will be feasible. Interoperable with host nation infrastructure, the joint commander will be provided rapid, multimedia communications with response times well within the decision cycle of the enemy. Major shortcomings of C3 on-the-move and range extension, as experienced in Desert Storm, will be corrected. Approximately 75 percent of research in this subarea is dual use in nature.

**c.** *Major Technical Challenges.* Commercial off-the-shelf (COTS) networks, products, protocols and standards must be adopted, adapted, and influenced to ensure their ability to meet military needs. Ongoing efforts with industry and within DoD to enable cooperative management of integrated networks will be needed. Hardware advances in signal processors, security devices, gateways and switches are needed and are expected to be available. Advances in engineering and system performance models, constructive models and virtual reality simulations are needed and must incorporate electronic warfare, meteorological, atmospheric nuclear, and other effects within network planning, management and operations. Research is underway to provide the technology needed. Projects include the Data/Voice integration ATD, Survivable Adaptable Systems ATD, Digital Battlefield Communications program, Multiband Multimode Radio program, SPEAKEASY and information for the Warrior ATD. These and others are described in the JDL C3 Joint Service Program Plan.

**d.** *Performing Organizations.* All Services, ARPA, and other government agencies such as DISA and DNA have active programs supporting this sub-area. The major service organizations involved are CECOM, NRL, NRaD, and Rome Laboratories. Between 70 and 85 percent of this research is conducted by industry.

**e.** *Related Federal and Private Sector Efforts.* Extensive research is conducted by the telecommunications industry in report of this sub-area. The military can leverage literally billions of dollars of commercial investments in achieving its objectives by active participation in standards bodies, promotion of commercial development, and appropriate DoD-specific research.

**f.** *Funding*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| **Funding ($M):** | 59 | 99 | 104 | 107 | 108 | 93 |

## 2. Information Management and Distribution

**a.** *Goals and Timeframes.* DoD efforts to achieve battle space superiority will depend on implementation of the services necessary to support transparent "information pull" operation of decision support systems. This infrastructure will be implemented as a distributed computing environment combining conventional networks, very high bandwidth networks, high performance workstations and massively parallel processors (MPP) to form an integrated and interoperable computing environment. Intelligent software agents will assist in the location, correlation, processing, and tailoring of the vast amounts of data available within the "infosphere". The complexities of the underlying system will be masked from the user through advanced interfaces that can use a range of human interaction modalities. Together these functions will automatically operate upon, and integrate data from distributed multi-level secure data bases and information sources. They will produce an information product that accurately portrays to the warrior, via mobile computing, tailored and scalable, locally accurate and globally consistent battle space conditions. Demonstration of important elements of this capability are currently being planned. Most of the technology will be available within five years and important elements will be in service. Full implementation could be completed within ten years.

**b.** *Potential Payoffs and Transition Opportunities.* Information dominance will be achieved through implementation of an environment through which commanders, staff and warfighters can immediately access and process critical C3I information. This new generation information system will support the information needs of a globally dispersed multi-service and multi-national force. New levels of survivability will be provided through dynamic reconfiguration of how and where tasks are executed, balanced load distribution during crisis and graceful degradation in hostile environments. This technology is inherently dual use and will enable enhancements and revolutions in area s such as health care, medical imaging, medical information transfer from knowledge center to remote location, manufacturing and process control, distributed corporate management, remote robotics control and education. Perhaps 65-70 percent of this effort is directly applicable to non-defense applications.

**c.** *Major Technical Challenges.* Advances in multiple disciplines are needed to achieve this forecast. Specifically, investments in mathematical optimization techniques, multi-level heterogeneous data bases, multi-level secure distributed computing, automated message/text/speech understanding, and high speed storage and retrieval will be required. Software for multimedia, network management and control, distributed data base management, and security must be developed and deployed. ATDs such as Real Time Support for Joint Power Projection, Distributed Air Operations Center , Combined Arms Command and Control, Multimedia Database Management Prototype and Survivable Multi Cluster Distributed Computing Environment are contributing to this sub-area. NSA-, ARPA-, and service-sponsored research in information security (INFOSEC) is also critical to realization of this technology. Some aspects of this area such as user-pull, mobile and highly distributed operation, bandwidth needs and degree of security are DoD-driven and require defense investment to be achieved.

**d.** *Performing Organization.* The major service organizations involved in execution are CECOM, NRL, NRaD, and Rome Laboratories. ARPA provides substantial funding to industry and universities in this sub-area DISA and DNA also active in this . Overall more than 70 percent of the funding in this sub-area supports industry or universities.

**e.** *Related Federal and Private Sector Efforts.* Many aspects of research in this area are addressed by the telecommunications and computer industry. The military is leveraging this work through active collaborations, participation in standards bodies and cooperative efforts.

**f.** *Funding*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Funding ($M): | 48 | 66 | 75 | 62 | 58 | 46 |

## 3. Decision Making

**a.** *Goals and Timeframes.* Battle space dominance will be accomplished by fielding advanced decision aiding systems for situation assessment, planning, targeting, combat identification, mission rehearsal and resource allocation. These decision systems will use the full range of information resources available and will support joint service and multi-national operations. This distributed decision architecture will readily accommodate rapid changes in tactical situations an d allow effective responses to unanticipated circumstances. Implementation will be based on COTS computing and interface platforms with transparent access to distributed and local information sources. Scenarios for demonstration and evaluation will evolve around crisis management planning and execution in order to emphasize time-critical decisions. Systems will be fully integrated at all levels of command including Theater CinCs, Joint Task Force organizations, Component Commands and mission execution units.

**b.** *Potential Payoffs and Transition Opportunities.* Operational users at all levels will be able to do their jobs more rapidly and accurately when these systems are in place. Fratricide will be reduced through better situational awareness. The biggest payoff will be the ability to respond to rapidly changing situations and effectively conduct multi-service and multi-national efforts planning cycle time is expected to be reduced by as much as a factor of five. The quality of plans and execution actions will also be substantially improved through the application of better information and the ability to consider more and better alternatives. C3 acquisition costs should be very favorably impacted by advances in prototyping methods and the use of COTS for implementation. Reduction in cost of 25 percent-40 percent should be feasible with 5 years. Commercial and non-defense payoffs include new methods for enroute air traffic control and new methods for industrial logistics, planning and management. An accurate estimate for the dual use potential of these often focused decision systems is difficult. Perhaps 40 percent-50 percent of the investment in underlying technolegy is likely to have utility in non-defense applications.

**c.** *Major Technical Challenges.* Key enablers in this area are methods for automated reasoning under uncertainty, automated arbitration , advanced optimization methods, and techniques for fusion of multi-mode/multi-sensor data. Advances in software requirements, specification, and prototyping techniques will also be necessary to field these complex systems in a cost-effective, timely manner. Advanced interface methods being developed under both the Human-systems Interface and Software research programs are important contributors to this C3 sub-area. Each of the services, DNA and ARPA are supporting decision aid efforts in exploratory development aimed at achieving the goals of this sub-area. These efforts are described more fully in the Joint Services Program Plan for C3. A number of ATDs support this sub-area: Real Time Support for Joint Power Projection, Combined Arms Command and Control, Common Ground Station, and Distributed Air Operations Center. The proposed ACTD Advanced Distributed Joint Planning addresses this sub-area.

**d.** *Performing Organizations.* The service organizations involved in most of these efforts are Rome Laboratories, NRaD, NRL, and CECOM. ARPO funds substantial effort in this sub-area.

**e.** *Related Federal and Private Sector Efforts.* Several Department of Energy Laboratories as well as the Federal Aviation Administration are conducting research applicable to this sub-area. Commercial interface, software and computing research products from the technological backbone for implementing these systems with many vendors contributing.

**f.** *Funding*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Funding ($M): | 50 | 86 | 100 | 87 | 68 | 47 |

### 4. Roadmap of Technology Goals

See Table 7-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

C3 implementation depends on advances described in the Computer sub-area for general purpose and high performance computers. The Software sub-area contributes significant research in general purpose software, languages, software engineering, environments, and computer networking. There is also strong interaction between C3 capability and advances in Sensors, Geophysical Operating Environments and Simulation research.

**Table 7-1. Roadmap of Technology Objectives for C3 S&T Goals**

| Sub-Area | By 1995 | By 2000 | By 2005 |
|---|---|---|---|
| Seamless Communication | • Integration of Voice/Data over low data rate (2400 baud) networks<br>• High throughput (155 megabit) dependable communication networks demonstrated<br>• 10x data rate increase for selected areas, mobile command posts | • Assured, anti-jam seamless communication<br>• Joint interoperable multi-media communications<br>• Adoption of commercial standards and protocols for most comms<br>• Multi-band, multi-mode wide band universal service programmable radios (40% logistics reduction, cost avoidance $500M) | • Seamless multi-media comms grid to any point in the battle space (bandwidth on demand) 622M B/S between land sites, >155 Mb/s to command posts, major ships >64 kb/sec to everyone)<br>• Incorporation of modeling and simulations for environmental impacts on comms systems<br>• Dynamic planning, monitoring and adaptation of communications networks |
| Information Management & Distribution | • Demonstration of distributed computing environment among services (>100 Mb/sec)<br>• Demonstration of near real-time Intel product on demand (<30 Min Deep Battle, <2 Min Close Battle) | • Access to multilevel secure distributed database<br>• Integrated, distributed semiautomated C2 at lower echelons<br>• Demonstration of seamless interoperable multilevel secure computing environment | • Demonstrate extended relational and object-oriented DBMS system<br>• Scalable, transparent mobile computing environment<br>• Total force synchronized battle management<br>• Scalable secure distributed databases |
| Decision Making | • Integrated multi-sensor and data fusion (Time from raw data to final product <30 min close battle, <2 hrs deep battle)<br>• Real time dissemination of time-critical information<br>• Demonstrate 2500 sortie air task order in <3 hrs, replanning options <10 min. | • Automated maintenance of consistent, timely tactical picture in distributed C3 system<br>• Automated situation assessment (30%-40% increase in loss exchange ratios)<br>• Demonstrate joint distributed collaborative planning and assessment tools (integrated targeting, weaponeering, tasking, mission planning in <10 min)<br>• Fratricide reduction through advanced situation awareness (>30% reduction in fratricide) | • Integrated all-level mission planning (2500 sortie air task order generated, reviewed, updated in 1 hr intervals)<br>• Universally interoperate decision aids incorporating speech, text, photo, video, map capability<br>• Direct sensor to shorter targeting in <1 min. |

# 8. COMPUTING AND SOFTWARE

## A. SCOPE

The Computing and Software Technology Area, by pushing the frontiers of advanced information technology beyond that normally achieved by the commercial sector alone, enables the creation of a broad range of advanced information processing systems of critical value in support of the missions of the Department of Defense (DoD). The Computing and Software area can be broadly grouped into six major subareas: system software, software and systems development, intelligent systems, user interface, computing systems and architecture, and networking. Funding for this area is $439.4M in FY 94; funding requested for FY 95 is $494.0M.

## B. VISION

Ensure that the DoD is provided with the most affordable, advanced, and robust information processing systems by effectively integrating software, hardware, and the required infrastructure connectivity to enable greater mission capability and interoperability in support of the warfighter.

## C. RATIONALE FOR INVESTMENT

Access to and exploitation of timely information is a key element of America's future warfighting and crisis management capabilities, as well as its national competitiveness. Joint and Allied forces need timely access to the most complete and accurate information, together with the ability to rapidly process and exploit it, to facilitate swift command and control decisions based on accurate, comprehensive knowledge of the current situation. Such capability, while greatly enhancing the autonomy and survivability of individual units, will quickly seize the advantage in any conflict, permitting early, decisive victory with minimal cost in assets and human life. Advanced computer software, computing systems, and communications technology is essential to supporting the top five Joint Staff future joint warfighting capabilities.

This technology area enables a wide range of defense-critical applications, such as new methods for design enabled by computational models in many science and engineering disciplines, advanced simulations for optimization and verification of weapons designs, and authentic, real-time engagement scenarios to be used in training at all levels. These have the potential to dramatically reduce cost while increasing quality. For example, the capabilities for high performance computing combined with advanced simulation and modeling techniques make possible the more effective investigation of diverse problems, including computational fluid dynamics (CFD) for modeling hypersonic flight or weather forecasting, technology computer-aided design (TCAD) for advanced microelectronics process development, and computational electromagnetics for improved stealth technologies.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. System Software

**a.** *Goals and Timeframes.* System software supports the development of the advanced software technologies needed to enable the development, introduction, and effective use of high performance information processing technologies. It is essential to maintain a stable software development environment and a robust collection of system services that can span several generations of computer hardware.

| | |
|---|---|
| 1995 | Development of advanced system services for security, real-time processing, fault tolerance, storage management, high performance input/output, and distributed operation. |
| 1997 | Experimental deployment of advanced system services demonstrating enhanced capabilities and improved performance, especially in the areas of improved security, privacy, and trust. |
| 2000 | Convergence of language run-time systems, compilation and interpretation technologies, and operating systems to provide an agile, adaptive, and responsive environment for the execution of application programs. |
| 2005 | Widespread usage of electronic commerce between government, business, and consumers, providing trusted and privacy-enhanced operation on behalf of users, and built on the technological foundation created by this activity. |

**b.** *Potential Payoffs and Transition Opportunities.* The existing commercial marketplace for system software remains focused on high performance workstations and personal computers. There is only a modest commercial effort aimed at developing the kinds of real-time, trusted, and very high performance computing services that are required by the DoD for its critical applications. In the past, the DoD has born the brunt of implementing custom applications on relatively untested operating systems and system services. In contrast, the thrust of this activity is to encourage commercial and DoD convergence, by developing a single system software technology (including compilers, run-time support systems, and applications libraries) spanning the highest performance computers, embedded computers, and commercial workstations. This activity seeks to cross-fertilize the special needs of the DoD community with the commercial technology base.

**c.** *Major Technical Challenges.* The development of dependable and secure information systems operating in a distributed and ubiquitous manner across a vast virtual network linking millions of computers. Development of the necessary support requires surmounting major challenges in operating systems and languages as well as the mechanisms for transacting significant parts of business electronically.

**d.** *Performing Organizations.* Performing organizations include numerous universities, industrial participants, defense contractors and cooperative groups. Government participants include national and service laboratories. Less than 3% of this effort is performed within DoD laboratories.

**e.** *Related Federal and Private Sector Efforts.* This technology area directly contributes to the Federal High Performance Computing and Communications (HPCC) program performed in collaboration with organizations such as the Department of Energy (DoE), the Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), National Science Foundation (NSF), NASA, and NIST. Major technology efforts are under way at industry/government sponsored consortia and the Technology Reinvestment Project (TRP) has targeted the area of information infrastructure interoperability testbeds as an opportunity for dual-use technology development and defense conversion.

**f.** *Funding.*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 68.5 | 78.1 | 81.8 | 87.5 | 91.2 | 91.4 |

## 2. Software and Systems Development

**a.** *Goals and Timeframes.* The goal of this subarea is to provide cost-effective tools, methodologies, and processes for developing, managing, and utilizing high quality software products and systems needed to enable modern military strategic and tactical capabilities that rely entirely or partially on automation. Mission critical systems depend increasingly on communication capabilities and automated applications systems that are software-driven at one or more levels in the total operational system. The fundamental capabilities of this subarea are essential factors in assuring the reliability, integration, and operational performance of any military system that incorporates electronically collected, stored, and processed information or includes embedded software.

| | |
|---|---|
| 1995 | Implementation of software metrics to establish baseline for measuring DoD software productivity in selected domains. |
| 1996 | Measurable software productivity improvements through the application of selected prototype tools and environments. |
| 1997 | Technology for measuring distributed, multi-processor system performance characteristics. |
| 2000 | Software engineering environment technologies for developing/adapting software specific to new architectures, such as high performance parallel applications and multi-functional, real-time distributed systems. |
| 2005 | Significant time, cost and quality improvements in providing software for information-based, globally distributed, real-time military applications. |

**b.** *Potential Payoffs.* The technology products for this subarea are intended to provide affordable, supportable mission-critical software systems, from the standpoints of both new systems and deployed or legacy systems. Thus, the technology will provide dollar savings that can be applied to enhancing existing weapons systems, keeping more existing systems in the inventory, building and adding new systems, buying more systems, or some combination of all of the above. Industry, which is presently automating at a faster pace than the DoD, is able to produce both larger and smaller quantities of goods at lower cost and to take advantage of new, more reliable, and powerful computer technology. This means that for new and custom automation, software must be produced and supported as in the DoD. Industry also has automated systems in the inventory that must be supported, modified, and reengineered.

**c.** *Major Technical Challenges.* The application of system software principles to the system process, supported through automation, is essential. It is important that the DoD have the ability to scale up research models that show promise and to assess and certify the quality of software components effectively within a system context.

**d.** *Performing Organizations.* Numerous Service laboratories are involved with this effort, along with several academic institutions. The Software Engineering Institute (SEI) is also working with the DoD to address the challenges of this subarea. The approximate split of funding is 10% in-house, and 90% to universities and industry.

**e.** *Related Federal and Private Sector Efforts.* The Services work very closely with the industrial sector when addressing the challenges of this subarea. The Software Productivity Consortium currently focuses on preparing those companies for software technology infusion and carrying out that infusion.

**f.** *Funding.*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 120.2 | 129.3 | 99.6 | 99.2 | 101.6 | 105.7 |

## 3. Intelligent Systems

**a.** *Goals and Timeframes.* Intelligent systems are needed to deal with the ever increasing complexity and speed of operations. Significant technological advances can be expected.

| | |
|---|---|
| 1996 | Demonstration of advanced tools for developing autonomous control logic for robotic systems and vehicles, increasing the reliability of such software. |
| 2000 | Advanced decision aids seamlessly integrating diverse kinds of reasoning methods and knowledge, and supporting extended high-level dialog in the human-computer interaction. |
| 2005 | New technology for distributed, collaborative planning, resource allocation and scheduling in virtual decision environments that are shared (multiple human and machine problem-solving agents), concurrent (multiple activities), informed (flexible knowledge exchange and timely migration), self-aware (consistent understanding of local and global context, and agile (responsive, reliable, and secure in a dynamic world). |

**b.** *Potential Payoffs and Transition Opportunities.* Quick reactions to impending threats and the ability to effectively use vast quantities of information are central to the core set of capabilities needed to increase the America's warfighting capabilities. Intelligent systems directly couple into quicker automated techniques for dealing with information and automated systems are able to scale up to deal with much greater quantities than possible with manual techniques.

**c.** *Major Technical Challenges.* The major challenge is the ability to properly abstract low-level signals, data, actions, and features to bring the reality of what is being done closer to the concepts that make sense to the consumer.

**d.** *Performing Organizations.* Performing organizations include numerous universities, industrial participants, including industry software and hardware, defense contractors and cooperative groups. Government participants include national and Service laboratories. Approximately 85% of the funding for this subarea is outsourced while 15% is allocated in-house.

**e.** *Related Federal and Private Sector Efforts.* Federal organizations studying the application of Intelligent Systems technology include NASA (expert systems and intelligent control), Central Intelligence Agency, NIST (intelligent manufacturing), Department of Transportation (land and air traffic control) and DoE (control of industrial processes). Many industrial firms, including major defense contractors, have internal research and development (IR&D) projects studying AI technology.

f. *Funding.*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 54.8 | 53.6 | 41.2 | 27.0 | 28.8 | 27.8 |

## 4. User Interface

**a.** *Goals and Timeframes.* There are three fundamental goals: (1) to provide improved human-computer interfaces (HCI) for weapon platforms, C3I systems, and associated support systems; (2) to create group-process support environments to aid humans in cooperative work; and (3) to develop HCI design support technologies to assist the HCI designer by automating portions of the design and evaluation process. Key to improving the human-computer interface is the enhancement of bi-directional human-computer transactions through the use of multi-sensory human-computer dialogs. A second major element is to provide intelligence in the interface so that it can adapt to the user, the application and the current situation.

| | |
|---|---|
| 1995 | Development of discrete user interface design tool kits. |
| 2000 | Initial application-independent task environments; early context-sensitive, agent-based interfaces; dedicated group decision support and intelligent information access tools; introductory collaborative engineering HCI support networks; and beginning HCI software designer's associate technologies. |
| 2005 | Comprehensive intelligent, adaptive user interfaces; comprehensive integrated cooperative environments; a fully integrated HCI collaborative design environment. |

**b.** *Potential Payoffs and Transition Opportunities.* The application of advanced single-user HCI technologies can enhance operator situation awareness, reduce operator workload, speed response to emergency situations, and improve the overall efficiency and adaptability of our weapon systems. It is reasonable to expect a 5% reduction in workload for current HCI tasking by the year 1995 and from 15 to 20% by 2000. Improved military applications including user interfaces will have application in any time-critical, high-stress commercial environment. Obvious applications include emergency response systems as seen in fire and police agencies, the civilian defense establishment, and hospital emergency rooms.

**c.** *Major Technical Challenges.* Whereas the single-user interface requires the development of software that can accurately model the human user, the multi-user interface requires the development of group-process tools that are intelligent enough to provide their respective without becoming bottlenecks.

**d.** *Performin. Organizations.* ARPA is a major participant in HCI development, along with several of the Service laboratories. Universities such as the University of Southern California and Stanford University are working with ARPA to conduct research in this subarea. About 80% of the ARPA research is spent in-house while 90% of the Service work is contracted out, mostly to universities.

**e.** *Related Federal and Private Sector Efforts.* Major efforts include NASA with work on human-computer interfaces for the space shuttle, the proposed space station, and ground-control workstations. Private sector participants pursuing HCI applications in the business domain include Apple Corporation, Microsoft, Sun Microsystems, International Business Machines (IBM), Xerox PARC, and American Telephone and Telegraph (AT&T). Universities having substantial programs in HCI include Carnegie Mellon University, the University of Southern California, Georgia Institute of Technology, and the Massachusetts Institute of Technology.

**f.** *Funding.*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 28.9 | 36.9 | 35.5 | 37.8 | 35.1 | 26.7 |

## 5. Computing Systems and Architecture

**a.** *Goals and Timeframes.* This subarea is concerned with the development, commercialization, and ultimate deployment of advanced computer systems and architectures offering very high performance, very low cost for a given level of performance, and very high performance in a small form factor, for a broad range of Defense and related industrial applications. These represent a wide ranging diversity of requirements, from very high computational performance to very high input/output processing, and every point in between. Computing Systems and Architecture technology includes scalable parallel architectures, highly available computing systems, storage and I/O architectures, enabling microelectronics technologies for high performance architectures, and novel computation structures and technologies that hold promise for radically new computer systems of the next century.

| | |
|---|---|
| 1994 | Demonstrate scalable performance on parallel machines of 100 gigaop per second performance, holding the promise of scaling to teraop per second performance within three years. |
| 1997 | Demonstrate the technology base for scalable high performance, capable of sustaining multi-teraop per second performance on large problems for the cost of today's large systems while also providing gigaops capability on the desktop. |
| 1999 | Increases of one or two orders of magnitude to reach scalable architectures with several thousand elements are expected. |
| 2000 | High performance computing technology in every day use on the National Information Infrastructure, enabling cost effective distributed product design, simulation-based planning and prediction, and computationally based prototyping of physical systems. |
| 2005 | Deployment of petaop (one thousand teraops) per second processing capability, based on new electronics, architecture, and software technologies. |

**b.** *Potential Payoffs and Transition Opportunities.* Computing Systems and Architecture is a fundamental enabling technology for enhancing America's warfighting capabilities. High performance computing technology, expressed in terms of computational, input/output, storage, and communications capabilities, make possible the collection and processing of huge quantities of information needed for dominance in the information age: command and control, training and mission preparation, and design and manufacturing of specialized military systems. High performance and highly available computer systems are having pervasive effect in the industrial, commercial, and financial sectors. Advanced computing systems are being used in such diverse fields as design of products like aircraft, automobiles, and pharmaceuticals; weather forecasting, climate modeling, toxic spill modeling, and seismic analysis for oil-field exploitation; financial engineering of new investment products; on-line transaction processing systems for banking and airline reservations applications; and information retrieval and "data mining" applications.

**c.** *Major Technical Challenges.* Many DoD applications exhibit unique computational requirements or physical constraints that are determined by the target installation site and thus preclude direct exploitation of general purpose scalable systems technology. The missions served by these applications, primarily in the signal processing domain, dictate deployment in the field either out of necessity or convenience. Where possible, DoD programs addressing these needs attempt to leverage the more commercially viable technologies through repackaging and hardening approaches, essentially creating embedded variations of the commercial systems with similar functionality. Some applications, however, require more computational power than can be feasibly provided by this approach under the given constraints.

**d.** *Performing Organizations.* Organizations participating in the research efforts include Intel, Cray Research, Honeywell, Hughes, Tera Computing, MassPar, Trusted Information Systems, Exa Corporation, and Myricom. Within the government NSF, DoE, and NSA are major participants. Mitre, Lincoln Lab, and the Oak Ridge National Laboratory are also participants. Less than 3% of this activity is performed with DoD laboratories.

**e.** *Related Federal and Private Sector Efforts.* Most of the major vendors of high performance computing systems, including the workstation manufacturers Hewlett-Packard, Sun Microsystems, and Silicon Graphics, are building on the scalable computing technology developed by this activity. Commercial interest in this technology is growing rapidly, with scalable computing technology being used in diverse commercial and industrial sectors, from automobile design to financial engineering to retailing/inventory management.

**f.** *Funding.*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 94.1 | 109.7 | 87.7 | 105.9 | 111.0 | 111.4 |

## 6. Networking

**a.** *Goals and Timeframes.* The goal of this subarea is to develop the technology base to enable a global, wide band, digital, data-oriented, multimedia-capable communications system. The technology will be developed to meet the military's strategic and tactical communications needs, supporting voice, data, and multimedia services, as well as services to enable high performance computation distributed across wide-area communications networks. This is a critical enabler for command and control, as well as a key technology for coupling dispersed high performance computing nodes into a scalable high performance computing system.

| | |
|---|---|
| 1995 | Demonstrate gigabit research networks and applications |
| 1996 | Demonstration of location-transparent access to data within wide-area distributed file systems. |
| 1997 | Deploy technology for secure and reliable network operation. |
| 1999 | Demonstrate cross-country 100 Gbit/second transmission technology. |
| 2000 | Demonstrate high performance distributed applications exploiting computations and resource sharing dispersed over wide area. |
| 2005 | Personal voice/image communication device for all sailors, soldiers and airmen. |

**b.** *Potential Payoffs and Transition Opportunities.* Future warfighting capabilities will depend critically on networking technology to provide the communications links in support of command and control applications. This technology is enabling access to specific critical information needed by all components of the defense community within the continental U.S. and rear-area command centers to the soldier on the battlefield. The Gigabit Networking Testbed activity, a cost-shared program among university researchers, computer and telecommunications industries, and Federal laboratories, has begun the exploration of high performance networks and related technologies and applications. The efforts to date have demonstrated the value of high speed networking, leading to the acceleration of such services to the commercial sector.

**c.** *Major Technical Challenges.* Technical issues being addressed include protocols for reliably maintaining connectivity as hosts relocate and techniques for maximizing the useful information transmitted over low bandwidth channels to sites with limited local storage under operational conditions that may result in intermittent loss of connectivity.

**d.** *Performing Organizations.* Industrial participants include Hybrid Networks, Bolt Beranek and Newman, Bellcore, Trusted Information Systems, SRI, Xerox Palo Alto Research Center, AT&T, TASC, Bell Atlantic, and TRW. Government participants include: NRL, NSF, DoE, NASA, and Lawrence Berkeley Laboratory. There are also many major University participants.

**e.** *Related Federal and Private Sector Efforts.* The ARPA HPCC program maintains a key program in high performance networking that forms an important part of the overall Federal HPCC program. The early utilization of pre-commercial gigabit services along with the Advanced Communications Technology Satellite (ACTS) and existing Internet infrastructure will provide the first demonstrations of DoD Global Grid capabilities. This program also builds on the results produced by ARPA programs producing advanced components and produces technologies that are used by ARPA programs needing High Performance Computing Systems. Less than 3% of this activity is performed using in-house resources.

**f.** *Funding.*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| 73.1 | 86.3 | 100.2 | 94.6 | 97.7 | 98.1 |

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

Computing and software technology has become an increasingly important component of military systems. The pervasive and critical nature of this technology is exposed in the types of improvements that are made in current military systems. Computing and software technology strongly feeds the areas of Command, Control and Communications, Electronic Warfare, Human System Interface, Manpower, Personnel & Training, Modeling and Simulation Technology. The research done in this subarea contributes significantly to the three major areas of emphasis within Command, Control, and Communications: seamless communications, information management and distribution, and decision making. This technology leads to improved capabilities in electronic warfare, such as increased jamming capabilities and better target recognition in A cluttered environment. This research also helps the Human System Interface area meet its goal of ensuring that fielded systems exploit the fullest potential of the warfighting team. Advances in the area of computing and software technology, especially in the area of artificial intelligence, will be transitioned into Manpower, Personnel, and Training systems. Finally, this technology plays a major role in all three subareas within Modeling and Simulation: architectures, environmental representations, and computer generated forces.

# 9. CONVENTIONAL WEAPONS

## A. SCOPE

This area develops conventional armaments technologies for all new and upgraded non-nuclear weapons. It includes efforts directed specifically toward non-nuclear munitions, their components, and launching systems, guns, bombs, guided missiles, projectiles, special warfare munitions, EOD devices, mortars, mines, countermine systems, torpedoes, and underwater weapons and their associated combat control. There are six major sub-areas: (1) Fuzing/Safe & Arm; (2) Guidance and Control; (3) Guns; (4) Countermine/Mines; (5) Warheads and Explosives; and (6) Weapon Lethality/Vulnerability. Funding for these subareas is $420M in FY94, with additional funds invested in system level advanced technology demonstrations.

## B. VISION

Develop and transition superior conventional weapons technology to enable the Services to maintain affordable, decisive military capability in execution of future missions.

## C. RATIONALE

The Conventional Weapons Technology Areas strongly supports needs of the services in both tactical and strategic mission areas. It responds to the services' operational needs for cost-effective system upgrades and next generation systems in support of the top five joint staff future warfighting capabilities. Performance objectives focus on projecting lethal force precisely against an enemy with minimal friendly casualties and collateral damage. Objectives address the need for affordable all-weather, day-night precision strike against projected critical mobile and fixed targets; all-weather defense against very low observable cruise missiles, aircraft and ballistic missiles; undersea superiority through highly lethal underwater attack capabilities against ASW/ASUW platforms at long range, in shallow water, increased speed, and with reduced weight and acoustic signature; an effective mine detection and neutralization capability to permit movement of forces ashore during amphibious assaults and during movement on land; gun/missile systems to support the development of advanced, lighter weight air/land combat vehicles; ship and vehicle self-defense systems; and lightweight high performance gun systems for artillery applications and naval surface fire support missions.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Fuzing/Safe & Arm

**a.** *Goals and Timeframes.* The major goals for "Fuzing/Safe & Arm" are to provide munitions with the ability to reliably and safely provide warhead initiation at the most optimum warhead location.

| | |
|---|---|
| 1997 | Demonstrate Guidance Integrated Fuzing (GIF) with neutral nets/sensors/high speed processors for 30% increase in PGM effectiveness and 25% decrease in weapon cost. |
| 2000 | Demonstrate fuze technology for 300% (27 feet reinforced concrete) improved weapon penetration capability and precise warhead detonation at a location that will yield maximum target damage. |

**b.** *Potential Payoffs and Transition Opportunities.* GIF will provide increased accuracy of warhead function by 20 to 30 percent and G&C/Fuzing will cost up to 20 pencent less, enabling more single shot kills, fewer sorties and/or quicker capture of air superiority and surface target neutralization. Transition opportunities include AMRAAM, Sidewinder, Patriot, and anti-surface missiles such as ARMs, JDAM, JSOW, and SSTD. Significant increases in penetration depths translate into at least 50 percent more hard targets that can be destroyed or disabled with single shots. Transitions will be possible for the GBU-27 (I-2000), GBU-28, and future weapons. For FY95, an estimated 15-20 percent of Fuzing/Safe & Arm investment can support dual-use technologies such as accelerometers for more efficient and reliable auto air bag release.

**c.** *Major Technical Challenges.* Challenges include all-weather, clutter ECM and chaff performance, high resolution target imaging, safe and affordable multi-mode warhead initiation and high-fidelity simulations for modeling system performance. For improved weapon penetration, challenges include cockpit selectable robust algorithms for deciphering target parameters and deciding on burst points in real-time, high-fidelity sensors and affordable, high-shock survival components.

**d.** *Performing Organizations.* Wright Laboratory, NAWC, NSWC, ARL, and ARDEC participate.

**e.** *Related Federal and Private Sector Efforts.* Include IR&D at Hughes, Ratheon, Motorola, Martin, Aerojet, DoE, SBIR efforts, ARPA, and DNA.

**f.** *Funding ($M)*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 | FY00 |
|---|---|---|---|---|---|---|
| 25 | 25 | 21 | 20 | 25 | 22 | 21 |

## 2. Guidance & Control (G&C)

**a.** *Goals and Timeframes.* The major goals for Guidance and Control are:

| | |
|---|---|
| 2000 | Reduce G&C component acquisition cost for Precision Guided Munitions (PGM) by 1/3. |
| 2005 | Develop autonomous all weather G&C technologies to increase probability of acquisition of targets in clutter and reduce the probability of a false alarm by 2. |
| 2005 | Reduce life cycle costs of PGM's by 1/3 with new hardware/software product/process technologies. |

**b.** *Potential Payoffs and Transition Opportunities.* Three to one reduction in number of PGMs required to defeat high-priority targets including time-critical mobile targets (SCUD launchers); decrease in false target acquisition and track will reduce weapons launched per desired target destroyed by four-to-one while reducing the number of sorties required to destroy a given target thereby reducing aircraft losses; high accuracy will severely reduce collateral damage and allow use of smaller warheads, future seekers will provide all-weather, completely autonomous operation with much longer standoff ranges against a broad target set in a very hostile, low observable environment and enable hit-to-kill intercept with aim point selection; and 40 percent increase in BMD interceptor effectiveness and reduced incidents of fratricide; Potential transitions: MLRS, TOW, JDAM, AMRAAM, and AIM-9X. Dual-use technologies such as the G&C High Speed Image Munition Processor can be used for real-time medical imaging and passive imaging millimeter wave can be used for airport security. For FY95, it is estimated that 15-20 percent of G&C investment will support dual-use technologies.

**c.** *Major Technical Challenges.* Challenges include design and manufacture of low-cost, high-performance G&C components; multi-mode/multi spectral seekers; high-speed signal and image processing; reliable aimpoint selection; jam-resistant data links; miniaturization and hardening of inertial measurement units.

**d.** *Performing Organizations.* Army, Navy, Air Force, DoE, NASA, ARPA, BMDO, and universities participate.

**e.** *Related Federal and Private Sector Efforts.* The NIH, FAA, FBI, EPA, and the National Forest Service participate in dual-use technologies.

**f.** *Funding (M)*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 | FY00 |
|---|---|---|---|---|---|---|
| 104 | 143 | 162 | 164 | 164 | 151 | 151 |

## 3. Guns (Conventional and Electric)

**a.** *Goals and Timeframes.* The goals are to develop technologies for small, medium, and large caliber guns, gun propellants, and fire control. The major goals are:

| | |
|---|---|
| 1995 | Demonstrate medium caliber Electromagnetic Gun for amphibious/land vehicles with .3MJ muzzle energy, 15 round salvo, and 300 rds/min. |
| 1996 | Demonstrate large caliber Electrothermal Chemical (ETC) Gun with 22MJ muzzle energy, 20 rds/min, and 50nm range for Naval Surface Fire Support. |
| 1997 | Demonstrate rotating machine with 5KJ/Kg power density for large caliber EM gun applications. |

**b.** *Potential Payoffs and Transition Opportunities.* ETC guns, together with guided projectiles will yield 3-4 times the range over conventional naval guns for naval surface fire support. Medium caliber EM guns will provide light-armor kill capability at twice the distance as a conventional fighting vehicle gun of the same caliber.

**c.** *Major Technical Challenges.* ETC technologies for compact, high efficient plasma ignitors at 22MJ muzzle energy, new high-energy-density propellant formulation, command guided, GPS/INS projectile, consistent rep rate and desirable life-cycle of pulse forming network; technologies for advanced medium caliber composite barrel with high-efficiency rail design, compact, affordable pulse and prime power system and ammunition handling technologies for high rate of fire.

**d.** *Performing Organizations.* Army, Navy, USMC, Air Force, DNA, and DoE participate.

**e.** *Related Federal and Private Sector Efforts.* In addition to DoE participation, SBIR efforts support the advanced medium caliber gun.

**f.** *Funding (M)*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 | FY00 |
|---|---|---|---|---|---|---|
| 88 | 78 | 85 | 91 | 88 | 93 | 88 |

## 4. Countermine/Mines

**a.** *Goals and Timeframes.* The major goals for countermine/mines are:

| | |
|---|---|
| Countermine | |
| 2000 | Demonstrate portable detection capability for buried non-metallic mines and demonstrate demining capability to clear afflicted areas rendering them safe for human use with 2-4 fold improvement in rate and cost of systems. Demonstrate Modeling & Simulation (M&S) capability to fully model mine/Countermine operational scenarios. |
| 2005 | Demonstrate reconnaissance of mines/minefields with high rate of search (50 square mile/hour & aerial standoff of 1000 feet). Demonstrate rapid clearing and 100% detection of mines in shallow water and on land. |
| Mines | |
| 1997 | Through the Intelligent Mine Field (IMF), remotely detect armored vehicles at several hundred meters and provide remote control of minefield. |

**b.** *Potential Payoffs and Transition Opportunities.* IMF will provide an affordable rapidly deployable system for early entry operations with 50 percent greater kill probability against armor vehicles. Rapid detection (2-4 times the current capability) of mine targets in shallow water is expected. A 10 to 1 reduction in required delivery assets is expected due to rapid, wide coverage of very shallow water mines. Potential transitions include Magic Lantern, Distributed Explosives systems, Coastal Battlefield Reconnaissance and Analysis System, and Remote Mine Hunting Systems. Dual-use opportunities include demining of afflicted areas.

**c.** *Major Technical Challenges.* Challenges include the ability of acoustic sensors to accurately track and locate targets, development of sensors and signal processing to differentiate mines from clutter in various soil and foliage types; echo ranging with covert waveforms and high frequency passive processing for Naval mines. Other challenges are acoustic/magnetic signature fidelity; automatic identification processing.

**d.** *Performing Organizations.* The Army Navy, USMC, and ARPA are participate.

**e.** *Related Federal and Private Sector Efforts.* DoE and EPA test range clearing and dump site remediation efforts require related technologies.

f. *Funding (M)*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 | FY00 |
|---|---|---|---|---|---|---|
| 81 | 105 | 110 | 97 | 104 | 103 | 103 |

## 5. Warheads & Explosives

a. *Goals and Timeframes.* The major goals are:

| | |
|---|---|
| 1999 | Triple the penetration (up to 27 feet of concrete) of hard targets to include counter proliferation of chemical, biological, and nuclear weapons. Demonstrate reliable hit-to-kill intercept. |
| 2000 | Reduce cost of insensitive explosives 3X & increase explosive energy by 50% for underwater applications. |
| 2005 | Reduce aimable/adaptable warhead size by 20% with 100% increase in lethality for air and surface target applications. |

b. *Potential Payoffs and Transition Opportunities.* Potential payoffs include aimable warheads in new/upgraded Navy missiles and the Army's Patriot and providing 100 percent increase in kill probability that will reduce requirements for missiles by 20-30 percent; adaptable warheads that are broadly lethal and resistant to modern countermeasures, reducing munitions inventory requirements by 30-40 percent; hit-to-kill kinetic energy warheads; and penetrating weapons that have 300 percent greater penetration capability, and will destroy 50 percent more C2 bunkers. Potential transitions include AIM-9X, Standard Missile, TOMAHAWK, AMRAAM, Patriot, SMART MORTAR, RAM, THAAD, and ERIMT.

c. *Major Technical Challenges.* Included are insensitive explosives without degraded performance; quantification of very high velocity penetrator performance; development of material property models for adaptable warhead design; hit-to-kill at very high closing speeds; and endoatmospheric hypervelocity environment.

d. *Performing Organizations.* Army, Navy, Air Force, BMDO, and DoE Laboratories participate.

e. *Related Federal and Private Sector Efforts.* DoE and also Aerojet, Alliant Tech Systems, Textron, and Thiokol IR&D efforts support DoD activities.

f. *Funding (M)*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 | FY00 |
|---|---|---|---|---|---|---|
| 85 | 103 | 105 | 119 | 122 | 123 | 123 |

## 6. Weapon Lethality/Vulnerability

a. *Goals and Timeframes.* The major goals for weapon L/V are to support the weapons community through the provision of M&S tools and databases:

| | |
|---|---|
| 1999 | Impact early in design phase of development. Realize savings of greater than 5:1. |
| 2005 | Decrease software preparation time by 5X, improve fidelity by 2X, & reduce life cycle cost of conventional weapons by 1/2. |

**b.** *Potential Payoffs and Transition Opportunities.* Application of L/V tools, methods and databases to include greater survivability and winning the war with fewer casualties through training; lethality enhancement of U.S. weapons, cost minimization for all weapons design, more timely response to PM's requests for analysis, and significant cost leveraging for T&E investments. Transition opportunities are many and include program support for all PMs/PEOs/SPOs/Acquisition Executives (e.g., JAST, AFAS, FSSVP, Torpedoes, Countermines, & Mines). For FY95, it is estimated that 15-20 percent of L/V investment will be in dual-use technologies.

**c.** *Major Technical Challenges.* "Damage Prediction": Developing statistically reliable predictions of target damage resulting from all sources and combinations of ballistic mechanisms (penetrator, fragments, blast, shock, fore, etc.): "Performance/Utility Prediction": Relating target damage states to diminished system performance; "L/V Software Environments": Developing reliable and extensible L/V computer environments to support expeditious code reconfigurations; "Geometric Tools": Developing advance geometric modeling environments which can support a broad class of L/V analyses with transitions to DMSO, the signature communities, and the private sector; "LV V&V Tools": Development of the tools, metrics, and data required for the Verification and Validation (V&V) of L/V methodologies.

**d.** *Performing Organizations.* All Services, BMDO, DNA, DoE participate.

**e.** *Related Federal and Private Sector Efforts.* Industry uses L/V products in support of government analysis at an estimated $40M/yr.

**f.** *Funding (M)*

| FY94 | FY95 | FY96 | FY97 | FY98 | FY99 | FY00 |
|---|---|---|---|---|---|---|
| 24 | 27 | 26 | 32 | 36 | 41 | 41 |

### 7. Roadmap of Technology Objectives

See Table 9-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

Conventional Weapons utilizes technologies that are developed in many of the other S&T areas, including materials, processes and structures; electronics; software; sensors; electronic warfare; manufacturing science and technology; and computers. In particular, there is a very close relationship to the science and technology area of sensors. This is because of the significant role that sensors play in the performance and affordability of the guidance and control systems in precision guided munitions.

## F. TECHNOLOGY TRANSFER AND DUAL USE

Approximately 15% of funding has dual-use application as shown in earlier paragraphs.

## Table 9-1. Roadmap of Technology Objectives for Conventional Weapons Roadmap

| Sub-Area | By 1995 | By 2000 | By 2005 | Sys Insertion Potential |
|---|---|---|---|---|
| 1. Fuzing/Safe & Arm (Guidance Integrated Fuzing) | | • Dual field of view optics for IR PGM's terminal guidance precise burst point control<br>• Reduce cost by 25% and increase accuracy with 30% increase in Ph. | • GIF insertion ready with 20% savings in G&C/Fuzing cost of current systems | • AMRAAM<br>• Sidewinder<br>• Patriot<br>• Future systems<br>• Standard Missile |
| 2. Guidance & Control<br>- (Seekers | | • Reduce life cycle cost of G&C systems by 1/3<br>• Demo Seekers & Signal Processing Technologies for autonomously acquiring & tracking targets in clutter, camouflage X2 in day/night & adverse weather conditions | • 3 to 1 reduction in PGM's to defeat high priority targets. | • AMRAAM, JSOWP3I, JDAM, ESSM, AIM9X, STANDARD BL4, SLAM, TOMAHAWK, TACAWS, TSSAM |
| 3. Guns (Conventional & Electric<br>- ETC Gun | • Demo 5" ETC gun (20 rds/min @ 50 nm) | • Demo gun-fired projectile with 3m CEP for ETC gun and pulse forming network with required life cycle & rep rate | • ETC gun ready for transition to Navy guns | • Naval guns (5 inch) |
| 4. Countermine/ Mines<br>- Countermine | • Demo a man-portable capability to detect metallic/non-metallic buried mines | • Develop Airborne detection for land and shallow water (>50 sq mile coverage per hour) | • Detect shallow water mines at 4 times the current rate | • Land Warrior<br>• ASTAMIDS<br>• Grizzly (Engr Obstacle Breaching Vehicle)<br>• Surface MCM Array |
| - Mine | | • Demo IMF that will remotely detect armored vehicles with 50% greater kill probability | | |
| 5. Warheads & Explosives<br>- Hard Target Penetration Warheads | | • Demonstrate target warheads that will increase depth of penetration to hard buried targets by a factor of 3 relative to the GBU-27 | • Demonstrate new explosives with 50% increase in frag/blast performance | • GBU-27 (I-2000)<br>• GBU-28<br>• Half-Length Heavyweight Torpedo |
| 6. Weapon Lethality | | • Reduce full scale testing of weapons by 25% through the use of new models and simulations | • Completed set of models for air/ ground systems will reduce acquisition life cycle costs conventional weapon systems by 1/2 | • PM's, PE's, SPO's, AE's (JAST, GAV, AFAS, TAD, FSSVP, SSTD) |

# 10. ELECTRONICS

## A. SCOPE

The Electronics Technology Area extends from basic research to applications at the subsystem level. Electronics includes the research, development, design, fabrication, and testing of electronic materials; electronic devices, including digital, analog, microwave, optoelectronic, vacuum and integrated circuits; and electronic modules, assemblies, and subsystems. The Electronics Technology Area is organized into five major sub-areas: RF Components, Electro-Optics, Microelectronics, Electronic Materials, and Electronic Models and Subsystems. Funding for this area is $771 million in FY 1994.

## B. VISION

Maintain U.S. world leadership, economic competitiveness, and improved military readiness through superior electronics technology.

## C. RATIONALE

### 1. Military Capabilities Addressed

An adaptive, and innovative program in electronics science and technology is essential to implement the U.S. military defense strategy of (1) electronic force multiplication with a minimum number of platforms and personnel and (2) avoidance of technological surprise on the battlefield. Electronic device technologies enable all five of the joint staff's Future Joint Warfighting Capabilities and support seven of the other key technology areas. The requirements of military systems such as EW, radar, and C4I translate into component requirements, which include performance, weight, size, radiation hardness, reliability interoperability, and maintainability. Furthermore, electronics represents over 40% of the procurement cost of many military and commercial systems. The ability to field weapons systems that meet requirements, that can be upgraded to meet future operational requirements, and that have affordable life-cycle costs, depends on our ability to adapt or exploit commercial electronic devices or develop new technologies.

### 2. Technical Forecast

Electronics has been, and continues to be, one of the fastest moving technology areas relevant to modern war fighting and conflict prevention. The present 30% per year increase in electronic subsystem performance can be expected to continue well into the next century as silicon-based ICs with feature sizes to 0.18 micrometer come into production. Impressive advances in fabrication, design technologies, and associated tools will be coupled with new electronic material systems to produce entirely new generations of sensors, sources, actuators, and display technologies that provide unprecedented capabilities in land-sea-air warfare.

Advanced computational tools, using advances in electronic hardware, will enable the rapid simulation and design of affordable future weapons systems with first-pass hardware success assured. The development of ultracompact, highly efficient microwave and millimeter-wave power modules will enable new concepts in unmanned airborne vehicle (UAV) radars, electronic decoys, and phased-array systems. Advances at millimeter waves will dramatically improve our ability to defend against stealth platforms, provide platform self-protection, and improve weapon accuracy in land, sea, and air encounters. Developments in electro-optics will significantly increase the speed with which information can be accessed and transmitted, thereby greatly enhancing the seamless communication required for information management and distribution.

### 3. Potential Payoffs

U.S. forces will have all-weather day/night precision weapons, the information and control to deliver payloads effectively with low collateral damage, and superior real-time knowledge of our adversaries' capabilities and intentions while denying them this intelligence about our own. Advanced information electronics capabilities will also increase dramatically and shift to forward-deployed units. This will permit the rapid collection, analysis, and dissemination of strategic, tactical, and logistical information, providing commanders with a common view of the tactical situation and increasing the tempo and synchronization of joint warfighting operations. It will also reduce personnel requirements for staffs and noncombat forces. Advanced electronics technologies will also reduce operating and support costs by a factor of 10 and extend the life and interoperability of existing fielded systems. Modernization of the force over the next decade will occur primarily through low-cost system upgrades, resulting in revolutionary performance improvements and capabilities.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. RF Components

**a.** *Goals and Timeframes.* The objective of the RF Components Sub-area is to develop and transition superior yet affordable technology to military systems for the generation, control, radiation, amplification, modulation, transmission, reception, and processing of microwave and millimeter wave signals. Major goals for this sub-area are:

| RF Components | | |
|---|---|---|
| 1995 | Solid State | 5x cost reduction in multifunction, millimeter-wave (MMW) ICs, relative to present capabilities. |
| | | 2x cost reduction in "brick style" T/R modules, relative to present capabilities. |
| | Vacuum Electronics | 4x volume reduction in integrated solid state/vacuum electronic power modules (MPMs), relative to present capabilities. |
| 2000 | Solid State | 10x volume reduction in mixed mode (MW/digital/E-O) device structures, relative to present capabilities. |
| | | High-density microwave "tile" MCMs (5x volume reduction, 10x cost reduction, relative to present capabilities). |
| | Vacuum Electronics | 5x cost reduction in MMW power modules (MPMs), relative to present capabilities. |
| 2005 | Solid State | 10x cost reduction in multifunction MW/MMW ICs, relative to present capabilities. |
| | | 10x cost reduction in multifunction phased-array antenna, relative to present capabilities. |
| | Vacuum Electronics | 5x output power improvement, 10x cost reduction for vacuum electronics transmitters. Affordable terahertz devices. |

**b.** *Potential Payoffs and Transition Opportunities.* Electronics S&T will lead to low-power, personal, wireless, hand-held communication devices for real-time C4I; aircraft shared aperture (e.g., ASAP, JAST) miniature transmit/receive (T/R) modules for Global Decisive combat; small, high-power, efficient sources and amplifiers for smart weapons, UAVs, and surveillance sensors; T/R modules for missile defense sensors; and small, high-power, efficient sources and amplifiers for decoys.

**c.** *Major Technical Challenges.* Among the technical challenges in the RF Components Sub-area is the achievement of high power; high efficiency; large dynamic range; wide bandwidth; flexible manufacture; modeling and simulation enabling first-pass success of components, modules, and arrays; and process integration necessary for high-yield, low-cost multifunctional ICs and vacuum tubes. All these attributes must be provided at an affordable cost.

**d.** *Performing Organizations.* Service Labs - 19%; Industry - 68%; Academia - 11%; National Labs (DoE) - 1%; FFRDC/FCRC - 1%

**e.** *Related Federal and Private Sector Efforts.* Related efforts include commercial activities in Direct Broadcast Satellite and automatic collision avoidance radar.

**f.** *Funding.*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| | 143 | 125 | 132 | 130 | 132 | 128 |

## 2. Electro-Optics Technology

**a.** *Goals and Timeframes.* The objective of the Electro-Optics Sub-area is to develop critical electro-optic components such as lasers, focal plane arrays, amplifiers, detectors, guided transmission media, and displays for application in military tactical and strategic systems. Major goals for this sub-area are:

| Electro-Optics | | |
|---|---|---|
| 1995 | FPAs | 100x cost reduction (to $2000) in LWIR IRFPAs. |
| | | 100x clutter rejection improvement in dual-band HgCdTe IRFPAs. |
| | Displays | True, full-color, flat-panel 1000-lines/in. head-mounted display. |
| | Photonics/ F.O. | 10 Gbit/sec data rate fiber optic interconnects. |
| 2000 | FPAs | Manufacturable uncooled IR arrays. |
| | | Multicolor staring IRFPA with "on focal plane" adaptive and rad-hard readout and processing circuitry. |
| | Displays | Megapixel full-color high-resolution smart displays in a range of sizes. |
| | Photonics/ F.O. | Monolithic optical transceiver chips for interconnections. |
| 2005 | FPAs | Flexible IRFPA manufacturing. |
| | | Integrated multispectral smart sensing unit cells. |
| | Displays | 3-D stereoscopic displays. |
| | Photonics/ F.O. | 100 GB/sec soliton lengths and networks. |

**b.** *Potential Payoffs and Transition Opportunities.* Lightweight display technology will provide the human interface to information that results in improved decision making in time-constrained environments. Use of multicolor and multidomain smart sensor elements will provide for near-perfect target recognition capability in all weather environments. Use of flexible manufacturing techniques will provide cost-effective optical modules for systems such as the E2C and AGEGIS.

**c.** *Major Technical Challenges.* Technical challenges include development of more reliable, higher efficiency, higher frequency solid-state lasers; cost-effective modules for information systems and IRFPLAs; receive architecture for optically- fed phased- array radar; and new flat-panel display technologies.

**d.** *Performing Organizations.* Service Labs - 13%; Industry - 70%; Academia - 15%; National Labs (DoE) - 1%; FFRDC/FCRC - 1%

**e.** *Related Federal and Private Sector Efforts.* Related efforts include commercial efforts in telecommunications.

**f.** *Funding.*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| | 203 | 191 | 203 | 203 | 194 | 176 |

## 3. Microelectronics Technology

**a.** *Goals and Timeframes.* The objectives of the Microelectronics Sub-area are to develop manufacturing processes and tools to ensure domestic manufacturing leadership, CAE/CAM/CIM to allow rapid and cost effective military utilization of state-of-the-art technologies, and promising high risk device/circuit technologies. Major goals for this sub-area are:

| Microelectronics | | |
|---|---|---|
| 1995 | Devices and Processes | 500nm TFSOS, SiGe LSI, 350C SiC SSI submicron rad-hard memories, and 4-16 bit high-speed ADC's. |
| | CAD | Chip/subsystem modeled in VHDL and synthesized for 100K gate circuits. |
| | Lithography | 0.35nm production; 0.18µm prototype subsystems, components, masks. |
| | SEMATECH | Key equipment and unit processes for 0.25µm. |
| 2000 | Devices and Processes | 200nm TFSOS, SiGe VLSI, 500C SiC MSI, 0.35-micron rad-tolerant dual-use microelectronics, and X-band ADC's. |
| | CAD | Concurrent design through virtual prototyping for affordable subsystem upgrades. |
| | Lithography | 0.18µm production; 0.12µm critical components and process prototyping. |
| | SEMATECH | Robust equipment scalable to 0.12µm; flex. mfg. with embedded intelligence. |
| 2005 | Devices and Processes | 100nm TFSOS, SiGe, ULSI , 500C SiC VLSI, 0.15-micron low-power rad-tolerant microelectronics, and III-V synthesizer. |
| | CAD | Integrated digital, analog, microwave, and photonic design, modeling, simulation, test. |
| | Lithography | 0.12µm leading-edge production. |
| | SEMATECH | Process synthesis for real-time product design mfg.; 10x development time and NRE reduction. |

**b.** *Potential Payoffs and Transition Opportunities.* Military utilization of devices and circuits with feature sizes 0.5 μm and below will enable order-of-magnitude advances in sensors, information, and electronic warfare signal processing systems. Low-power, radiation-tolerant microelectronics are critical for military and commercial satellites. Realization of high-level design methodologies will allow for affordable and rapid prototyping of new systems and technology upgrades to fielded systems with reduced life-cycle costs.

**c.** *Major Technical Challenges.* Among the technical challenges are creating new wide-bandgap semiconductor devices for high-temperature electronics and for low-leakage, high-breakdown, highly linear power devices; high-quality, radiation-hardened silicon-on-insulator devices; deep submicron mixed-signal operation of microelectronics with on-chip RF and electro-optic components; very low power circuits; and affordable ULSI submicron semiconductor processing. Another major challenge is the development of advanced, low-cost battery power technology.

**d.** *Performing Organizations.* Service Labs - 10%; Industry - 70%; Academia - 17%; National Labs (DoE) - 2%; FFRDC/FCRC - 1%

**e.** *Related Federal and Private Sector Efforts.* Related efforts include metrology at NIST and equipment development at Sandia Labs.

**f.** *Funding.*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| | 281 | 254 | 257 | 269 | 268 | 269 |

## 4. Electronic Materials

**a.** *Goals and Timeframes.* The objective of the Electronic Materials Sub-area are to create and develop new and commercially unavailable electronic materials enabling operation in previously unused portions of the spectrum, at much higher temperatures and speed, and with much greater power densities, robustness, and resistance to damage. Major goals for this sub-area are:

| Electro Materials | | |
|---|---|---|
| 1995 | SemiMat/ Proc | Demonstrate SiC very small scale integration. |
| | | Demonstrate 50% reduction in iron content required for semi-insulating InP substrates. |
| | Emit/Detect | Demonstrate vertical zone melting growth of single crystal GaSb (for HgCdTe substrates). |
| | | Develop OMCVD techniques for GaN growth. |
| 2000 | Emit/Detect | Demonstrate GaN-based heteroepitxy lasers. |
| | | Transfer bulk MLEK InP process, for 50% reduction in cost of wafers. |
| | | Produce InGaAs/InA1As heterojunction devices on 4 inch InP substrates. |
| | | Demonstrate high yield growth of single crystal CdTe (for HgCdTe substrates). |
| | | Demonstrate materials for uncooled pyroelectric focal plane arrays. |
| 2005 | SemiMat/ Proc | Demonstrate materials for microwave components with>300°C operation. |
| | | Develop InP-based materials for MSI millimeter-wave components and optoelectronic integrated circuits. |
| | Emit/Detect | Develop materials systems for multi-wavelength blue and ultraviolet laser sources. |
| | | Demonstrate long wavelength arrays based on perfected HgCdTe and III-V superlattices. |

**b.** *Potential Payoffs and Transition Opportunities.* Modern electronic and electro-optical components are inextricably linked to materials growth and processing. Materials advancements will enable revolutionary device improvements for communications and computing, increased power and efficiency at higher frequencies, greater packing density for nonvolatile data storage, and increased reliability for focal plane arrays, and will result in higher yields and lower manufacturing costs. Exploitation of these materials enables air, land, and sea superiority.

**c.** *Major Technical Challenges.* One of the most challenging problems facing new solid-state heterostructure device materials is understanding the relationships between various growth sequences and device/circuit performance, and the reproducible control of dissimilar materials at their interfaces. Other major challenges include transition of laboratory process methods to affordable manufacturing lines; control of impurity doping in heteroepitaxial materials and scaleup of substrate wafer size for low-defect concentration, high-purity materials.

**d.** *Performing Organizations.* Service Labs - 21%; Industry - 40%, Academia - 37%; National Labs (DoE) - 1%; FFRDC/FCRC -1%

**e.** *Related Federal and Private Sector Efforts.* Related efforts and coordinated by the NSTC's Material's Subcommittee.

**f.** *Funding.*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| | 31 | 24 | 24 | 24 | 24 | 24 |

## 5. Electronic Modules and Subsystems

**a.** *Goals and Timeframes.* The objective of the Electronic Modules and Subsystems Sub-area is to develop multi-chip modules (MCMs), microelectromechanical systems (MEMS), and electronic subsystems. Major goals for this sub-area are:

| Electronic Modules and Subsystems | | |
|---|---|---|
| 1995 | MCM | MCM design cycle and cost comparable to ASICs. MCMs used for highest performance and density applications. |
| | MEMS | 10x increase in the integration of sense and actuation components with on-chip electronics. |
| | RASSP | 2x reduction in prototyping time. |
| 2000 | MCM | MCM technology is lowest cost packaging approach for many applications. Billion dollar worldwide network. |
| | MEMS | MEMS devices embedded in high-end commercial and military systems. $10B worldwide market. |
| | RASSP | 4x reduction in concept-to-fielding time for digital signal processors. |
| 2005 | MCM | Majority of new leading-edge systems implemented in MCM technology. |
| | MEMS | MEMS technology enables ubiquitous, highly functional, affordable, smart systems. |
| | RASSP | Robust integrated commercial military industrial base. |

**b.** *Potential Payoffs and Transition Opportunities.* Electronic subsystems are critical to the development of revolutionary, low-cost, lightweight, portable, and highly capable systems that collect knowledge of the enemy and communicate that information to all forces in near-real time. They will increase the affordability and functionality of smart systems and will revolutionize the way in which the military perceives and controls the battlefield. These devices will significantly benefit a broad spectrum of military systems (e.g., surveillance, targeting, wireless communications, missiles, aircraft, ships, submarines, and space vehicles) at all levels from the individual warfighter to the National Command Authority. Examples of new products possible from these technologies include wristwatch GPS receivers, autonomous weapons, hand-held chemical and biological detectors, wide-area battlefield sensor networks, and predictive maintenance systems.

**c.** *Major Technical Challenges.* Major challenges include developing tests for known good die; hermetic coatings for reliability without the traditional hermetic package; design tools; DoD low-volume access to domestic commercial production facilities; quick-turnaround, chip-to-chip interconnect; and strengthening the commercial-military industrial base.

**d.** *Performing Organizations.* Service Labs - 6%; Industry - 77%, Academia - 15%; National Labs (DoE) - 1%; FFRDC/FCRC -1%

**e.** *Related Federal and Private Sector Efforts.* Related efforts include LLNL work on MEMS and Sandia work on MCMs.

**f.** *Funding.*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| | 113 | 149 | 156 | 111 | 195 | 188 |

## 6. Roadmap of Technology Objectives

See Table 10-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

Because the Electronics Technology Area is enabling and pervasive throughout military systems, it directly effects multiple technology areas, including Command, Control and Communications (Area 5), Computers (Area 6), Electronic Warfare (Area 9a), Human Systems Interface (Area 12), Manpower, Personnel, and Training (Area 13), and Sensors (Area 16). The Electronics Technology Area is dependent on Materials, Processes, and Structures (Area 14), and is closely intertwined with Software (Area 18), Manufacturing Science & Technology (Area 19), and Simulation and Modeling Technology (Area 20).

## Table 10-1. Roadmap of Technology Objectives for RF Components and Electro-Optics

| Sub-Area | By 1995 | By 2000 | By 2005 | Applications |
|---|---|---|---|---|
| **RF Components** | | | | |
| Solid State | 5x cost reduction in multifunction, millimeter-wave (MMW) ICs, relative to present | 10x volume reduction in mixed mode (MW/digital/ E-O) device structures, relative to present capabilities. | 10x cost reduction in multifunction MW/MM ICs, relative to present capabilities. | Multifunction (multi-spectral) sensors for radar, EW, comm, navigation; low-cost expendables; active arrays. |
| | 2x cost reduction in "brick style" T/R modules, relative to present capabilities. | High-density microwave "tile" MCMs (5x volume reduction, 10x cost reduction, relative to present capabilities). | 10x cost reduction in multi-function phased-array antenna, relative to present capabilities. | Radar, EW, navigation, communications, IFF. |
| Vacuum Electronics | 4X volume reduction in integrated solid-state/vacuum electronic power modules (MPMs), relative to present capabilities. | 5x cost reduction in MMW power modules (MPMs), relative to present capabilities. | 5x output power improvement, 10x cost reduction for vacuum electronics transmitters. Affordable terahertz devices. | Communications, radar, EW, low-cost electronic countermeasures. |
| **Electro-Optics** | | | | |
| Focal Plane Arrays (FPAs) | 100x cost reduction (to $2000) in LWIR IRFPAs. | Manufacturable uncooled IR arrays. | Flexible IRFPA manufacturing. | Affordable, muti-function IR systems and personal night vision devices. |
| | 100x clutter rejection improvement in dual-band HgCdTe IRFPA. | Multicolor starting IRFPA with "on focal plane" adaptive and rad-hard readout and processing circuitry. | Integrated multi-spectral smart sensing unit cells. | Clutter rejecting seekers, space interceptors, automatic target recognition. |
| Displays Components | True, full-color, flat-panel 1000-lines/in. head-mounted display. | Megapixel full-color high-resolution smart displays in a range of sizes. | 3D stereoscopic displays. | Commander/warrior situation awareness (aircraft, ship, battlefield). |
| Photonics/Fiber Optic Devices | 10-Gbit data rate fiber optic interconnects; integrated optical sensors (stress/ strain).<br>Multi-wavelength arrays.<br>Blue-green light emitters.<br>Smart pixel arrays.<br>4 Gbyte optical disk storage for 10 GHz data processors. | Monolithic optical transceiver chips for interconnec-tions.<br>Solition laser sources.<br>Fiber sensor smart structures.<br>Blue lasers for dense optical storage.<br>IR transmitting fiber for chemical sensing.<br>Fiber-based EW systems.<br>10 Gbyte optical disk storage. | 100 GB/sec soliton lengths and networks.<br>IR fiber-coupled FPAs.<br>Optically controlled phased array radars.<br>Free-space layer-to-layer optical interconnects of 3-D integrated monolithic processors. | Ultra-high-speed interconnects, multi-spectral, multifunc-tion sensor.<br>Fused multispectral sensor (image processing and visualization). |

Table 10-2. Roadmap of Technology Objectives for Microelectronics and Electronic Materials

| Sub-Area | By 1995 | By 2000 | By 2005 | Applications |
|---|---|---|---|---|
| **Microelectronics** | | | | |
| Devices and Processing | 500nm TFSOS, SiGe LSI, 350C SiC SSI, submicron rad-hard memories, and 4-16bit high-speed ADC's. | 200nm TFSOS, SiGe VLSI, 500C SiC MSI, 0.35-micron rad-tolerant dual-use microelectronics, and X-Band ADC's. | 100nm TFSOS, SiGe ULSI, 500C SiC VLSI, 0.15-micron low-power rad-tolerant microelectronics, and III-V synthesizer. | ASW receiver, radar and EW, AIEWS, AEGIS, Trident, F22, space systems, ALARM, MILSTAR, GPS, missile upgrades. |
| CAD | Chip/subsystem modeled in VHDL and synthesized for 100K gate circuits. | Concurrent design through virtual prototyping for affordable subsystem upgrades. | Integrated digital, analog, microwave, and photonic design, modeling, simulation, test. | Vast majority of fielded systems upgrade, developmental systems and ATDs, including RASSP and ASEM. |
| Advanced Lithography | 0.35 mm production; 0.18 mm prototype subsystems, components, masks. | 0.18 mm production; 0.12 mm critical components and process prototyping. | 0.12 mm leading-edge production. | Microelectric manufacturing. |
| Microelectronics Manufacturing (SEMATECH) | Key equipment and unit processes for 0.25 mm | Robust equipment scalable to 0.12 mm; flex. mfg. with embedded intelligence. | Process synthesis for real-time product design mfg.; 10x development time and NRE reduction. | |
| **Electronic Materials** | | | | |
| Semi-Conductor Materials and Processes | Demonstrate SiC very small scale integration. Demonstrate 50% reduction in iron content of semi-insulating InP. | Produce InGaAs/InAlAs heterojunction devices on 4 inch InP substrates. | Demonstrate materials for microwave electronics components with >300°C operation. Develop InP-based materials for MSI MMW components and optoelectronic ICs. | Extreme environment operation of power sources and microwave components. Reduced cooling requirements for avionics. |
| Emitters and Detectors | Develop OMCVD techniques for GaN growth. Demonstrate vertical zone melting growth of single crystal GaSb. | Transfer MLEK bulk InP process, for 50% reduction in cost of wafers. Demonstrate GaN-based heteroepitaxy lasers. Demonstrate high yield growth of single crystal CdTe for HgCdTe substrates. Demonstrate materials for uncooled pryroelectric focal plane array. | Develop materials systems for multi-wave length blue laser sources. Demonstrate long wavelength arrays based on perfected HgCdTe and III-V superlattices. | Integrated circuit millimeter-wave modulated optical communications and controls. High density optical storage. High intensity blue displays. UV source for phosphor excitation. Infrared surveillance systems. Night vision and all-weather vision. |

**Table 10-3. Roadmap of Technology Objectives for Electronic Modules and Subsystems**

| Sub-Area | By 1995 | By 2000 | By 2005 | Applications |
|---|---|---|---|---|
| **Electronic Modules and Subsystems** | | | | |
| MCM | MCM design cycle and cost comparable to ASICs. MCMs used for highest performance and density applications | MCM technology is lowest cost packaging approach for many applications. Billion dollar worldwide [illegible] | Majority of new leading edge systems implemented in MCM technology | Automotive, computers, consumer electronics, avionics |
| MEMS | 10x increase in the integration of sense and actuate components with on-chip electronics | MEMS devices embedded in high end commercial and military systems. $10B worldwide market | MEMS technology enables ubiquitous highly functional affordable smart systems | Fluid regulation and control, biomedical [illegible] applications, inertial sensors, optical switches, mass data storage |
| RASSP | 2x reduction in prototyping time | 4x reduction in concept to fielding time for digital signal processors | Robust integrated commercial/military industrial base | Signal Processing, IC Design |

# 11a. ELECTRONIC WARFARE

## A. SCOPE

The Science and Technology Program in the Electronic Warfare (EW) area develops technology for the offensive and defensive application of EW. It includes efforts to intercept, counter, and exploit the complex threat weapons spanning the entire electromagnetic spectrum, including radio frequency (RF), infrared (IR), rlectro-optic (EO), ultraviolet (UV) and multispectral/multimode sensors. These technologies are applied within three subareas: (1) Force Protection; (2) Offensive EW; and (3) EW Support Functions. Funding for the S&T Program in EW is $127M in FY94 and $128M in FY95.

## B. VISION

United States dominance of the electromagnetic spectrum based on the ability to use and deny its use by others at will.

## C. RATIONALE

The Electronic Warfare technology area is responsive to the services needs and directly supports the JCS' Top Five Future Joint Warfighting Capabilities. Flexible, robust sensor systems have significantly increased the services' overall warfighting capability and have become a true force multiplier. As was demonstrated during Operation Desert Storm, the use of precision guided munitions and advanced targeting systems greatly increased the ability of the Coalition Forces to eliminate hardened and heavily defended positions with extreme effectiveness and with minimal risk to aircrews. Performance objectives for Electronic Warfare focus on developing the capability to counter the extensive RF missile threat; to detect, identify and jam modern threat radar systems to defend against advanced IR missiles using imaging and pseudo-imaging seekers; to counter the coherent and millimeter wave (MMW) fire control/surveillance sensors. The S&T Program in EW makes extensive use of Electronic Countermeasures (ECM) effectiveness assessments, and simulation and modeling.

Over 90% of recent aircraft losses have been due to IR surface-to-air missiles (SAMs). Additionally, anti-ship cruise missiles are being developed with pseudo-imaging and imaging seekers which are immune to the current inventory of flares and jammers used for self protection. The threat to ground vehicles from top-attack munitions using IR sensor technology is increasing. Significant improvements can be made in providing IR countermeasures for ships, air and ground platforms with the development of advanced threat warning, recognition, expendables and on-board systems. In the near term, program efforts will concentrate on sensor and counterı :asures technology for the detection and jamming of top attack munitions and air defense missiles as well as laser designated/beam riding missiles. This technology supports the Hit Avoidance Advanced Technology Demonstration (ATD) and the multi-spectral countermeasures technology demonstrations with improved infrared flares and distributed decoy concepts. A series of field tests and demonstrations in the near (FY94-96), mid (FY97-00) and far (FY00-10) term will demonstrate technology solutions to the IR missiles threat. These tests will include laser and high power microwave technologies as an alternative to current techniques.

Advances in microwave technology allow smaller, more effective, and less expensive receiver systems, which can be used in ground, air, and naval applications. As threat sensors and weapons become more diverse and sophisticated, there is a corresponding need for radar warning receivers (RWR), electronic support measures (ESM), and countermeasures systems that can perform their function without detailed a priori information on the signals that they must recognize and act upon. Processing techniques are being developed to recognize and analyze certain signals in dense environments and generate articulate jamming waveforms. Knowledge-based systems using artificial intelligence and adaptive parallel distributed processing can provide "smart" software control to optimize performance in a dense, complex signal environment. Specific emitter identification (SEI), Unintentional Modulation on Pulse (UMOP) processing, and monolithic microwave integrated circuits (MMIC) are being incorporated in small, lightweight, affordable receivers with a 28,000% reduction in weight and a 3,600% reduction in cost.

The inventory of self-protection jammer systems for aircraft (i.e., ALQ-126B, ALQ-135, ALQ-136A, ALQ-144A, ALQ-184) has been upgraded through the insertion of advanced jamming techniques. Progress in Digital RF Memory (DRFM) technology (DRFM on a chip) is the basis for advanced, low cost, channelized ECM exciter subsystems. Improvements in expendables technology resulted in flares which respond to IR missile seekers employing discrimination logic processing and other Infrared Counter Countermeasures (IRCCM) capability. Although dual use opportunities are limited within the EW technology area, small, light weight and affordable analog and digital receivers can be developed for general purpose, home entertainment and satellite use. Wideband IR fiber optic cable used for laser based countermeasures has medical and surgical applications; brushless, electronically controlled direct current motors used for decoys can be used in home appliances and automotive devices.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Force Protection

Force protection includes those EW systems that detect, identify, and analyze weapons system signatures, and counter these systems with jamming and deceptive techniques, and passive and active decoys and expendable decoys.

**a.** *Goals and Timeframes*

- FY94-95: Live fire Directed Infrared Countermeasures (DIRCM) tests for rotary wing aircraft, including non-coherent IRCM techniques against con-scan seekers; and multispectral expendables and UV missile warning for tactical aircraft self-protection.

- FY96: Demonstrate next-generation EW digital receiver using a common tri-service modules based on ARPA Millennium development.

- FY95-98: Conduct at-sea captive carry tests of ship self-defense against pseudo-imaging IR seekers using a laser IRCM system.

- FY01: Demonstrate protection of tactical aircraft against imaging seekers through robust closed-loop IRCM, destructive lasers, and High Power Microwave Signals.

**b.** *Potential Payoffs and Transition Opportunities.* Improved Aircraft Survivability: Over 90% of recent aircraft losses have been caused by surface to air missiles using IR seeker technology. These missiles use pseudo-imaging techniques to reduce vulnerability to expendable decoys (flares) and non-coherent jammer technologies. Within the next five years, imaging seekers will be deployed by several countries. Proposed demonstrations under the Tri-Service IRCM Program Plan will quantify the effectiveness of jamming techniques and improved flares against pseudo-imaging seekers.

Advanced radars associated with air defense and SAM missiles are a continual problem for tactical aircraft and helicopters due to their large numbers and all weather ability to engage aircraft at all altitudes and long ranges. The proposed joint high power jammer pod will demonstrate the advanced broadband amplifier technology necessary to weight reduction in airborne ECM systems.

Improvement of Surface Ship Survivability: Air to surface and surface to surface cruise missiles are the principal threats to surface ships. The primary guidance technique of these weapons is the radar seekers, but the next generation is expected to incorporate IR imaging seeker technology or a dual mode capability. Planned demonstrations will quantify capabilities to defeat imaging seekers using laser based IRCM technology.

Improvement of Fighting Vehicle and Tank Survivability: Self-protection techniques, including re-active armor, have reduced the vulnerability of tanks and fighting vehicles to direct fire. Smart munitions and new anti-tank guided missiles represent the next generation of tank and armored vehicle threats. These threats, with their top attack engagements, cannot be countered by increases in armor because the additional weight would inhibit rapid force deployment. Techniques being demonstrated that will provide a quantification of EW capabilities to address these effects and allow trade-offs by the Program Executive Officer for Armored Systems Modernization (make cost-benefit analysis between EW and additional armor).

Subsystems compatible with reduced platform signatures are available for transition to engineering development. First-generation fusion algorithms that integrate passive sensor products with three-dimensional maps are in field evaluation and could enter operational use with limited additional effort.

**c.** *Major Technical Challenges.* The principal technical challenges in force protection are the development of countermeasures techniques that are effective without need for detailed information on the threat system; apertures and techniques that are compatible with low signature platforms; and increased power output at the longer wavelengths of the IR spectrum.

**d.** *Performing Organizations.* All military departments and ARPA participate in this portion of the EW S&T program and much of the developmental work is contracted to industry.

**e.** *Related Federal and Private Sector Efforts.* The nature of EW is such that other government agencies do not participate directly and significantly in it. Some interaction takes place with the National Security Agency, the Central Intelligence Agency, and the

FAA, FBI, and Customs on an irregular basis. Private sector efforts in EW are either intended for DoD adoption or export and are utilized whenever they fill DoD requirements.

**f.** *Funding.* The annual funding in EW S&T Force Protection totals approximately $70M.

## 2. Offensive EW Applications

**a.** *Goals and Timeframes*

Offensive EW applications provide the means to disrupt enemy command and control and weapons systems. Three categories are defined: Command, Control and Communications Countermeasures (C3CM), Suppression of Enemy Air Defenses (SEAD) and Support Jamming.

- FY94-95: Demonstrate real-time airborne integration and correlation of intelligence data for targeting in support of suppression of enemy air defense operations.
- FY96: Demonstrate highly reliable/efficient hybrid solid state and microwave power module (MPM) jamming transmitters.
- FY97: Perform UAV flight testing of the Intelligence and EW Common Sensor to extend target collection range.
- FY98: Demonstrate High Temperature Superconductive Antennas with reduced size and weight and increased HF jamming efficiency and instantaneous bandwidth.

**b.** *Potential Payoffs and Transition Opportunities.* The ability to manage an opponent's information can be used to prevent the passing of commands and information, to introduce incorrect orders, manipulate logistics or weather reports, and to conceal the location and status of US forces. Effectively exploited, offensive EW allows US commanders to influence the time and place of combat engagements as well as the perception of the opposing force commander.

Efficient microwave transmitter modules have been integrated with advanced antennas and are about to enter field evaluation. A mobile jamming capability against HF signals will be available for demonstration in FY99.

**c.** *Major Technical Challenges.* The critical needs in offensive EW are the development of more efficient jamming sources at the frequencies where new C3 threats are emerging, and automation of the counter-C3 decision process to reduce time and manpower.

**d.** *Performing Organizations.* All military departments participate in this portion of the EW S&T program, and much of the developmental work is contracted to industry.

**e.** *Related Federal and Private Sector Efforts.* The principal non-DoD federal agencies in this area are the CIA, DEA, DOT, and FBI, whose interests tend to be in different applications of the technology. However, S&T activities are coordinated and products are adopted when they fill an agency need. Much of the effort in hardware development is performed under contract with industry.

**f.** ***Funding.*** The annual funding in Offensive EW Applications totals approximately $30M.

## 3. EW Support Functions

Electronic Warfare support functions includes the technology that contributes to the maximization of effectiveness of existing and future EW systems in support of Force Protection and Offensive EW applications. It includes Tactical Electronic Intelligence (ELINT) capabilities; Simulation and Modeling; and Vulnerability Analysis, Assessment and Exploitation.

Simulation and modeling efforts are being pursued to evaluate EW techniques and to provide enhanced, multiple battle laboratory simulations of force structures and battlefield systems. Simulation efforts in missile countermeasures are being used to assess foreign missile seeker capabilities and the effectiveness of U.S. EW methods, either deployed or in development. Integration of battle laboratory simulators over the Distributed Interactive Simulation (DIS) network allows for meaningful simulation of integrated weapon systems and tactics without full maneuver costs.

The primary focus of the EW vulnerability efforts is the assessment of U.S. and selected foreign weapons and munitions associated sensors against countermeasures techniques. Technology programs in advanced antenna technologies are being pursued under a joint ARPA-Navy program. Conduct detailed testing and analysis of foreign weapon systems.

**a.** *Goals and Timeframes*

- FY95: Demonstrate a distributed interactive simulation linking operators, signal collection, aircraft equipment and other mission areas in real time.
- FY96-97: Conduct radar vulnerability assessment against adaptive threshold processing, mainbeam nulling, cross polarization and cross eye countermeasures techniques.
- FY00: Demonstrate a real time battle group simulation capability to accurately assess force management and response in a high threat environment.

**b.** *Potential Payoffs and Transition Opportunities.* The use of simulation in lieu of traditional training or physical deployment offers very significant economies. It allows exposure of many operators to new situations and signals, and permits examination of the relationships between EW and other mission areas, such as fire support, intelligence, and air defense.

The assessment of vulnerabilities is critical as new threat systems that are not well known replace the highly defined designs of the former Soviet Union. Rigorous assessments of vulnerability can avert situations in which weapons fail to perform as expected due to hostile countermeasures or accidental environmental conditions.

**c.** *Major Technical Challenges.* The principal challenges in this subarea of EW are the development of robust models of threat systems that can be used in distributed simulations; multi-level security information systems supporting distributed training activities; and improved instrumentation for assessment of foreign systems under test conditions.

**d.** *Performing Organizations.* All military departments, NSA, and DIA participate in this EW support activities. Where security permits and the nature of the task is suitable, work is performed under contract by industry.

**e.** *Related Federal and Private Sector Efforts.* A great deal of applicable activity is under way throughout the federal government and in the private sector and academia. Distributed simulations, data bases, and multi-level security systems have numerous applications and are being pursued by many organizations. Efforts in industry to improved diagnostics in automobiles contributes indirectly to improved instrumentation and techniques for assessment of threat systems.

**f.** *Funding.* The annual funding in EW Support Functions totals approximately $29M.

### 4. Roadmap of Technology Objectives

See Table 11a-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

High Power Microwave (HPM) and Directed Energy Weapons (DEW): The EW performing activities are coordinating with associated HPM/DEW activities in development of countermeasures against missile systems using IR seeker techniques and other threat systems. Related activities are conducted at the Air Force Phillips Laboratory, Army Research Laboratory and MICOM.

The EW performing activities are coordinating with ARPA under Congressional mandate in the area of laser development as briefly described in Force Protection and Support EW. In Force Protection, ARPA is developing advanced lasers for use in IRCM jammer systems. In EW Support, ARPA is developing advanced antennas to reduce vulnerability of US radars to EW.

## F. TECHNOLOGY TRANSFER AND DUAL USE

- Wide Band IR Fiber Optic Cable for Laser Based Countermeasures and Medical/surgical Applications
- Brushless Electric Motors for decoys, Household Appliances, Automotive.
- Digital Receivers for EW, Satellite and General Purpose/Entertainment Use.

## Table 11a-1. Roadmap of Technology Objectives for Electronic Warfare

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| FORCE PROTECTION<br>DEMO Short-Term IRCM Tech Capability | Multispectral Flare Sled Demo → | Flight Demo | | | | |
| | | Multicloud Chaff | | | | |
| | Laser Decoys Msmts Field Test | | | | | |
| Self Protection CM for Aircraft, Ships and Ground Vehicles | DIRCM Cable Car Live Fire Demo Live Fire Rotary Wing Army Lead | | MATBS at Sea Test | | | |
| | | ARPA Laser Phase I | | ARPA Laser Phase II | | |
| | RF Decoys Tethered Flight Demo | LASER IRCM FLYOUT EXPERIMENT (LIFE) Air Force Lead | | GROUND BASED LIVE FIRE | | |
| EO/IR Passive Missile Detectors | FOWLS DEMO | | | | | Missile Detection Algorithms Demo |
| | | EWAT QF-4 Demo | ESG V DEMO | | | |
| | | | EWPE DEMO | | | |
| RWR for Complex Signal Environment | Microscan Receiver Prototype | High Accuracy DF Ant Field Test | Signal Characterization Demo | | Tri-Service RWR Demo | |
| ARM CM | | | Concept Flight Tests | | | |
| OFFENSIVE EW<br>Airborne SEAD Fusion/Data Integration | | Airborne Demo | | | | |
| Defensive System Fusion | | Abn Testbed<br>Fusion Demos | | | | |
| MMI Tools for All Source Fusion & Integration | Map Tool Demos Intel Fusion Demos | | | | | |
| | | CGS Demo | | | | |
| | ERASE | | | | | |
| Adv Comm CM | Field Tests | | | | | |
| SUPPORT EW<br>Develop Advanced Tactic, CM and Effectiveness Assessment Algorithms | | Demo IRCM Jamming Waveforms During IRCM Anti-Ship Msl Field Tests | | | | |

# 11b. DIRECTED ENERGY WEAPONS

## A. SCOPE

Directed Energy Weapon (DEW) technologies are those that relate to the production and projection of a beam of concentrated electromagnetic energy or atomic/subatomic particles. Directed energy (DE) weapons and devices generate energy that travels at or near the speed of light from a beam source directly to the target. The DEW Technology Area is divided into three sub-areas. (1) *Laser weapons* are devices which destroy/negate targets using beams of electromagnetic radiation with wavelengths less than 1 mm. (2) *RF weapons* are devices which destroy/negate targets by radiating electromagnetic energy in the RF spectrum; i.e., with wavelengths greater than 1 mm (frequencies less than 300 GHz). (3) *Particle beam weapons* are devices which destroy/negate targets by projecting either energetic uncharged (neutral) atomic particles, usually hydrogen, deuterium, or tritium (Neutral Particle Beams (NPB)); or energetic charged atomic or sub-atomic particles, usually electrons (Charged Particle Beams (CPB)).

In FY94 approximately 80% of the $212M S&T funding for DEW technology is allocated for the development of laser weapon technology, 15% is for RF weapons technology, and the remaining 5% is for particle beam technology.

## B. VISION

Maintain US world leadership to develop directed energy technology that has the potential to provide 1) revolutionary, highly effective, rapidly retargetable, high capacity (short engagement timeline, rapid "reload," large magazine) weapon systems to destroy/negate evolving and proliferating strategic and tactical threats, e.g., ballistic and cruise missiles, anti-air missiles, aircraft, satellites, sensors and communications systems, as well as 2) hardening to protect US and Allied assets from attack by threat DEW systems.

## C. RATIONALE

DE weapons cause structural or material damage, disruption and disturbance of electronics, and non-lethal to lethal biological effects. Because the timeline of DEW target engagement is of the order of a few seconds or less and because the beam can be repointed very rapidly, many targets can be negated in a short period of time over a wide field-of-view.

DEW systems have the potential to address all of the Joint Staff Future Joint Warfighting Capabilities. High energy lasers used to achieve early boost phase destruction of ballistic missiles at long range offer a potential counter to these threats, especially important when their warheads contain weapons of mass destruction. All three DEW sub-areas are developing technologies to negate ballistic missiles and cruise missiles in various phases of missile flight. All sub-areas also offer the potential of space control through satellite negation. DEWs may also contribute heavily to establishing air supremacy. Beams from directed energy weapons offer surgical strike capability (at the speed of light) to defeat specific subsystems or systems, thereby minimizing collateral damage. Non-lethal to total destruction capability is available within a single DE system by adjusting power levels. Space-based lasers or neutral particle beams have the potential for instantaneous global response. Mobile systems under development could provide flexible response options. Passive or active imaging, either as a stand-alone system or inherent in all high power laser systems, provides high resolution images of enemy systems.

Because DEW is an emerging technology, transition opportunities usually involve deployment of new systems rather than upgrades or product improvements on existing systems. DEW systems are under development in each of the application areas listed below.

**Specific Applications Addressed in DoD Programs**

| Application | Laser | RF | CPB | Potential Warfighting Capabilities* |
|---|---|---|---|---|
| Theater Missile Defense | X | | | Global, Collateral, WMD |
| Cruise Missile Defense | X | X | X | Global, Collateral, WMD |
| National/Global Missile Defense | X | | | Global, WMD |
| Anti-Satellite/ Space Control | X | X | | Space |
| High Resolution Imaging | X | | | Knowledge, Global |
| Air Defense | X | X | | Collateral, WMD |
| Active Denial | X | X | | Collateral |
| Ship Defense | X | X | X | Collateral, WMD |
| Ground Combat/Close Support | X | X | | Collateral |
| Aircraft Self Protection | X | X | | Collateral |

*Key:

- Knowledge - Maintain and Communicate Near-Perfect Real-Time Knowledge of the Enemy
- Global - Engage Regional Forces in Decisive Combat on a Global Basis
- Collateral - Employ Range of Capabilities to Minimize Casualties and Collateral Damage
- Space - Control the Use of Space
- WMD - Counter Weapons of Mass Destruction and Ballistic/Cruise Missiles

The Laser and RF Weapon programs are ongoing technology development efforts which anticipate transition opportunities such as advanced technology demonstrations within the next several years. These efforts are described in more detail in the sub-area descriptions below. Dual use opportunities and achievements include laser sources for medical, manufacturing and materials processing applications; improved optics and beam control/propagation for high resolution imaging, astronomy, communications, and power beaming; and advanced RF sources and hardening techniques.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Laser Weapons

**a.** *Goals and Timeframes.* Specific technology goals for laser weapon technology include:

- By 1995: demonstrated lethality against head-on cruise missiles and tactical ballistic missiles (TBMs); demonstrated fabrication of full-scale Space-Based Laser (SBL) beam expander; demonstrated fabrication of uncooled beam optics;

airborne laser (ABL) atmospheric propagation path characterized; ABL beam propagation and atmospheric compensation demonstrated in ground tests; 3.5 meter telescope operational at Starfire Optical Range; Integration of acquisition, tracking, and pointing (ATP) hardware for High Altitude Beam Experiment (HABE).

- By 1996: scalable, traceable SBL beam train (wavefront control, pointing stability, etc.) validated at high power.
- By 1998: high efficiency, high power scaling of Chemical Oxygen Iodine Laser (COIL) device and optical components;† 100 kW Hydrogen Fluoride (HF) overtone laser; compact deuterium fluoride (DF) chemical laser compatible with ship-based EW system;† weapon-class atmospheric compensation and ATP validated at low power for GBL; demonstration of ATP technologies in HABE; weapon-class ATP and Fire Control (ATP/FC) demonstrated (without a high power main beam).
- By 2000: Integrated weapon-class SBL space platform demonstrated in ground facility.

**b.** *Potential Payoffs and Transition Opportunities.* The DoD requires improved or new capabilities in strategic and tactical missile defense, cruise missile defense, satellite negation, space and theater control, high resolution space object identification, air defense, ship defense, ground combat and close support, and aircraft self-protection. All of these requirements can be addressed by laser weapon systems. Laser weapon systems potentially have several distinct and unique advantages:

- High kill rate which permits addressing all threats in a salvo.
- Multiple shots or engagements are possible yielding "deep magazine" with large number of kills per platform and low cost per kill.
- Target maneuvers do not affect (reduce) kill probability since engagement occurs at the speed of light.
- Extremely long range engagements or imagery can be achieved from space.

To confirm the military utility of specific concepts, and/or the readiness of the technology for full scale development, the Services and BMDO are planning Advanced Technology Demonstrations (ATDs) and Critical Experiments. The Air Force has approved an ATD in Integrated Beam Control utilizing the 3.5 meter telescope at Starfire Optical Range which will establish the feasibility and integrated performance of a ground-based laser (GBL) beam control and atmospheric compensation system which meets the requirements for a GBL ASAT weapon system. The Air Force also has two ATDs in high resolution imaging and one ATD to develop an intelligence analysis capability. The Air Force airborne laser for theater missile defense program includes both ground-based and airborne critical experiments which will be conducted in parallel with concept definition activities. Under Alpha/LAMP Integration (ALI), BMDO has a major effort to demonstrate end-to-end ground operation of a space-based HF chemical laser concept; the existing

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† Specifics classified

MW-class Alpha laser, LAMP (Large Advanced Mirror Program) 4-meter segmented telescope and LODE (Large Optics Demonstration Experiment) out-going wave beam control technologies will be integrated in the ALI demonstration scheduled for FY96. The Star LITE program will demonstrate the fully integrated operation of the ALI high power beam train and HABE ATP/FC in a full spaceflight configuration. The ground demonstration is scheduled for FY00, a flight demonstration of the ground demo hardware could take place in FY01. The Navy will demonstrate point defense against anti-ship cruise missiles in FY94 and is working toward establishing an ATD to demonstrate shipboard compatibility.

**c.** *Major Technical Challenges.* The technical challenges for laser weapon technology include:

- packaging the system to meet platform constraints
- high power laser device scaling
- precision beam control
- atmospheric compensation for ground and air-based systems

**d.** *Performing Organizations.* The Air Force and BMDO retain comprehensive programs within their areas of interest, while the Army and Navy develop and advocate laser weapon concepts for their specific missions, and conduct limited technology development to address mission-specific requirements which are not covered within the Air Force and BMDO programs.

**e.** *Related Federal and Private Sector Efforts.* DoE efforts at Lawrence Livermore National Laboratory, Sandia National Laboratory, and Los Alamos National Laboratory complement DoD programs.

**f.** *Funding.*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Funding ($M): | 168 | 195 | 191 | 192 | 168 | 165 |

## 2. RF Weapons

**a.** *Goals and Timeframes.* Specific technology goals for RF weapon technology by 2000, include: Significantly increase source output energies, pulse repetition frequency and average power;† reduce system size and weight to be compatible with military platforms; significantly increase power-handling capability of antennas and antenna feeds.†

**b.** *Potential Payoffs and Transition Opportunities.* The DoD requires improved capabilities in countering artillery fire, ship defense against cruise missiles, aircraft self-protection against anti-aircraft missiles, and disruption or destruction of command and control assets. All of these requirements can be addressed by RF weapon systems which upset or damage the electronics within the target. If RF systems can be developed to produce the desired effect on a target at significant range, such systems offer several advantages:

† Specifics classified

- Radiation travels at the speed of light so the target is engaged nearly instantaneously.
- Nearly all-weather capability (frequencies above 10 GHz degrade somewhat).
- Beams designed to counter electronics do not appear to be hazardous to healthy humans
- The beam is relatively broad so that it generally floods the target. Thus there are no stressing beam-pointing requirements and it may be possible to engage multiple targets simultaneously.
- Unit cost, operation and maintenance costs are predicted to be low.
- In many applications the only expendable is fuel for conventional electrical generators/ alternators. Thus the "magazine" is a fuel tank.
- Because the RF weapon is similar to a radar system but usually with higher power, it may be possible to design one system which first detects and tracks the target and then, increasing the power, engages the target, all at electronic speeds.
- Because military personnel are familiar with radar systems and many of the logistics problems have been solved, implementation of RF weapons can utilize existing infrastructure.
- Because the effects are not highly visible, (upset circuit, damaged semiconductor component internal to a system) and the sources can be small and discreet, the technology is well-suited to covert operations.
- Applicable to non-lethal engagements.

Both wideband and High Power Microwave (HPM) narrowband RF DEW systems are being developed. Critical Experiments (CEs) and Advanced Technology Demonstrations (ATDs) will be the approach for progressing from laboratory experiments to field tests that confirm technological maturity, mission effectiveness, and readiness for full scale development. The Army will conduct a counter-munition CE at the end of FY94. The Air Force will conduct a series of Critical Experiments in aircraft self-protection (FY98), space control (FY98), Suppression of Enemy Air Defense (FY99), and command and control warfare (FY2000). Air Force Critical Experiments on Active Denial Technology are scheduled for FY94-95 with an ATD at the end of FY95. A DNA experiment to counter hardened targets will take place in FY96.

c. *Major Technical Challenges.* The technical challenges for RF weapon technology include:

- packaging the system to meet platform constraints
- increased source output energy and/or average power
- high-power, frequency-agile sources
- lethality modeling and predictions
- fratricide avoidance

**d.** *Performing Organizations.* The Air Force retains a comprehensive program within its areas of interest, while the Army and Navy develop and advocate RF weapon concepts for their specific missions, and conduct limited technology development to address mission-specific requirements which are not covered within the Air Force program. The Army is the lead Service for developing generic RF DEW hardening technology. The DNA effort is expanding from a small technology effort to include system-level experiments in the out-years. The BMDO technology effort will be terminated at the end of FY94.

**e.** *Related Federal and Private Sector Efforts.* DoE efforts at Lawrence Livermore National Laboratory, Sandia National Laboratory, and Los Alamos National Laboratory complement DoD programs.

**f.** *Funding.*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Funding ($M): | 35 | 37 | 33 | 40 | 41 | 42 |

## 3. Particle Beam Weapons

**a.** *Goals and Timeframes.* Specific technology goals for CPB weapon technology include lethality criteria against TNT mines by 1995 and a compact spiral accelerator at 9.5 MeV and 10 kA by 1996.

**b.** *Potential Payoffs and Transition Opportunities.* In recent years, DoD has supported development of three classes of particle beam technology, neutral particle beams (NPB) for use in space, laser-guided charged particle beams (CPB) for use outside the atmosphere, and endoatmospheric charged particle beams for use at or near the surface of the earth. Due to their limited utility, the laser-guided CPB program was terminated in FY92 and the NPB program was terminated early in FY94. The endoatmospheric CPB effort is addressing concepts to deposit energy within a target sufficient to cause catastrophic damage (e.g., ignite energetic materials such as HE or fuel, vaporize inert media, or burn out electronic devices). Applications of interest include clearing buried land mines and ship defense against cruise missiles.

**c.** *Major Technical Challenges.* The technical challenges for CPB weapon technology are predictable, stable atmospheric beam propagation for long range applications and, for all applications, development of compact, high-current (kA), high-kinetic-energy (>100 MeV) accelerators.

**d.** *Performing Organizations.* A Memorandum of Understanding among the Army, Navy and ARPA has been instrumental in obtaining Congressional release of $5.6M in FY93 funds from ARPA to address development of compact accelerator technology. A key feature of that MOU is a Milestone Zero Review in FY95. Funding beyond FY95 is contingent upon the results of that review.

**e.** *Related Federal and Private Sector Efforts.* There are currently no related federal or private sector efforts.

f. *Funding.*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| CPB | 2 | 1 | 0 | 0 | 0 | 0 |
| NPB | 8 | 0 | 0 | 0 | 0 | 0 |

### 4. Roadmap of Technology Objectives

See Table 11b-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

As defined in the recent Joint Chiefs of Staff Memorandum of Policy No. 6, Directed Energy is included under Electronic Attack, a subdivision of Electronic Warfare (EW). To ensure coordination between the two technical communities, the JDL Technology Panels for EW and DEW have established TPEW/TPDEW Ad-Hoc Working Groups for RF Technology and Laser Technology which include members of both communities from each Service. These groups are evaluating the applicability of DEW technology to EW missions.

## Table 11b-1. Roadmap of Technology Objectives for Directed Energy Weapons

| Sub-Area | By 1995 | By 2000 | By 2005 |
|---|---|---|---|
| Laser Weapons: Technology Development | • Demonstrated. lethality against head-on cruise missiles and TBMs, fabrication of full-scale operational SBL beam expander, fabrication of uncooled beam optics, ATP integration for HABE | • High power scaling of COIL device and optical components,† 100 kW HF-overtone laser, compact DF chemical laser,† Advanced non-linear optics beam control technology, demo of ATP technologies (HABE) | |
| Laser Weapons: Ground-Based | • 3.5 meter telescope operational | • Integrated Beam Control ATD for GBL - weapon-class atmospheric compensation and beam pointing | • Operational GBL System for Space Control |
| | • Demo vs. in-bound cruise missiles; in position to proceed with ADM | • ADM for ASMD Laser System completed (If FY95 decision to proceed) | |
| Laser Weapons: Airborne | • ABL propagation path characterized, atmospheric compensation demo | • ABL Concept Definition; In position to proceed with ABL Demonstrator | • Operational ABL on four or more aircraft (If FY97 decision to proceed) |
| Laser Weapons: Space-Based | • Integration of existing Alpha MW-class laser, LAMP 4-meter telescope and LODE beam control, ready for testing in ALI experiment | • ALI demo of high-power beam train; Star LITE ground demo of flight-configured SBL; In position to proceed with Star LITE space flight or begin prototype | • Partial constellation (6 satellites) of operational SBL systems to be complete in 2006 (If FY00 decision to proceed) |
| Laser Technology - High Resolution Imaging | • High Resolution Passive Imaging ATD | • Active Imaging and Data Analysis ATDs - End product is limited operational capability for optical imaging of space systems | • Demonstrate optical imaging of geosynchronous satellites |
| RF Weapons Technology | | • Significantly increase source output energy, PRF, average power, and antenna power-handling;† reduce system size and weight | |
| RF Weapons: Ground-Based | • Active Denial ATD | | • Operational AD System |
| | • Counter-Munition CE | • Counter-Munition ATD (if approved) | |
| | | • Demonstration against Hard Targets | |
| | | • Space Control CE | • Space Control ATD |
| RF Weapons: Airborne | | • Aircraft Self-Protect CE ASP ATD (If approved) | |
| | | • Suppression of Enemy Air Defense (Local) CE | • SEAD (Area) CE and SEAD ATD |
| | | • Command and Control Warfare CE | • Command and Control Warfare ATD |
| Particle Beam Technology | • Complete Milestone Zero Review for Mineclearing | • Compact Accelerator Demo (If FY95 decision to proceed) | |

*Transition opportunities are not tied to deployment of other systems, transition occurs through Advanced Technology Demonstrations (ATD) and Critical Experiments (CE)

†Specifics classified

# 12a. ENVIRONMENTAL QUALITY

## A. SCOPE

The Environmental Quality technology area provides technologies to reduce the costs of DoD operations while ensuring mission accomplishment is not jeopardized by adverse environmental impacts. There are four tri-Service sub-areas (Pillars): (1) **Cleanup** of sites contaminated with hazardous materials resulting from DoD operations, (2) **Compliance** with all laws concerning the treatment and disposal of DoD's hazardous waste products, (3) **Pollution Prevention** to minimize DoD's use and generation of hazardous wastes, and (4) **Conservation** of natural and cultural resources under DoD's stewardship. The SERDP Technology Thrust Areas include the four Pillars above plus **Global Environmental Change** and **Energy Conservation/Renewable Resources.**

## B. VISION

Provide technology development to solve our environmental problems as rapidly as possible and at the lowest pratical cost.

## C. RATIONALE

National and international laws demand the mitigation of environmental impacts resulting from the normal operations and maintenance of DoD and DoE activities. Base realignment and closure actions place an added urgency on bringing our sites into compliance. Reduced budgets and increased regulatory requirements dictate the need for new or improved technologies that 1) reduce the costs of contaminant cleanup, treatment and disposal, and 2) reduce the generation of hazardous materials while maintaining stewardship of resources.

Based upon a modest assumption that new technologies will reduce Cleanup costs by 25 percent, the immediate return on S&T investment is over 5000 percent. The payoff for investments in Compliance, Pollution Prevention, Global Environmental Change, Energy Conservation and Natural/Cultural Resources Conservation is also realized by maintaining our mission readiness without shutdown of assets, expenditure of limited manpower, and penalty costs resulting from environmental violations.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Cleanup

**a.** *Goals and Timeframes.* The primary thrusts of site cleanup R&D are to reduce cost, expedite cleanup, and ensure the protection of human health and the environment. R&D is conducted in Characterization/Monitoring, Remediation Technologies, and Fate and Effects.

Characterization/Monitoring R&D will produce innovative and cost effective site identification, assessment, characterization, and monitoring technologies. Advanced sensors and sampling devices will expand the range, accuracy, and precision of the system. Remediation technologies will provide composting, bioslurry systems, in situ biological treatment, and chemical immobilization methods. Fate and effects products will more rapidly determine the relative hazard of materials in soil and ground water. Products of cleanup research include field demonstrated technologies, equipment, criteria and advanced methods.

**b.** *Potential Payoffs and Transition Opportunities.* The cost to complete the DoD Cleanup Program is now estimated to be $24.5 billion. An aggressive R&D program is underway to deal with these military unique problems. The potential cost savings from new technologies such as bioremediation are estimated at 40 to 60 percent. A National Environmental Technology Transfer Test Center Program is being established to demonstrate and evaluate technologies for the remediation of contaminated soil and groundwater. It will allow side-by-side technology demonstrations to expedite implementation of emerging technologies, and improve joint development with the private sector.

**c.** *Major Technical Challenges.* The major technical challenge is site heterogeneity compounded by the number and varying concentrations of different contaminants encountered at cleanup sites.

**d.** *Performing Organizations.* The Army leads technology development for site characterization and monitoring; groundwater systems; treatment technologies for soils, sediments, organics, and heavy metals; and fate and effects. The Air Force leads in the area of treatment technologies for fuels and solvents.

**e.** *Related Federal and Private Efforts.* The DoE and EPA are conducting related R&D that do not address DoD-unique compounds. The DoD is working closely with these agencies, the private sector, and universities.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 114 | 93 | 84 | 76 | 68 | 58 |
| Other Tech Base | 57 | 62 | 65 | 69 | 72 | 76 |

## 2. Compliance

**a.** *Goals and Timeframes.* Compliance R&D will provide technologies for advanced "end-of-pipe" control, treatment and disposal of wastes to meet air, water, land, noise, or drinking water regulations. R&D is focused on (1) characterization of pollutant and waste behavior, (2) media specific control and treatment technologies, and (3) monitoring and assessment tools.

Technologies such as super critical water oxidation, cold plasma reaction, catalytic decomposition, biodegradation, sorption/concentration, seperation and conversion are examples of efforts to reduce costs and increase efficacy of treating and disposing of wastes.

**b.** *Potential Payoffs and Transition Opportunities.* Payoffs are the ability to affordably comply with regulatory statutes while continuing the DoD mission. Transition technologies include super critical fluid processes, membrane treatment, energetic waste disposal, and atmospheric modeling.

c. *Major Technical Challenges.* The major challenges include meeting existing laws on the discharge of solid wastes, complying with the Clean Air and Water Acts, and meeting the requirements of RCRA.

d. *Performing Organizations.* The Navy conducts R&D in global marine compliance, the Army develops base facilities support technologies and the Air Force focuses on atmospheric requirements.

e. *Related Federal and Private Efforts.* Joint programs and cooperative R&D are conducted with DoE, academia, and private industry in areas including plasma arc development, membrane technology, and super critical water oxidation.

f. *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 70 | 66 | 58 | 54 | 46 | 46 |
| Other Tech Base | 6 | 7 | 5 | 5 | 5 | 5 |

## 3. Pollution Prevention

a. *Goals and Timeframes.* As health effects of environmental pollution become better understood, restrictions on hazardous material use will limit the DoD's ability to carry out its mission. Unique requirements demand specialized, high-performance materials in the development and operation of sophisticated weapons systems. Pollution control technologies alone will be inadequate for the task as control techniques become too inefficient and costly and disposal continues to become more unacceptable. Material substitutions, manufacturing process changes, inventory and stockpile controls, and adjustments to routine, daily activities will be required as well as basic behavior modifications by field commanders.

b. *Potential Payoffs and Transition Opportunities.* Waste minimization programs in the commercial sector have demonstrated that pollution prevention saves money. R&D and demonstration efforts will provide technologies that minimize or eliminate hazardous wastes at the source and focus on ammunition manufacturing processes; equipment maintenance and overhaul; materials substitution; demilitarization of weapons systems; elimination of ozone depleting substances, and reduction of solid wastes and effluents. These waste reduction mechanisms will ultimately reduce the cost of doing business in the DoD.

c. *Major Technical Challenges.* We must strive to eliminate or minimize the use of solvents, soluable chromium, strong acids, bases, and oxidizers in production and maintenance activities. Replacement materials and processes to eliminate dependence on materials that produce HAZTOX waste streams and VOC and ODC emissions must be developed.

d. *Performing Organizations.* The military Services, DoE, EPA, and NASA participate. A significant amount of technology is being generated by the aerospace, electronics, and automotive industries.

e. *Related Federal and Private Efforts.* The DoE, EPA and industry participation in this area is comprehensive. The overall related federal and private expenditure is estimated at $10M in FY94 covering this entire area.

f. *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 108 | 63 | 66 | 61 | 37 | 34 |
| Other Tech Base | 3 | 6 | 9 | 10 | 11 | 12 |

## 4. Conservation

**a.** *Goals and Timeframes.* All DoD activities must co-exist with the conservation of natural and cultural resources which are protected by a variety of statutory requirements. R&D will provide enhanced mission effectiveness and maintenance of fragile ecosystems. The goalis to develop advanced models and measurement techniques to improve the characterization of resources and identify the impacts of military activities. These technologies will minimize impacts and sustain and enhance natural and cultural resources.

**b.** *Potential Payoffs and Transition Opportunities.* The payback is significant in terms of maintaining the land base to support the mission while maintaining stewardship of these resources for future generations.

**c.** *Major Technical Challenges.* The successive improvement to technology is the major challenge in conservation, developing and adapting techniques to a continuously changing environment and ecosystems that are thousands of years old. This challenge is complicated by advancements in the range and mobility of new weapons systems.

**d.** *Performing Organizations.* The Army is lead Service in this area supporting DoD conservation requirements.

**e.** *Related Federal and Private Efforts.* Approximately 45 percent of the R&D is accomplished by government laboratories with the balance accomplished by contract. The work is coordinated with all other Federal agencies and academic institutions having expertise in the ecological and cultural sciences.

f. *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 36 | 15 | 15 | 17 | 16 | 15 |
| Other Tech Base | 67 | 72 | 76 | 80 | 84 | 89 |

## 5. Global Environmental Change (GEC)

**a.** *Goals and Timeframes.* This Area focuses on R&D that describes the total environment at global and regional scales. Integration of new and existing programs in data collection and analysis, process study research, and environmental modeling are keystones of this effort, capitalizing on agency unique capabilities that fully leverage the U.S. Global Change Research Program (USGCRP). This program will contribute to the well established USGCRP effort and is based on the Administration goal to stabilize greenhouse gas (CO2) emissions at 1990 levels by the year 2000.

**b.** *Potential Payoffs and Transition Opportunities.* Global climate change and stratospheric ozone depletion are considered high risk problems affecting natural ecology and human welfare. Ozone depletion may be occurring more rapidly than previously predicted. R&D will establish the scientific basis for national and international policy-making related to changes in the global Earth system.

**c.** *Major Technical Challenges.* The major challenge is to distinguish natural changes in the environment from anthropogenic impacts.

**d.** *Performing Organizations.* 35 percent of FY93 SERDP funds were devoted to the execution of the GEC Phase I program conducted by DoE, ARPA, DSPO, and the Navy.

**e.** *Related Federal and Private Sector Efforts.* This work supports the USGCRP program. New science and technology research, sensor systems, and new and existing databases will address science and policy questions identified by the USGCRP while concurrently satisfying needs of the DoD and DoE.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 44 | 33 | 14 | 14 | 14 | 0 |

## 6. Energy Conservation/Renewable Resources

**a.** *Goals and Timeframes.* This area focuses on the generation, transmission, use, and conservation of energy, and includes technology development and demonstration of environmentally sound alternative energy sources. The main goals are to optimize the utilization of present energy sources, determine applicability of alternate and/or renewable energy, and seek and/or develop replacement for present fuels. This will result in reduced energy consumption by 20 percent and reduced $CO_2$ emissions to 1990 levels by the year 2005.

**b.** *Potential Payoffs and Transition Opportunities.* Properly managed application of renewable energy technologies has the potential to save DoD $95M annually and greatly reduce $CO_2$, $NO_X$, and $SO_X$. A 20 percent reduction in Federal agency energy consumption equates to an annual savings of 30 million barrels of oil or $650M.

**c.** *Major Technical Challenges.* The major challenge is to reduce DoD facility energy consumption by 20 percent by increased efficiency and alternative energy sources while ensuring energy security (e.g. conserving strategic petroleum reserves).

**d.** *Performing Organizations.* DoE leads this R&D with support within the DoD by the Army.

**e.** *Related Federal and Private Effort.* Related efforts include many of those in DoE as well as specific efforts sponsored by the energy industry and related state offices.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 10 | 8 | 9 | 9 | 9 | 0 |

## 7. Roadmap of Technology Objectives

See Table 12a-1.

## Table 12a-1. Roadmap of Technology Objectives for Environmental Quality Technologies S&T Goals

| Sub-Area | By 1995 | By 2000 | By 2005 |
|---|---|---|---|
| Cleanup | • Site characterization sensor for POL and geology<br>• Commercialized magnetometer-based system for UXO detection<br>• DoD groundwater modeling system<br>• Bioventing for soils remediation<br>• Advanced oxidation treatment for explosives in gic undwater<br>• Anaerobic degradation of fuels in soils | • Advanced contaminant detection sensors<br>• Physical separation for inorganic contaminants<br>• Nondestructive decontamination of chemical agents contaminated structures<br>• Biotreatment of explosives in soils, Polyaromatic hydro carbons, Hydrozine/propellants, and solvents in soil and groundwater (in-situ) | • Remote/multisensor UXO detection and remediation<br>• Insitu biotreatment of explosives in soil |
| Compliance | • Jet engine test cell exhaust treatment<br>• Hydraulic maceration for shipboard solid waste treatment<br>• Alternative technologies for open burning/open detonation<br>• Short and long range impulse and continuous noise prediction | • Atmospheric transport and fate forecasting<br>• Membrane technology and evaporative treatment for ships liquid wastes<br>• Ultrahigh pressure water jet technology and hydraulic maceration for PEP disposal<br>• Standardized noise assessment methodologies | • High resolution instrumentation to detect and monitor air pollutants<br>• Supercritical water oxidation for destruction of ships liquid waste<br>• Hardware, operational, & source technology for noise mitigation and cancellation |
| Pollution Prevention | • Advanced metal cleaning and processing<br>• Demonstrated non-hazardous high performance coatings<br>• 25% reduction of VOC's in manufacturing<br>• Advanced land and ship streaming agents | • Implemented non-hazardous metal cleaning processing<br>• Large craft robotics water jet paint stripper<br>• 75% reduction of solid waste in packaging<br>• Solventless explosives manufacture<br>• 75% reduction in depleted uranium wastes | • Non-electroplating processes for metal coating<br>• Environmentally safe air and ship coatings and coating removal<br>• 100% elimination of solid wastes in packaging<br>• 90% reduction of manufacturing VOC's<br>• Advanced non-toxic miron aerosol fire agents |
| Conservation | • Design techniques for erosion control of land damaged by military activity<br>• Protocols for evaluating and reporting threatened and endangered species (TES)<br>• Soils and vegetation inventory, monitoring, and analysis standards | • Land revegetation species selection software<br>• Natural resource carrying capacity models for military training/testing lands<br>• TES impact analysis thresholds<br>• Erosion control management models for watersheds<br>• Non-invasive archeological site characterization | • Bioenginnering for rehabilitation of damaged training lands<br>• Robotics/remote assessment and monitoring of training lands<br>• Multiple-objective land use allocation decision support to optimize the use of land resources. |

## 12b. CIVIL ENGINEERING

### A. SCOPE

Science and technology (S&T) efforts solve critical DoD civil engineering problems related to training, mobilizing, deploying, and employing a force at any location at any time. S&T areas include Survivability and Protective Structures, Airfields and Pavements, Conventional Facilities, Critical Airbase Facilities and Recovery, Ocean and Waterfront Facilities and Operations, Sustainment Engineering, and Fire Fighting. Total FY94 funding is $228M.

### B. VISION

Civil engineering R&D programs will provide the militarily unique infrastructure needed to project and sustain U.S. troops world wide to fight and win at the lowest possible life-cycle cost and logistical and support troop burden.

### C. RATIONALE

The payoff will be enhanced fighting readiness that allows true global reach and power projection with minimal friendly force risk. The implications to national security interests of this (0.00005 percent of the annual total DoD budget) research budget make the return on this investment large. Unique DoD civil engineering needs arise from the characteristics of the weapons and transportation systems. The requirement to counter the effects of advanced conventional weapons and saboteur threats is not found in the private sector and, accordingly, there is no robust civilian R&D effort. The need to rapidly establish, maintain, and upgrade or retrofit facilities and transportation infrastructure within a theater of operation is unique; the private sector has no like requirement and no significant R&D investment. Our aging CONUS infrastructure (45 percent of all military facilities are over 35 years old) requires modernization on a scale not seen elsewhere. Mobilization, deployment, fore reception within theater, and mission execution of the force are directly dependent upon efficient operation, maintenance, and upgrading or retrofit of our facilities.

### D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

#### 1. Conventional Facilities

**a.** *Goals and Timeframes.* Develop technologies to revitalize and operate DoD aging infrastructure to ensure that effective strategic Power Projection Platforms, for maximizing productivity of resources in acquisition, revitalization, and operations and maintenance management of infrastructure.

**b.** *Potential Payoffs and Transition Opportunities.* DoD's $400 billion physical plant, and requires $8.5 billion annually on operations, maintenance, and repair. Technologies developed are dual-use and critical to FY 2000 goals to reduce acquisition costs of facilities, building and utility systems maintenance and repair costs by 15 percent, and energy consumption by 20 percent. Transitions are through CRDAs and licenses.

**c.** *Major Technical Challenges.* CRDAs are in place in all laboratories. Aging infrastructure revitalization with scarce resources yet delivering mission enhancing, energy efficient and environmentally sustainable facilities is a challenge. Affordable automated condition assessment technologies, integrated facility maintenance management tools, innovative revitalization technologies, and technologies to determine applicability and DoD-wide energy prioritization conservation opportunities are needed to reduce O&M costs.

**d.** *Performing Organizations.* CERL is the DoD lead laboratory. CRREL addresses cold regions effects; foundations and computer-aided structural engineering tools by WES. In FY93 at CERL 62 percent was performed in-house. Contract work involves universities (University of Illinois, Penn State, Georgia Tech, and Carnegie Mellon) and industry.

**e.** *Related Federal and Private Sector Efforts.* Research is highly leveraged with related work at NIST and funded by NSD. Little private sector facilities research investment exists. CERL works closely with the Civil Engineering Research Foundation to ensures cooperation and encourage private sector R&D.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 11 | 12 | 11 | 11 | 12 | 14 |
| Other Tech Base | 18 | 14 | 15 | 16 | 17 | 17 |

## 2. Airfields and Pavements

**a.** *Goals and Timeframes.* To reduce costs and extend life of DoD's military unique roads, airfields, ports, and railroads by the year 2000.

**b.** *Potential Payoff and Transition Opportunities* include providing the U.S. Military with a reliable launching platform to project mobile forces to support worldwide contingency conflicts. The DoD pavements research leads the Nation and directly affects all U.S. airports (military and civilian), and 26 states' and 138 municipalities' infrastructure.

**c.** *Major Technical Challenges* include the development of dynamic 3-D analytical models, viscoelastic material responses, laboratory characterization of new and innovative materials using physiochemical analysis, and field verification of mechanistic designs.

**d.** *Performing Organizations.* WES has the DoD lead in Airfields and Pavements; Wright Laboratory-Tyndall AFB; and CRREL. These organizations with $75M of unique facilities are partnered with appropriate industry and interested universities.

**e.** *Related Federal and Private Sector Efforts.* The construction industry conducts no related research in airfields or roadways and depends entirely on Federally funded research. Sponsors and clients such as FAA, FHWA, the State Department, and the Forest Service greatly support DoD R&D facilities and expertise.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 3.6 | 3.8 | 3.2 | 3.8 | 3.3 | 3.7 |
| Other Tech Base | 14.5 | 15.4 | 16.7 | 17.6 | 18 | 19 |

## 3. Survivability and Protective Structures

**a.** *Goals and Timeframes.* Provide reliable and affordable structural hardening, camouflage, concealment and deception (CCD), and electromagnetic shielding that will increase survivability of facilities, equipment, and personnel against a broad spectrum of increasingly lethal modern weapon threats ranging from terrorist attack through regional conflicts and up to nuclear warfare. By 2000, the use of lightweight composite materials, nonlinear numerical modeling in blast and shock, penetration, and large structural deformation will increase survivability at reduced cost. By 2005, increases in survivability will be achieved through decreased detection by CCD.

**b.** *Potential Payoffs and Transition Opportunities.* Lightweight, highly ductile, and high-strength materials with enhanced energy absorption will reduce hardening costs. Revised design and field manuals will provide greater survivability of fighting positions, fixed facilities, and retrofit of existing facilities to survive large L/D penetrators and enhanced blast and thermal weapons. Transition opportunities include industrial explosions, earthquake engineering design and civil structural designs to counter terrorism.

**c.** *Major Technical Challenges.* Innovative uses of lightweight, high strength, high ductility materials in protective construction and retrofit of existing structure to increase hardness at low cost. Coupled 3-D nonlinear numerical models to improve internal and external blast predictions.

**d.** *Performing Organizations.* The Army is the lead with participation from other Services. Approximately 80 percent is performed in-house. Sponsors include DNA, DoE, DOT, State and Treasury, Intelligence Agencies, NATO, and other countries.

**e.** *Related and Private Sector Efforts.* Research is coordinated and leveraged with those related to munitions development and hard target kill. Seismic-structural research and computer-aided structural design are related areas funded by the Corps of Engineers.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 25.6 | 26.3 | 27.2 | 29.1 | 30.8 | 32.3 |
| Other Tech Base | 56.8 | 62.4 | 65.5 | 68.8 | 72.2 | 75.8 |

## 4. Sustainment Engineering

**a.** *Goals and Timeframes.* Develop technologies required to sustain a deployed force in an austere theater, to provide Engineer troops with faster, lighter, less voluminous, and less manpower-intensive ways of executing mobility, countermobility, and general engineering missions by FY05.

**b.** *Potential Payoffs and Transition Opportunities.* Engineer troops will have faster, lighter, less voluminous, and less manpower-intensive ways of executing combat engineer mission. Transitions include Technical and Field Manuals and Guide Specifications and the Army Facilities Components System.

**c.** *Major Technical Challenges.* Major challenges include lightweight composite materials, robust analytic vehicle-terrain interaction models, rapidly implacable breakwaters at real time sea-state forecasts for LOTS planning tools which consider synergistic effects of obstacles, direct and indirect fire, course of action, and artificial intelligence.

**d.** *Performing Organizations.* WES, CRREL, and CERL perform 90 percent in-house.

**e.** *Related Federal and Private Sector Efforts.* Related efforts include dust control and nondestructive testing of pavement studies conducted by private companies, local transportation agencies, and universities. Sand-grids developed through this program are being used world wide for construction of roads, revetments, and slope protection.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 6.6 | 7.0 | 7.1 | 7.8 | 8.4 | 9.2 |
| Other Tech Base | 68.0 | 75.0 | 79.0 | 83.0 | 87.0 | 91.0 |

## 5. Fire Fighting

**a.** *Goals and Timeframes.* The goals and timeframes encompass transitioning by the year 2005: (1) more effective, environmentally safe fire extinguishing agents (beginning in FY96), (2) improved fire fighting equipment/crash rescue vehicles, and (3) realistic fire threat assessments and firefighter training systems. Advanced firefighter protective ensembles doubling firefighter operational times in high temperatures, and will enter validation in FY97. Investigations of space lift facilities, fire threats, and composite materials will ensure fire protection of critical aerospace assets.

**b.** *Potential Payoffs and Transition Opportunities.* Finding replacements for currently used ozone depleting fire fighting agents and development of advanced firefighter protective ensembles are major opportunities.

**c.** *Major Technical Challenges.* Includes (1) synthesizing chemicals that meet fire extinguishing performance and environmental requirements, can be used in existing systems, and can be manufactured at reasonable cost and (2) application of advanced cryogenic technologies to body cooling and breathing air systems for protective ensembles.

**d.** *Performing Organizations.* Wright Laboratory (WL) is DoD lead for fire fighting research. NRL and WL investigate new agent applicability to ship and aircraft fire extinguishing systems, respectively. Airbase Systems Branch (ASB) Contractor support includes NMERI, DONMAR, and the University of Florida. In-house research is 50 percent.

**e.** *Related and Private Sector Efforts.* Includes large-scale fire fighting tests conducted by the ASB for the FAA or private contractors related research include Pacific Scientific, Dupont, 3M, Fire Combat, DONMAR, and Aerospace Design and Development.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 5.1 | 4.3 | 4.1 | 4.7 | 2.8 | 2.5 |
| Other Tech Base | 0.9 | 0.4 | 1.0 | 1.0 | 1.1 | 1.2 |

## 6. Ocean and Waterfront Facilities/Operations

**a.** *Goals and Timeframes.* Support the Navy's emphasis on forward presence as described in "..From the Sea." For littoral operations an advanced open sea modular platform not sea state 3 limited, is being designed for acquisition by FY03. Develop, within the decade, techniques, tools and materials to offset $1.6B of shoreside deficiencies.

**b.** *Potential Payoffs and Transition Opportunities.* Expanding the weather window for lighterage capacity meets demands of emerging logistics concepts and increase operational days in LOTS by 20 percent. Modernizing shore infrastructure provides flexibility for mission realignments.

**c.** *Major Technical Challenges.* Assessing low freeboard open seaways' pontoons stability requires complex mathematical simulations. The dynamic mooring analysis study improves nonlinear stochastic systems solutions. Advanced materials structures work looks for new usages for composites.

**d.** *Performing Organizations.* NFESC is the only Navy RDT&E Center for shore and ocean facilities, the Marine Corps as well as the NCF.

**e.** *Related Federal and Private Sector Efforts.* Structural assessment work by NSF, Industry, other DoD, and universities is closely monitored but have limited applicability in a salt water environment.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 5.7 | 6.6 | 13.5 | 18.4 | 18.0 | 15.4 |

## 7. Critical Airbase Facilities/Recovery

**a.** *Goals and Timeframes.* Include advanced modular and airmobile utility systems and structures for bare base by FY98 reducing airlift by 30 percent and manpower requirements by 45 percent. Airfield rapid repair goals are to develop systems to reduce costs by 70 percent by FY97.

**b.** *Potential payoffs.* Include a 30 percent decrease in airlift for forced projection airbases, up to 20 percent reduction in operational support, and 45 percent in manhours for base setup. Reduced fixed infrastructure and limited airlift dictate technology advances in bare base operations. Dual use technologies include CFC free air conditioners, seismic resistant materials, and infrastructure recovery techniques for natural disasters. Almost 80 percent of R&D in this area has dual-use and can be transitioned to industry by FY98.

**c.** *Major technical challenges.* Include lightweight high-strength materials, advanced energy distribution and generation technologies, high- efficiency environmental control units, and flexible innovative structural systems.

**d.** *Performing organizations.* The Air Force is lead in this area. Industry, universities, allied nations, and joint service coordinating groups such as JOCOTAS for tactical shelters. Specific sponsors and clients include the Marine Corps, DNA, Navy, DOT, and OSD. Approximately 80 percent of research is conducted in-house.

**e.** *Related Federal and Private Sector Efforts.* Include research in DoE, FHA, NIST, state highway department, universities, and allied nations. CDRA's with industry, universities, and joint programs with DNA and FHA provide leveraging.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| S&T | 4.5 | 4.4 | 3.3 | 3.3 | 3.6 | 4.1 |
| Other Tech Base | 4.7 | 5.2 | 5.5 | 5.7 | 6.0 | 6.3 |

## 8. Roadmap of Technology Objectives

See Table 12b-1.

## Table 12b-1. Roadmap of Technology Objectives for Civil Engineering S&T Goals

| Sub-Area | By 1995 | By 2000 | By 2005 |
|---|---|---|---|
| Conventional Facilities | • Reduce facilities acquisition, M&R costs by 7% of 1990<br>• Reduce energy consumption by 10% of 1985 | • Reduce facilities acquisition, M&R costs by 15% of 1990<br>• Reduce energy consumption by 20% of 1985 | • Reduce facilities acquisition, M&R costs by 20% of 1990<br>• Reduce energy consumption by 30% of 1985 |
| Airfields and Pavements | • Constitutive and predictive models for pavement response<br>• Provide stabilized surfaces for contingency aircraft operations in 20% less time and with 10% less Class-IV material<br>• Blast resistant paved surfaces | • Fundamental understanding and analytical capability to address all aspects of pavement response and behavior<br>• Ameliorate methods and materials to rapidly construct operating surfaces<br>• Reduced life-cycle costs and increased durability of DOD's pavements by 15% of FY93 cost | • Provide criteria for APOE power projection platforms<br>• Criteria for airfield design and construction to support contingency operations worldwide<br>• DoD transportation systems designed with confidence levels of serviceability and performance<br>• 25% life-cycle cost reduction of FY93 cost |
| Survivability and Protective Structures | • Constructible 4X conventional concrete strength for hardened construction<br>• Cost-effective retrofit of windows subjected to blasts from vehicle bombs<br>• Increase survivability of mobile tactical operations centers by 25%<br>• Reduce time for demolitions preparations by 75% and required troops by 50%<br>• Incorporate CCD into protective construction design guidance<br>• Conductive composite materials with improved processibility and electromagnetic shielding | • PC-based design manual for hardened structures<br>• Constructible 5 to 6X conventional concrete strength at reduced cost for hardened facilities<br>• Antipenetration systems to defeat very heavy robust penetrators<br>• Lightweight, high-strength composite framing elements for hardening upgrades<br>• Deployable protective packages for light forces<br>• Automated CCD design/analysis capability<br>• Advanced materials with integrated structural and electromagnetic shielding attributes to reduce cost by 25% | • Vulnerability assessment model for retrofitting critical facilities to enhance survivability against advanced weapons<br>• Develop criteria for survivability of conventional facilities against entire spectrum of terrorist weapons<br>• Increase force survivability with 40% reduction in logistics burden<br>• Decrease probability of detection by 50% through advanced multispectral signature management techniques<br>• Concurrently engineered electromagnetic shielding with improved life-cycle performance and to reduce cost by 50% |
| Sustainment Engineering | • Improve dry soil stabilization construction time by 25%<br>• Halve LOTS site selection time<br>• Stochastic Mobility model with capabilities of quantifying reliability of mobility predictions<br>• Direct and indirect-fire/obstacle synergistic relationships for Obstacle Planning | • Reduce soft soil construction time in soft soils by 35%<br>• First-generation theoretical mobility model<br>• Doctrinal breaching and river crossing planning times; reduced 50% through TDA's<br>• First Logistics-Over-The-Shore Operational Simulator (LOTSOS)<br>• Automated countermobility planning and execution for C2 systems | • Reduce horizontal construction time by 20%<br>• Reduce logistic requirements for engineer construction materials by 20%<br>• High-resolution mobility model for advanced vehicle platforms<br>• Gap/river crossing site selection procedures based on trafficability and crossability |
| Fire Fighting | • Reduce ozone depletion for streaming and flooding agents by 5%<br>• Increase biodegradability of firefighting foam by 10%<br>• Firefighting training improved by 10%<br>• Firefighting at space launch facilities improved by 25%<br>• Firefighter protective equipment improved by 10%<br>• Fire fighting vehicles improved by 10%<br>• Fire detector/ suppression systems improved by 5% | • Reduce ozone depletion for streaming agent by 20% and flooding agent by 40%<br>• Increase biodegradability of firefighting foam by 40%<br>• Firefighting training improved by 50%<br>• Firefighting at space launch facilities improved by 50%<br>• Firefighter protective equipment improved by 50%<br>• Fire fighting vehicles improved by 50%<br>• Fire detector/ suppression systems improved by 40% | • Reduce ozone depletion for streaming agent by 50% and flooding agent by 80%<br>• Increase biodegradability of firefighting foam by 90%<br>Firefighting training improved by 90%<br>• Firefighting at space launch facilities improved by 95%<br>• Firefighter protective equipment improved by 95%<br>• Fire fighting vehicles improved by 75%<br>• Fire detector/ suppression systems improved by 75% |
| Ocean and Waterfront Facilities/ Operations | • 25% improvement in ocean mooring design parameters<br>• 100% enhanced capability in site seismicity microzonation<br>• 25% improvement in crane shaft NDT & failure analysis<br>• 80% improved reliability of diver operated seawater hydraulic powered rock drill<br>• 75% improvement in offshore fuel transfer throughput using in-line boosting<br>• 35% improvement in over-the-shore logistics throughput via optimization of pontoon lighterage loading at sea state | • Increase service life of pier repairs from 3 years to 15 years using<br>• 80% improvement in ocean mooring capability<br>• Validate 80% NDT improvement for crane lift components: shafts & connections<br>• For expeditionary situations, provide rapid geotechnical site investigation techniques reducing current assessment time of several weeks to one day<br>• Validate increase of 30% in operational days using high seastate advanced pontoon system<br>• Provide 100% fuel transfer capability upon retirement of LSTs | • Validate 50% improvement of pier stability analysis and NDT structural flaw detection capability<br>• 100% capability for diagnostic sensor specification and software<br>• 99% improvement in certainty of the viscous theory Modified Wave Force<br>• Validate 80% improvement in locating and tracking of supplies and equipment (RTT)<br>• Provide 50% improvement in rapid cargo off-loading systems |
| Critical Airbase Facilities | • Reduce cost of rapid setting cement by 70% for rapid runway repair<br>• Reduce equipment weight and volume by 30% for Airmobile Utilities/Energy systems<br>• Increase efficiency by 20% and reduce repair time by 10%<br>• Reduce bare base shelter weights and packing volumes by 50% | • Develop new or adapt emerging technologies for Air Force operating surfaces<br>• Reduce equipment weight and volume by 40% for Airmobile Utilities/Energy systems<br>• Increase efficiency by 30% and reduce repair time by 20%<br>• Reduce man-hour assembly time of bare base structures by 50%<br>• Reduce recovery time of Rapid Facility repair by 30% | • Develop new or adapt emerging technologies for Air Force operating surfaces<br>• Reduce equipment weight and volume by 50% for Airmobile Utilities/Energy systems<br>• Increase efficiency by 40% and reduce repair time by 30%<br>• Reduce weight, volume, and assembly time of mobile shelters by 100%<br>• Reduce recovery time of Rapid Facility repair by 50% |

# 13. HUMAN SYSTEMS INTERFACE

## A. SCOPE

Human Systems Interface (HSI) technology fully leverages and extends the capabilities of warfighters and maintainers to ensure that fielded systems will exploit the fullest potential of the warfighting team, irrespective of gender, mission or environment. It is organized into four areas. *Crew systems integration and protection* integrates the human with weapon system hardware and software to maximize the safety and effectiveness. *Performance aiding* produces technologies to minimize human error, overcome sensory and physical limitations, and improve mission performance. *Information management and display* develops methods and media to deliver task-critical information to individuals, teams and organizations. Lastly, *performance assessment & design methodologies* develops specialized databases, metrics, software tools, and models of human system performance, and incorporates them into engineering design processes.

Funding for this area is $195 million in FY94.

## B. VISION

Boost weapon systems performance and affordability by developing and transitioning technology to ensure superior human systems operability, supportability, and survivability.

## C. RATIONALE FOR INVESTMENT

Human system interfaces, ranging from the individual soldier's weapon to complex team-operated systems, are essential to joint warfighting capabilities. Quick-reaction, information-intensive operational environments pose an increasing challenge to achieving the JCS warfighting needs. The human has become, simultaneously, the critical component and the limiting factor in military operations. Major gains in system performance and affordability will be realized through technology advances from DoDs HSI program, enabling 50 percent reductions in crew size 25 percent reductions in workload, a doubling of critical decision-making accuracy and reliability, a quadrupling of crewmember situation awareness, an 80 percent reduction in fatalities and injuries from aircrew escape, and a conservative 50 percent reduction in costs through common displays.

These improvements will have far-reaching impact on the operability, effectiveness and affordability for a variety of military systems. Typical examples include a doubling of first pass target kills, a 50 percent reduction in maintenance trouble-shooting time, a ten-fold reduction in the re-engineering of crew systems, and reduced vehicle size, weight and training costs through crew size reductions. The transition opportunities include future air defense weapons, FMBT, next generation ships, new attack submarine, AS to VO, ASTOVL derivatives, and upgrades to aircraft such as F-15, F-16, and F-22.

Complex technologies are pervasive in tasks, jobs, and processes from the factory floor to the family living room. Linking humans effectively with these technologies is the key to affordability and international economic competitiveness. The unique R&D assets within DoD are a national center of excellence and lead the nation's HSI efforts. Products from the DoD investment in HSI have been extensively and successfully used by commercial industry, academia, local government and other federal agencies. New administration initiatives such as the National Information Infrastructure are aggressively capitalizing on enabling technologies developed under the HSI R&D area. Multi-use applications have been achieved or are planned in medical instrumentation and techniques, automotive interior packaging and assembly, industrial safety and job design, job performance aiding, commercial aviation safety and air traffic control, product producibility and manufacturing, computer-aided human engineering, and entertainment.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Crew Systems Integration and Protection

**a.** *Goals and Timeframes.* This sub-area provides technology to enhance system effectiveness, affordability, and safety through the overall integration of the operator with the weapon system. The pace, complexity, and precision of the future joint warfighting environment requires a high degree of integration of all crew system elements into the weapons platform.

By 1998, mission reconfigurable crewstations and decision support systems will be demonstrated for aircraft and land vehicles. By 2005, a fully functional electronic crew associate will be available to support platform operations. Advanced distributed simulation methods will be verified. Survivability will be increased through the integration of NBC protection, greater "G" protection for fighter pilots, and crew escape technologies. By 2010, our land, sea and air vehicles will have common, standard components that allow the warfighter to "wear the cockpit to the platform. The total integration of enhanced life support systems with leading edge cockpit controls and displays will provide a safe and virtual interface environment for the crew, independent of the platform.

**b.** *Potential Payoffs and Transition Opportunities.* The principal payoffs of crew systems integration and protection technology will be 50 percent reductions in crew size, up to 80 percent reductions in fatalities and injuries through improved protection, a doubling of targeting capability, and through commonality, a 33 percent reduction in costs. The integration of aural and visual perception aiding for enhanced situation awareness, and the lessened workload from the intelligent operator associate, will permit reductions in crew size and complement. The consequent benefits are reduced costs for acquisition and training, while significantly improving the "steel on target" performance of all weapon platforms. Improvements in human performance, weapon systems effectiveness and in crew protection will significantly decrease casualties in combat and in training. These technologies are readily adaptable to existing platforms such as M-1, AV-8B, TRIDENT, and F-16, and also to improve advanced systems such as RAH-66, FMBT, 21st Century Land Warrior, Next Generation Ships, New Attack Submarine, F-22, and derivatives for JAST. Approximately 40 percent of the FY95 investment in the crew systems integration and protection sub-area can be exploited for dual-use applications.

**c.** *Major Technical Challenges.* The integration of all advanced technology subsystems with the crew into a unified and functioning entity that is able to accommodate the requirements of unique missions for each class of weapon platform is the biggest challenge ahead. New methodologies for applying distributed interactive simulation to exercise a full range of potential weapon system capabilities for both low and high intensity operations are critical to successful and cost-effective systems. Another significant challenge is the protection and accommodation of the full range of men and women warfighters in high stress environments.

**d.** *Performing Organizations.* Crew system integration research is performed by the Army (22 percent), Navy (32 percent), and the Air Force (46 percent). Of the work, 36 percent is directly performed by the services, 61 percent is contracted with industry, and 3 percent is performed by universities.

**e.** *Related Federal and Private Sector Efforts.* NASA performs related federal R&D programs, and the major aircraft companies have related IR&D projects. Private industry is also involved through TRP awards.

**f.** *Funding.*

| FUNDING ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Services | 57 | 86 | 98 | 85 | 65 | 65 |

## 2. Performance Aiding

**a.** *Goals and Timeframes.* Performance aiding technology will enable the nation's warriors and maintainers to operate well beyond their normal mental and physical capabilities, and to enhance system performance in stressful, hazardous, time-constrained, uninhabitable, and remote environments.

This technology melds research from service and national programs in cognitive science, decision science, and knowledge engineering into focused defense applications. The goals are to advance the technology in the areas of intelligent planning and decision support, supervisory control and teleoperation, algorithms for adaptive associates, and related performance aids for operators and maintainers across the Services at all levels. The milestones to achieve these goals are to demonstrate by 1996 an intelligent multi-platform integration with multiple sensors, to establish specifications by 1998 for authoring electronic technical data, to formulate models by 1999 of situation assessment and decision-making in real-time operations, to demonstrate by 2002 system prototypes for collaborative decision-making and distributed information processing, and to validate by 2005 an adaptive architecture for a family of job performance aids usable across the services and defense agencies, to include using the operator's intent as a means of control.

**b.** *Potential Payoffs and Transition Opportunities.* Performance aiding technology will extend the performance envelope for human operators and support personnel to foster effective real-time operations in hostile environments. The specific payoffs are to eliminate procedural error rates (zero tolerance) for operators of tactical workstations, produce a 50 percent reduction in crisis planning time, permit standoff target sorting and selection outside threat weapon ranges, introduce new means for hazard and risk avoidance through telerobotics, multiply by a factor of ten the human ability for lifting and moving, save millions of dollars annually by converting from paper to electronic technical data, and improve situation assessments by a factor of three in operating mobile armor, tactical aircraft, carrier battle groups and command centers. Transition of this performance aiding technology to operational land, air, sea and undersea systems will include aids for system operability and supportability. This technology will apply both for new systems such as FMBT, F-22 and JAST derivatives and for upgrades to existing systems, such as AH-64, F/A-18E/F, F-14 Quickstrike, AEGIS, RAH-66 and F-15E. Approximately 65 percent of the planned FY95 investment in the performance aiding sub-area can be exploited for dual-use applications.

c. *Major Technical Challenges.* The principal challenges are the maturation of very high speed, real-time decision support systems, provision of accurate models of operator cognition merged with models of complex systems and with realistic mission scenarios, validation of large-scale cooperating intelligent systems, and technology to speed the formation and delivery of technical, maintenance and logistics data to the field.

d. *Performing Organizations.* Performance aiding research is performed by the Army (15 percent), the Navy (19 percent), and Air Force (66 percent). Of the work, 40 percent is performed in-service, 30 percent is contracted with industry, and 30 percent is performed by universities.

e. *Related Federal and Private Sector Efforts.* The FAA, NASA, DOT and DoE support related programs that apply performance aiding technology to civil domains (civil aviation, ground transport, and nuclear power generation). IR&D projects and Cooperative R&D Agreements are in place for work on Performance Aiding Technologies, especially in the aerospace sector.

f. *Funding.*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Services | 15 | 16 | 15 | 14 | 13 | 12 |

### 3. Information Management and Display (IM&D)

a. *Goals and Timeframes.* The aim of IM&D research is to rapidly and effectively transfer task-critical information to individuals and teams of planners, operators, and maintainers.

By 1998, ejection-safe helmet-mounted display and sight systems will link to missiles for quick, multiple high off-boresight air-to-air and air-to-ground kills in fighters and helicopters. High resolution, wide field-of-view night vision devices will greatly decrease helicopter accident rates and significantly improve ground troop and special operations capabilities. By 2003, the ability to transfer information will increase by at least a factor of three and advanced data processing and fusion techniques will provide near real-time information during missions for enhanced situation awareness and replanning. Large color flat displays will allow panoramic views. Also, 3-D audio, speech recognition, and color helmet displays will assist in threat warning and targeting for aircraft, ground forces, and ships. Finally, by 2010, 3-D image volumetric displays and immersive virtual reality devices will be usable for combat crewstations.

b. *Potential Payoffs and Transition Opportunities.* The services and ARPA IM&D programs support three of the five Joint Staff future warfighting needs, and will produce numerous "enabling technologies" critical to the National Information Infrastructure Initiative. Specific payoffs include 50 percent reductions in display costs from common components, a ten-fold increase in the probability of detection and pinpoint targeting from 3-D auditory and display integration, a 50 percent reduction in attrition during night and adverse weather from enhanced situation awareness, soldier head-mounted displays for enhanced team control, a 75 percent reduction in ground-to-ground and air-to-ground fratricide, helmet displays to enable rapid high off-boresight kills and doubling of first-pass ground kills, a 30-times increase in the volume of ocean surface and subsurface data handling. Transition targets are underway in many areas, including helmet-mounted display integration and flight tests in RAH-66, F/A-18, and F-15, advanced large flat panel displays for C-17, C-141 and C-130, immersive displays in crew stations, training systems, and medical applications, and 3-D aural and visual displays for sonar, command, and air traffic control. Both ARPA and the services are transitioning advanced technologies directly through manufacturers, including high resolution flat-displays, miniature color flat-displays, 3-D visual displays, 3-D audio, and high definition systems. Approximately 70 percent of the planned FY95 investment in the IM&D sub-area can be exploited for dual-use applications.

**c.** *Major Technical Challenges.* Comprehensive models must be developed for optimizing IM&D based on human characteristics and task requirements. The complex multi-task conditions and extreme operating environments typical of military missions are a particular challenge. Achieving real-time information transfer and control will require innovation and extensive system integration.

**d.** *Performing Organizations.* IM&D research is performed by the Army (12 percent of service program), Navy (28 percent of service program), and Air Force (60 percent of service program). The ARPA high definition system program contributes a substantial added boost to the technology. Of the service programs, 35 percent of the work is in-service, 60 percent is contracted with industry, and 5 percent is performed at universities. All of the ARPA work is contracted with industry.

**e.** *Related Federal and Private Sector Efforts.* Related efforts are underway at NASA and the FAA, and at 10 major aerospace companies through the IR&D program. One international effort is an MOU and Nunn program between the Air Force and France for Virtual Crewsystem Technologies.

**f.** *Funding.*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Services/ARPA | 16/75 | 17/75 | 14/75 | 13/75 | 10/75 | 9/75 |
| Total | 91 | 92 | 90 | 88 | 85 | 84 |

## 4. Performance Assessment and Design Methodologies

**a.** *Goals and Timeframes.* The overall goal is to expand operational performance and reduce life cycle costs by systematically incorporating operator and maintainer capabilities into the design process. Systems must fully exploit the human contribution to mission effectiveness, which can be assured by inserting human performance and cost variables into design. This sub-area is developing a national technology base in human performance assessment and modeling, design aids for supportability (improving reliability, maintainability, and requirements estimation for manpower, personnel, and training), tools for physical accommodation, methods for human error and reliability assessment, and methods and tools for crew station design and test, all in the context of weapon system engineering.

By 1996, the service test agencies will evaluate a common set of tools for planning and performing crew station evaluation during flight test. By 1997, an electronic database offering quantified and diagnostic HSI data will be distributed to designers, and a crew-centered cockpit design process will be verified for five different weapon system applications. By 1998, valid evaluation metrics will be established for assessing human decision-making, operator workload and situation awareness. By 2002, analytic and simulation tools that make designing for operability and supportability more efficient will be proven. By 2005, tools for evaluating performance data from distributed interactive simulation will be embedded into a total design environment for the human system interface.

**b.** *Potential Payoffs and Transition Opportunities.* This research will improve mission effectiveness and reduce the cost of designing, fielding and supporting weapon systems through human-centered design processes that are fully integrated into the concurrent engineering infrastructure. The specific payoffs include quantifying the human-system performance baseline at Milestone I, reducing by 50 percent the time needed to develop and evaluate the crew system, reducing by 75 percent design-induced operator errors, and reducing by a factor of ten the need for redesign at the test and evaluation stage. Customers span the acquisition, test, logistics, and operational communities and include the defense industry. Opportunities for transition include crew systems for land vehicles such as FMBT, new air vehicles such as JAST and upgrades to the entire range of existing fixed-wing and rotary-wing aircraft, and to Navy surface and subsurface platforms including the next generation ships and the new attack submarine. Approximately 60 percent or the planned FY95 investment in the performance assessment and design methodologies sub-area can be exploited for dual-use applications.

**c.** *Major Technical Challenges.* A convincing validation is needed for methods, models, simulations, databases and tools for design and evaluation. In addition, strong acquisition management oversight will be needed to assure that industry includes an effective HSI program during development. To be effective, HSI will need to be a recognized design discipline on a par with other engineering disciplines.

**d.** *Performing Organizations.* Performance assessment and design technology is performed at the Army (35 percent), Navy (one percent), and Air Force (66 percent). The work is distributed 66 percent to in-service projects, 29 percent to industry through R&D contracts, and 5 percent to universities.

**e.** *Related Federal and Private Sector Efforts.* Although NASA and the FAA also have crew station design efforts, DoD's efforts have a special emphasis on reducing manpower, personnel, and training costs. DMSO and ARPA have efforts in distributed interactive simulation that are being exploited. IR&D programs are under way at several aircraft and avionics companies.

**f.** *Funding.*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Services | 32 | 29 | 30 | 37 | 38 | 37 |

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

Human Systems Interface technology advances are closely coupled with the DoD investment areas for Air, Ground, and Surface/Undersurface Vehicles. Crew systems and operator protective equipment must be fully integrated with the other vehicle and weapon subsystems to achieve the highly integrated and affordable combat systems of the future. Software advances in human computer interaction, from the DoD software area, and communication and distributed control technology from C3, combined with performance aiding and information management and display technology from Human Systems Interface form a broad base of information technology needed for future military operations, in order to ensure that our defense systems will prevail in the new information warfare arena. Programs in these areas are coordinated by the services to achieve the needed synergy.

**Table 13-1. Roadmap of Technology Objectives for Human-Systems Interface S&T Goals**

| Sub-Area | By 1995 | By 2000 | By 2005 | Transition Opportunities |
|---|---|---|---|---|
| Crew Systems Integration and Protection | • Demonstrate 1st Generation Crew System Engineering Process<br>• Establish Accommodation Criteria for Women | • Demonstrate Mission Reconfigurable Cockpit<br>• Safe Escape to 700 KEAS<br>• Extend G-Protection to 12 Gz<br>• Demonstrate 2-Person Tank Crew Station | • Fully Functional Electronic Crew Associate<br>• Integrated NBC, G-Protection, Crew Escape<br>• Demonstrate Single Seat All Weather Strike Cockpit | RAH-66, 21st Century Land Warrior, AFAS, AGS Next Gen Ships, New Attack Sub, JAST, F-22 Upgrades to AV-8B, Trident |
| Performance Aiding | • Demonstrate Interface for Tactical Decision-Making Under Stress<br>• Algorithms for Automated Mission Planning and Vehicle Management | • Algorithms for Real-Time Tactical Decision-Making<br>• Demonstrate Aiding Technology for Distributed Operations<br>• Demonstrate Soldier-Worn Machine which Doubles Mobility, Strength, Stamina | • Develop Architecture for Adaptive, Intent-Based Aiding<br>• Demonstrate Biocybermedic Interface Concept | RAH-66, FMBT, AFAS, AGS JAST, F-22 Upgrades to AEGIS F/A-18E/F, F-14 Quickstrike |
| Information Management and Display | • Display Symbology Standards<br>• Panoramic Display Concept Demonstration<br>• 3-D Audio Flight Demonstration<br>• Lightweight Night Vision Image System | • Ejection Safe Helmet Display for Off-Boresight Targeting<br>• 300 sq. in. Flyable Flat Panel Display<br>• Soldier Head-Mounted Display Demonstration | • Real-Time Data Fusion Processor and Display<br>• Full Color Helmet Displays<br>• Virtual Reality Helmet with Integrated Visual, 3-D Audio, Speech Recognition | RAH-66, C2V, JAST, F-22 Upgrades to F/A-18, F-15, C-17, C-141, C-130 |
| Performance Assessment and Design Methodologies | • Crew Station Test System<br>• Human Workload Metric for System Design<br>• Maintainability CAD Program | • Electronic Database for HSI Design Data<br>• Verified Crew-Centered Cockpit Design System<br>• Decision-Making and Situation Assessment Evaluation Metrics | • Distributed Interactive Virtual Design System<br>• Unobtrusive Real-Time Measures of Human Performance<br>• Hi-Fidelity 3-D Human Model<br>• Intelligent Life Cycle Design Support System | All New Systems and Upgrades with a Human Systems Interface |

# 14. MANPOWER, PERSONNEL, AND TRAINING

## A. SCOPE

The Defense Manpower, Personnel, and Training science and technology program seeks to maximize human military performance. **Manpower and personnel technology** directly affect the department's single highest system cost—the personnel system. This technology area addresses the recruitment, selection, classification, and assignment of people to military jobs. It seeks to reduce the attrition of high-quality personnel and helps the senior department leadership to predict and measure the consequences of policy decisions. **Training systems technology** improves the effectiveness of the Department's $19 billion annual training investment in individual (and many times this amount in team, crew, unit, and joint training) instruction, improves the efficiency of student flow through the training pipeline, enhances military training systems, provides opportunities for skill practice and mission rehearsal, and lowers life-cycle costs of training systems and combat systems. Funding for this area is $115 million in FY 1994.

## B. VISION

Manpower, personnel, and training S&T seeks to develop and transition superior technology to ensure that operating forces have the right people, with the right training, at the right time to enable affordable, decisive military capability. It provides highly motivated, highly skilled, well-trained personnel resources, as well as personnel and training technologies that flow back to the civilian community to enhance economic security.

## C. RATIONALE

The Defense Science and Technology Strategy revolves around the five highest priority Joint Staff Future War Fighting Capabilities. The manpower, personnel, and training S&T program directly contributes to all of those necessary capabilities by optimizing the use of the DoD's most critical resource—its people—in achieving those capabilities.

The guiding principles for defense S&T management include (a) reducing weapon and support system life-cycle cost, (b) strengthening the commercial-military industrial base, and (c) developing, transitioning, and inserting technologies to improve the capabilities of new and existing systems. The defense manpower, personnel, and training S&T program directly aligns with these guiding principles. Over a system's life-cycle the cost of the people to operate and maintain the system is significantly higher than the cost of the system itself. Reducing that cost is the over-riding objective of this technology area. In addition, virtually all these technologies are dual-use technologies that can be directly applied to strengthen the civilian economy. Finally, manpower, personnel, and training technologies provide efficiencies in the operation and maintenance of both current and future systems.

The potential payoffs from success in the manpower, personnel, and training S&T area are immense. Supporting the active-duty force costs in excess of $70 billion annually. In addition, DoD spends over $19 billion annually in individual training costs. This number increases dramatically when the costs of crew, unit, and joint training exercises are added. Even very small efficiencies from this technology area result in significant cost and risk reductions for the department, resulting in increased readiness for our warfighting forces.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Manpower and Personnel

In the future the services will perform combat missions with smaller forces that must achieve and maintain a higher level of peacetime readiness than ever before. In order to achieve these goals, an increased emphasis must be placed upon force multipliers. One major force multiplier is the quality of the people who will perform the mission. Despite the drawdown, the DoD personnel system still contains over 2 million active duty personnel and several hundred thousand reserves. Accessions in the future must be of the quality and assigned in such a way that they will excel in their assigned roles. Research in acquiring and managing the force will accomplish this through: (1) new theories of human potential and basic human abilities that lead to maximum performance; (2) new methods of identifying individuals with abilities necessary to perform complex missions; (3) new and improved job analysis methods and job assignment methods to achieve optimum performance; and (4) tools for personnel force managers to make better planning, policy, budgetary, and execution decisions in a rapidly changing military personnel environment.

**a.** *Goals and Timeframes.* The manpower and personnel sub-area will demonstrate: (1) a new generation of aptitude tests (by FY 1996) and new systems for structuring military jobs (by FY 98) that will allow more precise recruitment, selection, and classification into jobs of those people most likely to be successfully trained and to perform effectively; (2) an ability to prescribe the set of recruitment, promotion, and retention policies needed over a succession of years to achieve future force levels (by FY 99); (3) more effective strategies for manning units, ships and squadrons to minimize the turnover of critical personnel during key readiness periods (by FY 99); (4) strategies and techniques to develop and maintain command knowledge and skills (by FY 99); and (5) a model of the leader-development process across organizational levels (by FY 98).

**b.** *Potential Payoffs and Transition Opportunities.* Payoffs from the sub-area include increased personnel and unit readiness, minimized personnel dislocations costly to personnel readiness, reduced student downtime from better training management, and more effective personnel policies. In addition, outcomes will include reduced training costs and time, reduced attrition from training (including flying training), and improved mission effectiveness through higher performance levels of military members. The department will see improved mission performance through more efficient allocation of personnel to duties with requirements that match individual strengths and reduced manpower requirements through better alignment of job structures to accomplish the mission. The next generation of aptitude tests will be inserted into DoD and service-specific testing programs for accessing new recruits. Techniques for developing and training tactical decision skills, methods for assessing organizational impacts of peace-keeping operations, and cost/benefit methods for evaluating peacekeeping operations will all become available by FY 00.

**c.** *Major Technical Challenges.* Technical improvements in statistical forecasting, mathematical optimization, information storage and retrieval technology, and artificial intelligence will be needed to produce more accurate, defensible plans and policies, accelerate the organization and delivery of information and provide recommended personnel actions based on captured expertise. Other technical challenges confronting this sub-area include necessary developments in: (1) comprehensive job analysis effectively identifying unobservable requirements; (2) self-report measures that resist faking and contribute to overall prediction; (3) measuring performance in relatively unstructured contexts; (4) realistic and objective measures of mission performance; and (5) Battle Command performance effectiveness baseline measures.

**d.** *Performing Organizations.* In-house work in this area constitutes approximately 55 percent of Army efforts, 50 percent of Navy efforts, and 36 percent of Air Force efforts. Industry receives 37 percent of Army, 30 percent of Navy, and 44 percent of Air Force funding. The remaining percentages are distributed across university and other government agency funding.

**e.** *Related Federal and Private Sector Efforts.* This sub-area cooperates fully with investments by RAND and the Center for Naval Analyses, FEMA and the National Fire Academy, the Departments of Labor and Commerce, and the Office of Personnel Management.

**f.** *Funding*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Funding ($M) | 25 | 25 | 23 | 23 | 24 | 25 |

## 2. Training Systems

While the superpower threat has radically diminished, the training problems faced by commanders have increased—training readiness now aims at a diverse set of operations other than war, while the capability to conduct major engagements must be maintained. Added to this increased complexity of training management are the pressures to reduce the training budgets for flying hours, steaming days and operating tempo. Training system technologies are being developed to reduce the cost and increase the effectiveness of current training, and to re-engineer training for the future. These technologies include the development and application of instructional and learning theories and techniques, to improve initial skill acquisition and retention in classroom settings and to facilitate the generation of curriculum materials. They also include the evaluation of methods and media in these environments. Finally, this sub-area encompasses activities aimed at improving the effectiveness and lowering the costs of training devices.

**a.** *Goals and Timeframes.* This sub-area includes ambitious goals in several diverse areas. At its most basic level, the area will develop technologies to deliver any training the DoD offers to personnel worldwide. This involves developing: (1) "virtual classrooms"—computer visual and networking technologies that enable a student to attend and participate in any distant classroom; (2) "immersion" technologies for remote visual display systems, and real-time remote instructor control of these systems; (3) scenario scripting and authoring techniques based on improved understanding of learning and cognition; (4) technologies to remotely monitor real-time student performance, including biopsychometric (e.g., cortical-evoked potential) measurement technologies; and (5) technologies to double the training readiness of high-priority National Guard units.

Capitalizing on advances in computing power and software, including the application of artificial intelligence technologies, this area will make intelligent tutors affordable through low-cost authoring systems. In FY96 a prototype automated instructional design environment will be delivered. In FY98-00, an advanced instructional design advisor will be delivered to enable subject matter experts to perform as interactive courseware experts. An authoring shell to develop simulation-based intelligent tutoring systems for equipment-related tasks will be delivered in FY96.

Further goals of this program include: (1) development of design guidelines for the acquisition of future deployable aviation trainers to support training for strike missions and timely mission rehearsal; (2) replacement of high-cost training simulators with flexible, deployable VE-based training systems; (3) development of innovative ways to improve training using simulation-based technology; and (4) increasing the use of simulation technology to replace expensive prime equipment. Full color, high fidelity, low cost helmet mounted display systems for simulators will be available in FY96; a deployable night vision device training system prototype will be complete in FY97; combat mission rehearsal strategies for airborne and ground-based environments will be ready in FY99; and joint-service training guidelines for air warriors will be available by FY00.

In addition, technologies in this area will provide efficient and effective classroom infrastructure. This involves developing: (1) "paperless classrooms" which link electronic technical manuals with other electronic curricular materials; (2) the capability for automated authoring and technical content updates for electronic curricula; and (3) the capability to produce learning materials adapted to different learning levels from common content databases.

Training strategies are needed that make the most cost-effective use of live firing, field and sea training, and the inventory of training aids, devices, simulators, and constructive simulations; training management technologies are necessary for commanders to rapidly adjust training programs to meet changing mission requirements with constrained resources. This area will also develop a system to have potential issues in tactical doctrine, unit organization, and training resolved in time to meet implementation of the new digitized systems in the force. Major areas include training for combat information center operations, battle group tactical team training, damage control training, and embedded training. These technologies will be developed in FY94-FY99.

**b.** *Potential Payoffs and Transition Opportunities.* Payoffs from the training systems program will include reductions in travel cost and "awaiting instruction" time now spent for fixed-schedule, single-site courses; reduced need for duplicative training infrastructure; and increased readiness through appropriate training. The payoffs of intelligent, computer-aided training technologies will be reduced training development time and costs, improved deployability of training, more effective courseware, and improved performance by trainees. These technologies will be widely transitioned across the services, other government organizations, the educational community, and the private sector. Strong ties to the educational and private sectors have been established via CRDA and consortium participation. Research on how to train tactical decision making will potentially increase decision-making accuracy by 40 percent and reduce the time required to make critical decisions by 30 percent.

In other arenas, air combat units will be able to deploy with complete ground- based training systems, to realistically rehearse missions anywhere in a timely manner, and to fulfill all their training requirements, not just those that their flying hour programs allow. With better air combat training systems, air warriors will attain expertise at the tenth combat mission level of experience before they fly their first combat mission. The potential payoff of training simulation S&T is very high in terms of improved mission performance and an order-of-magnitude cost reduction in comparison to current simulators. VE-based simulation technology will enable the replacement of a large inventory of unique, expensive simulators with a single human-computer interface which will serve a wide variety of applications with reconfigurable software. Transitions are expected to support specialized non-defense applications such as surgical and dentai training, equipment operation and maintenance, and complex concept learning. Substantial improvements in learning and retention of critical skills are anticipated from the use of innovative, generalizable instructional features. The development and application of relatively low cost simulation technology will result in improved training cost-effectiveness and safety.

**c.** *Major Technical Challenges.* Technical challenges involve improving capabilities in biopsychometrics, the measurement of cognitive functioning and brain processes, applying natural language processing to automating the generation and maintenance of instructional content, and developing remote instructor control of advanced display and monitoring technologies. New ground is being broken in how people learn and how to facilitate that learning, in how to reduce costs and time associated with developing and delivering high quality intelligent computer-aided training, and in learning how to effectively use digital libraries for interactive learning and courseware design.

While research is to be conducted using stand-alone and networked simulators, validation must be carefully conducted in combat-like environments, such as that provided by the National Training Center at FT Irwin. Training strategies need to be validated by objectively measuring the combat performance capabilities of units that experimentally adopt alternative strategies using different mixes and sequences of field training, Distributed Interactive Simulation, simulated and live weapons firing, and the varieties of devices and simulations available to units.

Other technical challenges include refinement of head-mounted visual displays and packaging of technology for high performance in space-constrained environments. There are numerous behavioral science and engineering challenges in the development and refinement of VE-based constituent technologies. Creating realistic synthetic environments, creating visual systems that provide photo-realistic imagery, measuring situational awareness, and providing timely and effective mission rehearsal systems are all challenges to be dealt with.

**d.** *Performing Organizations.* The service in-house share of this sub-area ranges from 20 percent in the Air Force to 40-50 percent in other services. Industry share ranges from 44 percent in the Air Force to 30 percent in the other services. University share is approximately 30 percent in each service. All ARPA efforts are contracted.

**e.** *Related Federal and Private Efforts.* The ARPA Technology Reinvestment Program (Training/Instruction Technology; Authoring Tools), the NSF/ARPA Digital Libraries Initiative, the National Science Foundation, and Department of Education programs in instructional technologies and math and science education are directly related efforts.

**f.** *Funding*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| **Funding ($M)** | 90 | 87 | 82 | 75 | 63 | 63 |

### 3. Roadmap of Technology Objectives

See Table 14-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

The Manpower, Personnel, and Training area depends heavily on enabling technologies developed under the cognizance of the Modeling and Simulation area. In addition, advances in computer hardware and software, including advances in artificial intelligence, are transitioned into personnel and training systems to more effectively and efficiently deliver products to users. Similarly, advances in the Human Systems Interface and Medical areas often provide technologies that the Manpower, Personnel, and Training area can exploit.

**Table 14-1. Roadmap of Technology Objectives for Manpower, Personnel, and Training S&T Goals**

| Sub-Area | By 1995 | By 2000 | By 2005 | System Insertion Potential |
|---|---|---|---|---|
| Manpower and Personnel | • New theory of human intelligence and principles for constructing cognitive tests<br>• Methods to capture information processing skills for jobs<br>• Analysis tools to determine manpower, personnel & training requirements for new weapon systems<br>• Tests to identify skills underlying situational awareness | • Demonstration of a new generation of aptitude tests<br>• Demonstrate a new system for structuring military jobs<br>• A model of the leader-development process<br>• Techniques for evaluating peacekeeping operations and their organizational impacts | • Mission-ready personnel system to allocate personnel to jobs<br>• Identify domain-specific knowledge & skill determinants of job performance<br>• Develop new predictors of job success<br>• Measures of nontraditional components of job performance | Personnel selection and classification systems |
| Training Systems | • Validated techniques for training situational awareness skills for air combat<br>• Prototype virtual environment trainer<br>• Fundamental skills Word Problems solving Tutor and Reading/Writing Tutor<br>• Prototype intelligent training systems for complex job skills | • Authoring shell for simulation-based intelligent tutors<br>• Color, high fidelity, low cost helmet mounted display systems<br>• Flexible, reconfigurable, deployable VE-based training systems<br>• Double the training readiness of National Guard units | • Intelligent instructional development system<br>• VE-based intelligent tutor authoring shell<br>• Combat situational awareness training system<br>• Integration of live players into virtual constructive air warrior training<br>• Secure, networked, joint-service synthetic training | Aircrew and technical training systems |

# 15. MATERIALS, PROCESSES, AND STRUCTURES

## A. SCOPE

Materials, Processes, and Structures (MP&S) technologies produce an enabling array of capabilities for every DoD system that flies in air or space, navigates on land or over/under the sea, and fires or is fired upon. MP&S technologies are equally critical in maintaining the DoD infrastructure, from military piers and trucks to sophisticated sensors and optical systems, and in reducing the impact of defense systems on the environment. MP&S spans all material categories—metal and intermetallic alloys; ceramics; polymers; composites of all types; semiconductors; superconductors; optical, ferroelectric, and magnetic materials; and materials for power sources.

Funding for this area is $517 million in FY 1994.

## B. VISION

Discover, develop, and transition enabling materials, processes, and structures technologies to produce and sustain affordable, decisive military capabilities; avoid technological surprise; and enhance economic security.

## C. RATIONALE

All military hardware relies on MP&S for its performance and, indeed, its very existence. Continued progress in MP&S is essential to increased affordability, performance, and longevity in DoD hardware and, therefore, crucial in meeting all the Joint Chiefs of Staff Warfighting Capabilities. MP&S supports not only prime development programs, e.g., composite aterials and armor for lightweight, rapidly mobile fighting vehicles and aircraft, but also operational needs, such as corrosion control, life management/extension of aging military assets, and, not least, materials to protect eyes and sensors against future agile (tunable) lasers.

The evidence of advances in MP&S surrounds us in both civilian and military life and is so widespread and deep that space permits few examples. The future will bring artificial diamond for 200-400 percent harder sensor windows, intelligent processing using embedded sensors for control to eliminate scrap loss, polymer composites for 30-50 percent structural weight reduction, adaptive structures that respond and tailor themselves to environments—allowing rock-solid space platforms and aircraft wings that shape themselves to flight requirements and report their structural health as well, and advanced ship hull steels, which have saved the Navy $125 million so far and have many commercial possibilities beyond ships, e.g., bridges.

All upgrades and new military systems provide transition opportunities. Lightweight combat vehicles, low observable aircraft and ships, advanced propulsion systems of all types, high temperature microcircuits, and comfortable chemical/biological suits and body armor for the individual war fighter, and many more are dependent critically on MP&S. Furthermore, the government technical personnel who produce and procure these S&T products form a crucial cadre that guarantees that DoD remains technically current.

Although driven by defense needs in terms of performance, protection, and life-cycle costs, MP&S technologies are inherently dual-use and many have been exploited by the commercial sector to enhance the economic position and security of the United States in products ranging from aircraft engines to high temperature circuits and sensors in automobiles and steel production. Concomitantly and symbiotically, often a commercial technology is exploited by tailoring or further development to meet DoD needs. Since the majority of the MP&S Program is performed by U.S. industry and universities, it bolsters the academic and industrial infrastructure and promotes linkage among them.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

MP&S is divided into four functional sub-areas. Because of the extensive and detailed nature of each, only a limited number of illustrative examples can be provided.

### 1. Materials and Processes for Survivability, Situational Awareness, and Weapons Delivery

**a.** *Goals and Timeframes.* This critical and defense-specific area includes developments primarily aimed at protecting personnel and systems either directly (armor) or indirectly through situational awareness (sensors) or counter fire (anti-armor). Key examples are lightweight composite armor (armor), personal ballistic protection (BalPro), infrared control coatings (IRCoat), agile laser protection (Laser), and transducers (electromechanical sensors and actuators) (Trans) with goals detailed below:

| TIME | AREA | GOALS |
|---|---|---|
| 2000 | Armor | • 25-35% weight reduction vs. steel with < $10/lb material cost |
| | BalPro | • 20-30% weight reduction for small arms & fragment protection |
| | IRCoat | • Combined high emissivity & low reflectivity coatings |
| | Laser | • Develop materials with < 1 microsecond response time |
| | Trans | • 90% reduction in submarine/ship acoustic radiation via active control |
| 2005 | Armor | • Eliminate need for separate spall liners in heavy & lightweight armor |
| | BalPro | • 20-30% weight reduction in hardened shelters for personnel |
| | IRCoat | • Independently controllable emissivity/reflectivity coatings |
| | Laser | • Develop materials that respond inherently to lasers (infrared to visible) |
| | Trans | • Reduce unmanned underwater vehicle drag for 10 knot speed increase |
| 2010 | IRCoat | • Develop adaptive coatings/systems that respond automatically to background & threats |
| | Trans | • Provide full active vibration control of ship systems virtually eliminating acoustic signature |

**b.** *Potential Payoffs and Transition Opportunities.* The payoffs in this area correspond to greatly increased survivability of personnel and systems in threat intensive environments and increased mobility for troops and platforms. Transition into the Generation II Soldier Advanced Technology Demonstrator, personal laser protection systems, and next generation platforms and major upgrades will follow demonstrations.

c. *Major Technical Challenges.* The greatest challenges in this area are affordable production and fabrication of novel materials and components for military systems. In the laser and infrared materials areas scientific breakthroughs are needed in non-linear optical properties and properties control, which will be followed by affordability challenges in material synthesis in fieldable quantities.

d. *Performing Organizations.* Industry, 50 percent; University, 18 percent; Government, 32 percent.

e. *Related Federal and Private Sector Efforts.* Because of the highly defense-specific nature of this area there are few parallel efforts beyond defense industry independent research. Laser protection materials have been commercialized in a small way in welding and other industrial and laboratory protection systems.

f. *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| | 166 | 153 | 147 | 157 | 162 | 161 |

## 2. Life Extension, Reliability, and Affordable Processing

a. *Goals and Timeframes.* The Defense Department is faced with maintaining aging fleets of all platforms in a state of readiness. This is exacerbated by reduced budgets. Material advances will reduce costs of components and maintenance of systems without compromising war fighting capability. Approaches involve life-cycle management (Life), increased reliability (Rely), and innovative affordable processing (Process). Specific goals are:

| TIME | AREA | GOALS |
|---|---|---|
| 2000 | Life | • 90% cost reduction in batteries via novel recharging methods/materials |
| | Rely | • 50% reduction in corrosion-initiating flaws for life cycle component cost savings of 40% |
| | Process | • 90% reduction in small lot (10-100) component costs via intelligent and flexible manufacturing |
| 2005 | Life | • Wear monitoring sensors for life management with 30% reduction in ship maintenance hours |
| | Rely | • 100% life increase for helicopter replacement parts via increased corrosion and fatigue resistance |
| | Process | • Pilot shipboard use of solid free form processing and electronic storage of material shape specs |
| 2010 | Life | • Provide model-based maintenance on condition for 80% reduction in mechanical flight mishaps |
| | Rely | • 40% reduction in rework costs associated with wear via advanced coatings |
| | Process | • 100 to 1 life cycle cost reduction for small parts via solid free form processing small parts |

b. *Potential Payoffs and Transition Opportunities.* The cost of maintaining air, surface, and subsurface platforms at high readiness levels costs billions of dollars per year. This cost is expected to escalate due to the aging of current equipment, making the payoff potential of life extension as high as $50 billion per year through improved life management, reliable replacement materials for upgrades and more cost-effective processes. Major examples include a 50 percent reduction in aircraft maintenance hours per flight hour and a 35 percent reduction in spare parts inventories (>$1 billion savings). Transition opportunities include materials for the CH-46 and other aircraft, advanced sensor and model-based maintenance schedules for ship machinery and aircraft engines, processes at depots for supplying small parts on demand for multiple systems.

**c.** *Major Technical Challenges.* Significant advances in understanding degradation (corrosion, wear, and erosion) and failure processes under complex loading in realistic environments are needed along with new sensors to monitor the health and predict the condition and remaining life of platforms. Innovative routes that permit the cost effective manufacture of high performance parts are required. Improvements are needed in both corrosion resistant materials and in predicting fatigue and failure under three dimensional complex loads. Innovative processing routes using sensors for intelligent control and computer material design are key to achieving these savings.

**d.** *Performing Organizations.* Industry, 53 percent; University, 23 percent; Government, 24 percent.

**e.** *Related Federal and Private Sector Efforts.* NASA (High Speed Civil Transport), the Federal Aviation Administration (Aging Aircraft), and related industry are involved in parallel efforts. The massive Department of Transportation & Federal Highway Administration infrastructure renovation program is heavily dependent on defense technology advances in composites and nondestructive testing.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| | 85 | 79 | 76 | 81 | 92 | 96 |

## 3. Military Structural and Propulsion Materials

**a.** *Goals and Timeframes.* Includes synthesis processing and testing of all metallic and non-metallic materials, composites and associated structures as load bearing or mechanical support components in all classes of military vehicles, weapons, and other platforms. This broad area spans S&T from more affordable and weldable alloys for ship and submarine hulls to lighter weight materials of all types for aircraft and satellites (costing many thousands of dollars per pound to orbit). Some specific thrusts include lower cost resin-matrix composites (RMC), low cost titanium alloys (Ti), and alloys and composites for engines (EngMat) as detailed below:

| TIME | AREA | GOALS |
|---|---|---|
| 2000 | RMC | • 10-20% cost reduction via automated manufacturing and reduced parts count |
| | Ti | • 40% weight reduction and immunity to corrosion via substitution of $7/lb Ti alloys for steel |
| | EngMat | • 40% component weight savings via substitution of intermetallics for nickel superalloys |
| 2005 | RMC | • 25-50% weight reduction in ship superstructures with lowered signature |
| | Ti | • 50% reduction in welding and machining costs |
| | EngMat | • 30-50% reduction in fuel consumption & 50% less nitrogen oxides via ceramic components |
| 2010 | RMC | • Complete field repairablity of composite structures |
| | EngMat | • Reliable joining & inspection of ceramics and metals for hybrid components |

**b.** *Potential Payoffs and Transition Opportunities.* The greatest payoffs in this area are in weight savings (up to 50 percent), permitting enhanced mobility structures and higher performance engines. In engines at least half the desired performance increase is based on higher temperature, lower density materials. All advanced systems are being designed with lower density materials and some systems, such as advanced short takeoff and vertical landing aircraft, will not be fieldable without them.

**c.** *Major Technical Challenges.* The greatest challenges are in affordable processing, fabrication, and inspection of these increasingly complex materials systems and in maintaining low costs in relatively low volume, non-commodity materials and processes.

**d.** *Performing Organizations.* Industry, 56 percent; University, 19 percent; Government, 25 percent.

**e.** *Related Federal and Private Sector Efforts.* Weight reduction and increased quality are major initiatives in virtually all areas of vehicle and aircraft research and development with NASA, the Departments of Energy (DoE) and Commerce, and the U.S. automotive and aircraft industries being major participants. The DoE Continuous Fiber Ceramic Composites and Ceramic Matrix Composites Multi-Megawatt turbine programs are being built on defense technologies developed over the past decade. As these sectors become greater consumers of advanced composites and high temperature alloys, specific costs for the defense specific applications should decline conjunctively.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| | 173 | 151 | 166 | 169 | 195 | 204 |

## 4. Weapons Systems Structures Science and Technology

**a.** *Goals and Timeframes.* This area includes all generic structures efforts such as design methodologies, modeling concepts, structural mechanics, and non-system specific structures development. Notable thrusts include all aspects of more affordable design and fabrication, smart structures with embedded sensors and antennas, higher temperature polymer structures, and active/adaptive structures that can respond to their immediate environment. Some highlights include the Army composite armored vehicle (Vehicle), carbon-carbon composites (Carbon) for ballistics and space systems, space structures (Space), and aircraft. Some specific goals are:

| TIME | AREA | GOALS |
|---|---|---|
| 2000 | Vehicle | • 30% weight reduction vs. aluminum vehicles for 50% increase in air deployability |
| | Carbon | • Demonstrate structural thermal management panels with 30% increase in thermal conductivity |
| | Space | • 30% lower weight and 50% greater damping capacity vs. aluminum |
| 2005 | Carbon | • Increase shape stability of carbon-carbon nosetips for 50% increase in ballistic accuracy |
| | Space | • Zero coefficient of thermal expansion with no warpage for reconnaissance and communication |
| 2010 | Aircraft | • Common fuselage structure for Joint Advanced Strike Technology and other joint systems |

**b.** *Potential Payoffs and Transition Opportunities.* The Army composite armored vehicle forms a crucial part of modernization plans for future rapid mobility. Tactical ballistic systems require even greater accuracy than strategic and upgrades are likely. All satellite systems have more stringent weight and damping requirements for both precise communication and surveillance. Commercial satellite by-products will enhance the affordability and industrial base as well.

**c.** *Major Technical Challenges.* Affordable manufacturing and assembly techniques for these new structures are required as are inspection and repair procedures in-service. A particular challenge is the technology base to enable the evolution of a common Air Force-Navy fuselage in any Joint Advanced Strike Technology Program aircraft.

**d.** *Performing Organizations.* Industry, 59 percent; University, 14 percent; Government, 27 percent.

**e.** *Related Federal and Private Sector Efforts.* The National Science and Technology Committee, Aircraft Materials and Manufacturing Technology, coordinates NASA/DoD aircraft structures efforts. NASA and the civilian satellite industry have parallel efforts in the development of lightweight space structures, although with much lower survivability requirements. There are few efforts outside the defense industry that are directly relatable to the structural requirements of military platforms.

**f.** *Funding*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| | 93 | 106 | 95 | 99 | 89 | 88 |

### 5. Roadmap of Technology Objectives

See Table 15-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

MP&S is pervasively related and a critical path in twelve other technology areas: Aerospace Propulsion and Power; Aerospace Vehicles; Chemical and Biological Defense; Clothing, Textiles and Food; Conventional Weapons; Electronic Devices; Electronic Warfare/Directed Energy Weapons; Environmental Quality and Civil Engineering; Sensors; Surface/Under Surface Vehicles; and Manufacturing Science and Technology. Further, Structures technologies are individually crucial to all platform and weapons areas.

**Table 15-1. Roadmap of Technology Objectives for Materials, Processes & Structures**

| Sub-Area | By 1995 | By 2000 | By 2005 | Transition Opportunities |
|---|---|---|---|---|
| Survivable Materials | • High Strain (0.5%) Actuators for Dynamic Vibration Control<br>• Order of Magnitude Increase in Hydrostatic Properties for Towed and Conformal Arrays | • 30% Weight Reduction in Mobile Command Posts<br>• High Speed (1 microsec.) Switching Materials for Laser Eye Protection<br>• Reduce Submarine High Speed Acoustic Signature by 90% | • 30% Body Armor Weight Reduction for Small Arms Defeat<br>• Reduce IR Emissions Vulnerability to Same Levels as Radar Vulnerability<br>• Increase Torpedo/UUV Speed by 10 knots | DDG-51<br>SSN-21<br>Gen II Soldier ATD<br>V-22<br>F-22<br>JASTP<br>M2/3<br>MLRS<br>AMRAAM<br>Standard Missile<br>HARM |
| Life Extension, Reliability, and Affordable Processing | • Reduce Corrosion Initiating Defects by 50%<br>• Establish Solid Free Form Fabrication Processes | • Predict Residual Structural Life after Fatigue, Particulate, or Rain Damage<br>• Reduce Small Component Replacement Part Costs by 90% | • Model Based Predictive Capability for Machinery Lifetime<br>• Reduce Cost of Ceramic Components by 25% | CH-46 F-15<br>CH-53E F-16<br>SH-60<br>LM2500<br>SSN-688<br>RAH-66<br>AH-64<br>SSN-21<br>F-18 |
| Military Structural and Propulsion Materials | • Low Cost, Corrosion Resistant Structural Titanium for Combat Vehicles with 40% Weight Reduction<br>• Polymer Composite Materials with 50% Weight Reduction, 20% Cost Reduction for Ship Superstructures | • Reduce Aircraft Engine Component Weight by 40%<br>• Implement Intermetallic and Metal Matrix Components for 50% Weight Reduction in Motors | • Reduce Aircraft Compressor Weight by 50%<br>• Incorporate Engine Component Coatings to Reduce NOx by 50% | Comp Armored Veh<br>JASTP<br>V-22<br>ASTOVL<br>F119<br>F414<br>F402<br>F-18E/F<br>MK 50 Torpedo Propulsor<br>UUV<br>Tomahawk |
| Weapons Systems Structures Science and Technology | • Develop Advanced Sensors Utilizing Neural Networks for Vibration Analysis | • Reduce Weight of Air Deployable Light Armored Vehicles by 50%<br>• Implement Active Control for Vibration Damping | • Develop Full Scale Structures Life Time Models<br>• Incorporate Advanced Sensing Techniques for Maintenance Schedules | JASTP<br>Adv. Satellites<br>NAVSTAR<br>ASTOVL<br>F-18<br>F-22<br>V-22 UAV |

# 16. SENSORS

## A. SCOPE

This area develops technologies in five major subareas: Radar Sensors, Electro-Optic Sensors, Acoustic Sensors, Automatic Target Recognition, and Integrated Platform Electronics & Sensors. Applications include strategic and tactical surveillance, identification and targeting of threats from all military platforms including satellites, aircraft, helicopters, ships, submarines, ground vehicles and sites, unmanned air vehicles, unattended ground sensors and the individual soldier.

Funding for this area is $981 million in FY94.

## B. VISION

Affordable sensors that provide U.S. forces continuous, near-perfect situation awareness and rapid, precise discrimination and targeting of all threats in all environments.

## C. RATIONALE

Sensors are pervasive ... the eyes and ears for nearly all U.S. tactical and strategic weapon systems as well as the intelligence community and represent an increasingly high percentage of total weapon system cost. The planned DoD S&T investment in Sensors will significantly reduce future sensor costs and provide technologies crucial to meeting the top five JCS future warfighting capabilities including: all-weather, day-night surveillance, precision targeting and damage assessment; detection and tracking of difficult targets such as cruise missiles, anti-ship missiles, ballistic missiles and quiet submarines; and positive combat ID.

Significant improvements in performance and cost of sensors -- e.g., 50% reduction in cost of imaging radars and infrared search track sensors, 10:1 improvement in thermal sensitivity of infrared sensors, and a 100:1 improvement in false alarm rate and search rate of automatic target recognizers are attainable through foreseeable advances in: affordable microwave integrated circuits, ultra-large and multi-color infrared focal plane arrays, low noise fiber optic sonar arrays, very high speed signal processors, common modules, shared aperture and adaptive processing. Illustrative payoffs include: Cost-effective imaging radars for UAVs, 5:1 improvement in RV/decoy discrimination, 2:1 improvement in detection range of submarine and 2:1 increase in non-cooperative identification and weapon engagement ranges against tactical targets.

Because of their pervasiveness, potential for cost-effective system upgrades, and potential for revolutionary next generation systems, sensor technologies have a myriad of transition opportunities. Examples include: Ground Based Radar, THAAD, Brilliant Eyes, F-14, F-15, F-16, F-18, F-22, U-2R, E-3A, JSTARS, Long Bow, Apache, Tier II+ UAV, Scout Vehicle, all tanks, all submarines, all ASW aircraft, unattended ground sensors and 21st Century soldier. Dual-use applications include: environmental sensing, air traffic control, GPS navigation equipment, airline landing systems, and medical imaging equipment.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Radar Sensors

**a.** *Goals and Timeframes.* Radar is the sensor for all weather detection of space, air, ground and buried targets. Radars are located on space based, airborne, shipborne, and/or stationary and moving ground based platforms. The radar spectrum is used for theater and ballistic missile defense, detection of over-the-horizon (OTH) and foliage concealed targets, fire control, classification, ID and recognition. Improved reliability, availability and lower costs with improved platform sensor integration are important goals.

| | |
|---|---|
| 1999 | Near "Leak-Proof" Ballistic Missile Defense Ground Based Radar (10X Coverage). |
| 2005 | 50% Reduction in Imaging Radar Cost. |

**b.** *Potential Payoffs and Transition Opportunities.* Ground Based Radar technology provides "Near Leak-Proof" theater and ballistic missile defense coverage and timely warning, discrimination and assessment. Tactically, radar technology provides detection, track, classification and ID of all advanced target threats including those with a 1000 fold reduction in target cross section. Potential payoffs include 3 orders of magnitude on detection and track performance for all targets and a 50% reduction in cost. Results of these developments will be transitioned, retrofitted, or become adjuncts to AWACS, JSTARS, E-2C, ASARS, F-15, F-16, F-18, JAST, Tier II+ UAVs, Naval Battle Fleet sensors, and Army's Battlefield Surveillance sensors. Dual use opportunities include: Counterdrug program, Ocean current monitoring, tracking hurricanes, and tracking commercial airlines. Other applications include: Ground penetrating radars for geo-research for buried pollutants, oil and gas reserves. The commercial airlines use airborne radar intercept technology to improve wind shear detection, and the FAA benefits in the Air Traffic Control area.

**c.** *Major Technical Challenges.* The ability to detect and track advanced targets (1000 fold reduced cross section) immersed in severe clutter and jamming environments is required by all Wide Area Surveillance, Tactical Surveillance, and Point Defense Systems. Three orders of magnitude in system sensitivity require improvements in power aperture product, space time adaptive processing to mitigate severe clutter and jamming, adaptable radar waveforms, affordable transmit/receive modules and electronically scanned arrays.

**d.** *Performing Organizations.* All military Services, ARPA, and BMDO participate in the radar sensor area. Approximately 70% of the funds are contracted to industry and universities.

**e.** *Related Federal and Private Sector Efforts.* NASA is using radar technology for remote sensing, atmospheric weather research, and digital terrain mapping. DOE uses radar for resource protection and strategic buried objects surveillance.

**f.** *Funding.*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Radar | 63.9 | 110.4 | 132.9 | 197.5 | 90.9 | 73.0 |

## 2. Electro-Optic (EO) Sensors

**a.** *Goals and Timeframes.* EO sensors goals are to provide passive/covert and active target surveillance detection, designation, classification and recognition at reduced cost. Increased survivability and defeat of difficult, tactical targets are primary payoffs. Major developments include: Affordable thermal imaging receivers; IR search and track (IRST) systems for air intercept and ship self-defense; and multi-spectral sensors for detection of targets in "deep hide". EO sensors also provide the majority of strategic space technology for a near perfect capability to detect, discriminate, track, and defeat Theater and Ballistic missiles. Major EO sensor investments in critical space observations and demonstrations such as MSX and MSTI provide threat missile signatures, upper-stages and PBV signatures and RVs/Penaids signatures. Investments for terrestrial and celestial backgrounds system performance is also included in this area.

| | |
|---|---|
| 1998 | Theater Ballistic Missile target acquisition & 3-D tracking from space. |
| 2005 | 50% Reduction in Imaging Radar Cost. |

**b.** *Potential Payoffs and Transition Opportunities.* Significant payoff will be realized from reductions in fratricide and 40% improvement in target acquisition ranges. Transition opportunities exist for all of the Services' major platforms. Dual use applications include thermal sensors for night driving of cars, laser wind profilometers for wind shear detection, obstacle avoidance systems for commercial helicopters, environmental monitoring and remote earth sensing.

**c.** *Major Technical Challenges.* For MSX and MSTI experiments/demonstrations EO sensors, acquisition of threat representative boosters, tracking of PBV deployment phase, and kinematic discrimination represent major challenges. Challenges for tactical EO sensors include the introduction of affordable, smart, focal plane arrays with advanced signal processing, motion stabilization, advanced background/clutter rejection techniques, sensor fusion of FLIR, IRST, LASER, and LADAR subsystems, advanced digital signal processing for the detection and extraction of concealed targets, algorithms for built-in digital maps and situational awareness, highly efficient cryogenics, multi-wavelength windows, and advanced FPAs, cryocoolers, optics and processors for space systems. Additionally, new modeling and simulation capabilities are required to provide a cost effective method for design trade-offs, enhanced training, and reduced manufacturing costs.

**d.** *Performing Organizations.* All military Services, ARPA, and BMDO participate in the EO sensor area. Approximately 80% of the funds for sensors are contracted to industries and universities.

**e.** *Related Federal and Private Sector Efforts.* Industry investment is conservatively estimated at approximately $60 million per year.

**f.** *Funding.*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Electro-Optics | 381.8 | 263.0 | 316.5 | 293.5 | 274.2 | 264.0 |

## 3. Acoustic Sensors

**a.** *Goals and Timeframes.* Acoustics (Sonar) is the primary U.S. technology for providing undersea surveillance to detect, classify, localize and track undersea targets. The world-wide proliferation of modern quiet diesel-electric submarines require the use of active sonar for detection. Improved operating performance of existing active sonar systems, in shallow water, is the short-term (<5 yrs) goal. Within 10 yrs, active sonar systems that can sense the highly variable littoral environment, adapt to the variations, and properly classify targets in high clutter environments are required. Acoustic techniques are also being developed for battlefield applications that detect and identify ground vehicles, and aircraft.

| | |
|---|---|
| 2000 | Demo ultra-wideband (5KHz) variable depth sonar with 20dB improvement. |

**b.** *Potential Payoffs and Transition Opportunities.* Use of UWB signals/processing and interoperability will provide shallow water ASW capability. Transition of classification algorithms will be implemented on SQS-53C surface ship sonar and ALFS helicopter dipping sonar.

**c.** *Major Technical Challenges.* To detect, identify , and classify targets technology improvements are required in sensor sensitivity, reduction in size and cost to enable the use of greater numbers, and improved signal processing techniques that process many sensors with large bandwidth and dynamic range. Active sonar operation is severely limited in shallow water by high clutter and multi-path returns. Classifying target returns from non-target returns is the primary issue. Understanding of the propagation path continues to be needed for improved sensor performance.

**d.** *Performing Organizations.* Naval: NSWC, NAWC & NRL. Army: ARL.

**e.** *Related Federal Organizations and Private Sector Efforts.* Limited non-DoD use.

**f.** *Funding.*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Acoustics | 90.0 | 91.9 | 92.5 | 91.7 | 89.0 | 86.0 |

## 4. Automatic Target Recognition (ATR)

**a.** *Goals and Timeframes.* ATR goals are to provide high confidence recognition and identification of ground, ship and airborne targets using radar and EO sensors.

| | |
|---|---|
| 1995 | 100% RV/debris discrimination. |
| 2005 | 1000X search rate improvement for imaging radar tactical target recognition. |

**b.** *Potential Payoffs and Transition Opportunities.* Potential payoffs include increased sensor search rate, reduced operator workload, quicker reaction time and positive combat ID. Transition opportunities include 1) ground attack platforms - Apache, Comanche helicopters; M1 tanks; F15, F16, F18, JAST fighters, and B1 & B2 bombers; 2) surface surveillance platforms -JSTARS, U2R, Tier 2+, P3, and classified; 3) counter air platforms - Patriot and Hawk, AEGIS, AWACS and S3, F15, F16, F22, F14; and 4) counter missile platforms - Patriot, THAAD, GBR, and AEGIS; ERV, SMTS(BE), and BPI national missile defense systems.

**c.** *Major Technical Challenges.* Challenges for ground targets include increasing the recognition performance, reducing false alarm rate, and extending ATR performance to handle larger target sets, difficult/complex target states, and future sensor data rates. Airborne targets include high confidence ID at long ranges, at all aspects, and extending ID performance for multiple and LO threats. Challenges for missile targets include performing discrimination for RV's from debris and increasingly sophisticated decoys. A significant challenge for all of ATR is the rapid retraining of algorithms to contend with changes in target signature and new threats/decoys.

**d.** *Performing Organizations.* DoD Labs 30%; Industry 60%; Univ./Non-Profit 10%.

**e.** *Related Federal and Private Sector Efforts.* Significant private sector investments in image processing includes medical and robotic imaging, and remote sensing.

**f.** *Funding.*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| ATR | 129.9 | 119.7 | 113.3 | 113.8 | 115.0 | 119.1 |

## 5. Integrated Platform Electronics and Sensors (IPES)

**a.** *Goals and Timeframes.* Goals are to effectively integrate sensors, electronics and structures in the design of military platforms through use of common modules, components, and standard interfaces. The military platforms of interest include spaceborne, airborne, and ground/ship/soldier based platforms. Integrated approaches, where all of the anticipated functional requirements are considered in harmony with the constraints imposed by the platform system, result in very superior electronics systems. Integrated electronics approaches will result in systems at half the cost and weight and over three times the reliability of conventional approaches.

| | |
|---|---|
| 1995 | 2 man tank crew station with performance of a 4 man crew. |
| 2005 | Demo multifunction RF avionics with 50% cost savings. |

**b.** *Potential Payoffs and Transition Opportunities.* As electronics subsystems currently approach 40% of the acquisition cost of aircraft systems (comparably high and growing percentages of space, vehicle and shipborne systems), the payoffs for reduced cost electronics systems is through an integrated approach. The payoff is particularly great for "mission electronics", for electronic warfare, and communications, navigation, identification. Integrated electronics permit rapid technology insertion and reduced "logistics tails". The transition targets are virtually every military platform that incorporate electronics subsystems.

**c.** *Major Technical Challenges.* The most significant challenge to IPES is to determine an architecture or set of architectures which prove sufficiently robust over a long period of time to readily accept technology innovations developed in the commercial sector.

**d.** *Performing Organizations.* All military Services, ARPA, NASA, and universities participate in IPES. Over 85% of DoD IPES funds are contracted to industry.

**e.** *Related Federal and Private Sector Efforts.* IPES plays a major role in the private sector for automotive and airline systems and subsystems.

**f.** *Funding.*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| IPE | 69.3 | 90.1 | 92.3 | 101.6 | 89.2 | 59.7 |

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

Sensors depends heavily on technologies developed in the Electron Devices and Computer areas. Basic sensor technologies are leveraged by Conventional Weapons for guidance and control and Human Systems Interface for operator display and performance aiding.

# 17a. SURFACE/UNDER SURFACE VEHICLES
# - SHIPS AND WATERCRAFT -

## A. SCOPE

The Ships and Watercraft Technology Area provides the technology for improved combat efficiency, survivability, and stealth of surface ships, submarines and unmanned undersea vehicles. Funding for this area is $108 million in FY1994.

## B. VISION

Develop innovative, next generation technologies that meet the joint military forces warfighting needs. Transition those superior technologies to enable affordable, decisive military capability and to enhance economic security.

## C. RATIONALE

The potential for large scale regional conflicts, the proliferation of weapons of mass destruction, and the proliferation of conventional weapon and information technologies are major threats to the security of the United States. Ships and Watercraft play a critical role in countering these threats, particularly in the joint mission/support areas of strike, littoral warfare, strategic deterrence, surveillance, strategic sealift, forward presence, and readiness. The vehicles addressed by this technology area provide the essential means by which personnel, weapons, and sensing devices are delivered and positioned in remote global areas to effectively prosecute both military and non-military objectives.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Surface Ships

**a.** *Goals and Timeframes.* Surface Ship S&T supports the Joint Staff future joint warfare capabilities by developing hull, mechanical and electrical options which provide: significant reductions in the detectability and targetability of U.S. Naval Ships; increased ability to absorb both combat and peacetime damage with minimum degradation of mission capability; and increased operational efficiency as measured by the cost of ownership and mission execution.

*Covertness.* Technology developments will enable Navy combatants to engage regional threats rapidly and decisively. U.S. Navy ships must operate covertly to avoid enemy detection, targeting and engagement. 1995 goals include a closed loop degaussing system for mine countermeasure ships, and a low-cavitating propeller. For 2000, goals include: an advanced enclosed mast/sensor system that will minimize topside signature and enhance sensor performance; a shipboard electromagnetic condition monitoring system that will enable a ship to manage electromagnetic transmissions to minimize interference and active electromagnetic signature; and an advanced combatant degaussing system that will minimize magnetic mine vulnerability. Goals for 2005 include 10-25 dB or similar reductions in radar cross section (RCS), infrared (IR), acoustic, magnetic, and electric signatures.

*Survivability.* Technology enhancements will minimize surface combatant casualties while enhancing capabilities to achieve military objectives. The U.S. Navy will have less ships to conduct future operations. Therefore, ships must be able to sustain casualties and continue to fight hurt. To accomplish this, 1995 goals include advanced fiber optic temperature and smoke sensors, and an affordable double hull concept to increase combatant toughness. Goals for 2000 include: non-ozone depleting substitute for halon to meet environmental standards; and design guidelines for blast hardened bulkheads and hull girders. Goals for 2005 are: shipboard fire and smoke containment for up to 60 minutes; detection and classification of shipboard damage within 60 seconds after a casualty; increased payload by 50 percent through the shipboard application of advanced composite materials and structures; an integrated hull armor system that costs 50 percent less and is 20 percent lighter than current systems.

*Operational Efficiency.* Technology developments will allow Naval forces to promptly and globally engage regional forces. With projected cuts in the U.S. Navy force structure, technologies must be developed that provide affordable ships through reduced acquisition and life cycle costs, reduced manning and more efficient operation. Goals for 1995 include: more reliable, reduced emission (NOx) and more efficient marine gas turbine engines; an advanced electrical distribution system; and machinery monitoring and control system architecture. Goals for 2000 are: permanent magnet electric drive system and shipboard solid state power building blocks. Goals for 2005 include: shipboard mechanical and electrical systems that: reduce weight by 30-60 percent, reduce required manning by up to 50 percent, cost 50 percent less to buy and operate, require 50 percent less maintenance and logistical support, and meet future environmental requirements.

**b.** *Potential Payoffs and Transition Opportunities.*

*Ship Covertness.* Payoffs include: decreased detection range; increased reaction time; improved sensor performance; and increased countermeasure effectiveness.

*Survivability.* Payoffs include fire containment and reduced progressive damage. Hull structures payoffs include: 50 percent increase in combat payload; 30 percent reduction in repair costs; hull can survive 2 anti ship cruise missile hits and 1 torpedo hit; and no mass detonation of weapons magazines.

*Operational Efficiency.* Payoffs include 20 percent increase in ship range; 30-60 percent weight reduction, 50 percent reduction in manning and acquisition costs for electrical and mechanical shipboard systems; reduced life-cycle costs; increased power continuity and fault detection.

Transition Opportunities for 1995 include both backfits (MCM-1, DDG51 Flight I, CG47 and DD963) and new construction ships (DDG51 Flight IIA and LPD17). Transition opportunities for 2000 and 2005 include backfits and new construction ships (SC21/ NGSC, etc.)

**c.** *Major Technological Challenges.* Ship detectability and targeting challenges include: developing reliable and accurate signature prediction and measurement techniques; and developing affordable and effective signature control techniques. Survivability technological challenges involve: developing affordable and reliable damage control systems; defining multi-dimensional failure mechanisms for shipboard structures; developing affordable and light-weight armor systems capable of surviving anti ship cruise missile and torpedo hits; and developing and manufacturing aerospace quality composite ship structures at shipbuilding costs. Operational efficiency challenges include: increasing the service life and efficiency of the marine gas turbine engine; developing power distribution systems that are load insensitive, providing rapid reconfiguration during casualties, and mitigating transients; and developing a pollution-free fuel cell power system that can operate in the shipboard environment using diesel fuel.

**d.** *Performing Organizations (FY94 Baseline).* In-House-50 percent, Universities-4 percent, Industry-44 percent, Other Government-2 percent

**e.** *Related Federal and Private Sector Efforts.* This subarea relates to many other federal and private efforts and is a primary governmental provider of dual use technology to the U.S. maritime industry. The Surface Ship Subarea uses the following programs/organizations to leverage technology investments: The National Shipbuilding Initiative, Technology Reinvestment Program (TRP), Manufacturing Technology (MANTECH), Department of Energy, Electrical Power Research Institute (EPRI), The Great Lakes Composite Consortium and Cooperative Research and Development Agreements (CRDA).

**f.** *Funding*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| DoD | 40 | 37 | 42 | 44 | 27 | 28 |

## 2. Submarines

**a.** *Goals and Timeframes.* Submarine S&T provides the attributes for a covert survivable platform having improved advanced joint warfighting capabilities to: maintain real-time knowledge of the enemy; engage regional forces promptly and on a global scale; employ capabilities suitable to actions at the lower end of the full range of military operations; and counter the threat of weapons of mass destruction and ballistic and cruise missiles to continental United States (CONUS) and deployed forces.

*Stealth.* Technology focuses on maintenance of SSN21 acoustic signature goals at reduced cost, reduction of the signature of surfaced submarines, and reduction of electromagnetic signatures consistent with the threat. Ship self noise goals support the ability of the platform to maintain knowledge of the enemy and to engage forces promptly in decisive combat. These will be achieved through assessment tools (FY96), design methods (FY2000+), active mount and coating concepts FY(2000), composites hull components FY(99), and imaging and diagnostic technologies. To reduce ship vulnerability to mines and EM detection systems, advanced magnetic and electric signature reduction systems will be developed (FY98).

*Hydrodynamics.* Addresses propulsor technology for cost reduction, reduced wake signatures, and improved maneuvering and control for warfighting capabilities in all environments. Propulsion concepts are focused on achieving SSN21 propulsor performance in open preswirl (FY96) and in open propulsors (FY2000). Other near-term goals are to develop computational tools to predict envelopes for wakeless operation (FY97) and maneuvering models for submerged operating envelope (SOE) (FY94/98).

Future goals are to achieve integration of propulsion and control surfaces for improved SOE and platform cost reduction (FY2000+).

*Survivability.* Aims at enhancing the ability to maintain mission capability during weapons engagements and to sustain operational combat capability after being hit. Technology to reduce vulnerability to the mine threat is the primary focus. The survivability goals will be accomplished through the development of computational tools to assess hull survivability (FY95), structural dynamic design criteria (FY99) and integrated static/dynamic design methods (FY2000+). Technologies and concepts will be developed for hull and equipment shock hardening and damage control and will include the use of composites, advanced rafting (FY96/2000+), and hull concepts.

*HM&E.* Goals are to develop advanced hydraulic components (FY94) and systems (FY96/FY2000+); non-Chloro Flouro Carbon (CFC) air-conditioning and air systems (FY04+); DC and solid-state electric systems (FY94); and electric drive (FY2010). To support these aims, design optimization tools (FY94/99) and system studies (FY97) will be developed.

**b.** *Potential Payoffs and Transition Opportunities.*

*Stealth* payoffs will include covert surfaced operations; protection against mines and search & detection systems; increased tactical speed; and covert weapons launch.

*Hydrodynamics.* Payoffs include cost reduction of 30-50 percent and weight reductions of 20 percent over the SSN21 propulsor; improved near-surface operations; accurate prediction of normal and extreme maneuvers; and exploitation of platform speed and depth capabilities.

*Survivability.* Payoffs will include: improved capability to remain combat-capable after attack; and technology to support incorporation of commercial off-the-shelf (COTS) equipment.

*HM&E.* Payoffs will reduce cost ($55M construction & $25M lifecycle), weight (275 tons), and volume (3800 $ft^3$) of machinery and electrical systems while maintaining performance and meeting environmental requirements.

Transition opportunities for all thrusts include the New Attack Submarine (NAS), post-NAS, backfits to SSN688 and Tridents, and Unmanned Undersea Vehicles (UUVs) and Swimmer Delivery Vehicles (SDVs). In limited cases, transitions to the commercial sector and other programs are expected.

**c.** *Major Technical Challenges.* The operating environment and required performance attributes result in technology needs that are often unique and not addressed in the commercial sector or other government programs. Transition of research into systems that can perform within the constraints of SUBSAFE requirements, covertness, shock, at-sea submergence, and reliability are significant challenges.

Also required are manufacturing technologies to affordably exploit new materials and systems.

In the stealth area, detailed knowledge of physical phenomena to enable active control of signatures by proper sensor and actuator selection and placement is a key issue. Acoustic hull coatings must provide uniform performance over a wide range pressure loadings to meet signature goals while being inexpensive to manufacture, install and maintain. Hydrodynamics and hydroacoustics are constrained by understanding the details of flow effects and reversals, boundary effects, and shed vorticity. Signature reduction techniques for surfaced submarines must also be compatible with its full operational envelope.

**d.** *Performing Organizations.* In-House- 33 percent, Universities-22 percent, Industry-45 percen, Other Government-0 percent

**e.** *Related Federal and Private Sector Efforts.* Due to security issues in stealth and survivability, related efforts are extremely limited and usually associated with basic science issues such as sound propagation and fracture. Cooperation with foreign navies is governed by national security but the U.K. has provided platforms for electromagnetic (EM) efforts. Computational fluid dynamics (CFD) work, especially adaptive gridding, by NASA and the aerospace industry is coupled as constraints allow. In general, the unique operating environment and military requirements result in a limited community capable of addressing submarine science and technology objectives.

**f.** *Funding*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| DoD | 42 | 52 | 55 | 48 | 30 | 35 |

## 3. Unmanned Undersea Vehicles

**a.** *Goals and Timeframes.* Unmanned undersea vehicles (UUVs) will be developed to extend battle space knowledge through the employment of cost effective, covert, off-board sensors capable of operating reliably in areas of high risk and political sensitivity. UUVs will be able to operate where manned systems cannot. Listed below are the S&T focus areas for unmanned undersea vehicles.

*Vehicle Technology.* UUVs must be smaller, lighter, be able to operate in shallow water and have low signatures. Lightweight, low signature composite hull technology is being developed for transition in FY96. A thrust vector pump jet will provide optimum control at low speeds (FY96). Technology is being developed for small vehicles that move on the ocean bottom in very shallow water. Prototype development will complete in FY97.

*Energy.* Increased energy density is a critical factor for extending the duration of UUV missions. Rechargeable lithium batteries are being developed with expected availability in 3 years. Aluminum-Oxygen semi-fuel-cells, with 4 times energy density of silver zinc batteries, will be tested at sea in FY95. A Wick-Stirling thermal system program is proceeding toward demonstration in FY97.

*Sensors.* Sensors and signal processing are critical to find and identify mines and map the terrain with precision. A toroidal volume search sonar, an advanced high resolution side look sonar, and a synthetic aperture sonar for detection of buried mines are under development for transition during the next three years. A 3-dimensional mapping capability for topographical features, including precise mine locations, will also be developed and demonstrated in the same time frame. A program is planned for completion during FY 1998 that will apply synthetic aperture sonar technology to significantly improve long range search rate/classification.

*Navigation and Control.* Covert, fully autonomous UUV operations require precision navigation and adaptable control systems. Sonar based (FY95) and non-acoustic systems (FY97) will provide velocity and position updates to the navigation system without reference to the global positioning systems (GPS). An adapative system controller is being developed to modify vehicle and sensor operations in response to oceanographic conditions. Technology for a fault compensating controller will also complete initial development in FY97.

*Communications.* Techniques are being developed to achieve data rate twenty times current state-of-the-art in the near-term; advanced research will continue in this area, including development of an acoustic network that will enable control of UUV operations over a large area.

**b.** *Potential Payoffs and Transition Opportunities.* Lightweight hulls maximize space/weight allowance for energy source and payload. Small vehicles adaptable to the surf zone enable buried mine search and neutralization. Advanced sonar systems provide 3-dimensional mapping and much higher search rate and resolution. Covertness is enhanced by sonar based and non-acoustic navigation systems. Performance is optimized by control systems that autonomously adapt to unexpected events and environmental conditions. Improved acoustic communications enable selected missions without a tether and enable Command, Control, and Communication Intelligence (C3I) across an expanded area.

**c.** *Major Technical Challenges.* Advancements in critical technologies such as shallow water vehicle control, shallow water sensors, acoustic/magnetic signature reduction, energy storage and conversion, propulsions, signal processing, autonomous control/application, and communications are vital to the design and evolution of unmanned undersea vehicles.

**d.** *Performing Organizations.* In-House-24 percent, Universities-17 percent, Industry-58 percent, Other Government-1 percent

**e.** *Related Federal and Private Sector Efforts.* Department of Energy, National Oceanographic and Atmospheric Association, and commercial organizations have interest in DoD unmanned systems for dual-use

**f.** *Funding*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| DoD | 26 | 36 | 36 | 31 | 27 | 26 |

## 4. Roadmap of Technology Objectives

See Table 17a-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

The ship and watercraft area draws on most of the other technology areas and modifies developments for the marine environment. For example, aircraft gas turbine improvements are incorporated into marinized variants for ship propulsion and power generation. Advances in computers, software, simulation and modeling, sensors and electron devices are leveraged in the development of intelligent power distribution and control systems. Materials and structures, along with the manufacturing science and technology area provides the basis for more reliable metallic hull systems. They are also the basis for affordable composite machinery and structural systems for ships, submarines and UUVs. The understanding gained from chemical and biological defense, and from conventional weapons helps in the development of more survivable marine vehicles. The electronic warfare, environmental sciences and command, control, and communications areas help establish realistic goals for various signature reduction efforts.

## F. TECHNOLOGY TRANSFER AND DUAL USE

The following listing highlights potential dual use opportunities in this area. More than a quarter of the $125 million investment planned for FY95 has potential for dual use.

| Technology | Potential Dual Use |
|---|---|
| Intelligent power distribution and control systems | Commercial power industry, heavy machinery |
| Intermittent service generators | Processing plants needing high power transients |
| Permanent magnet propulsor motors and generators | Electric vehicles, in plant material movement systems |
| Shock hardened power circuit breakers | Power plant grid control systems |
| Lo-temp Super-C magnets & cryogenic cooling | Power transmission lines, MRI, locomotive propulsion |
| Composite diesel | Trucking, boating |
| Diesel fed fuel cells | Non-polluting industrial power, electric vehicles |
| Undirectional double-hulled ships | Commercial tankers |
| High quality, low cost composite fabrication technique | Commercial boats |
| Smart fiber optic and surface acoustic wave fire, smoke, flooding sensors | Commercial building fire fighting systems |
| Chemical fire suppression alternatives to Halon 1301 | Commercial fire extinguishers |
| Antennae EM compatibility analytic codes | Commercial antennae design |
| Electro-optical EM emissions monitoring system | Personnel RF emissions hazard system, communications industry signal modulation control systems |
| Vertical axis propulsor | Commercial boat propulsion |
| Gas turbine engine technology | Commercial shipbuilding |
| Advanced degaussing technology | Supertanker protection |

## Table 17a-1. Surface/Under Surface Vehicles S&T Goals - Ships And Watercraft -

| Sub-Area | BY 1995 | BY 2000 | BY 2005 |
|---|---|---|---|
| Surface Ships | • Closed Loop Degaussing for MCM Ships<br>• Low Cavitating Fleet Propeller<br>• Fiber Optic Temperature and Smoke Sensors<br>• Affordable Double Hull Design Capability<br>• Reliable, Low Emission Gas Turbines<br>• Electrical Distribution System Architecture<br>• Monitoring and Control System Architecture | • Advanced Enclosed Mast / Sensor System<br>• Shipboard External Electromagnetic Condition Monitoring System<br>• Combatant Degaussing System<br>• Blast Hardened Bulkhead & Hull Girders Design Guidelines<br>• Permanent Magnet Electric Drive System<br>• Power Electronics Building Blocks | • 10 - 25 db Equivalent Reduction in all Signatures<br>• Shipboard Fire and Smoke Containment for 60 Minutes<br>• Detect & Analyze Shipboard Damaged Within 60 Seconds of Casualty<br>• 50 Percent Cheaper and 20 Percent Lighter Advanced Armor System<br>• 30 - 60 Percent Lighter Machinery & Electrical Systems<br>• 50 Percent Manning Reduction<br>• Affordable Diesel Fed Fuel Cell for Ship Propulsion / Service Power |
| Submarines | • Hull Survivability Assessment Capability<br>• Capability to Predict Submerged Operating Envelop<br>• DC Electric System Design Capability | •Hull Survivability Design Capability<br>•Hull Acoustic Performance Assessment Capability<br>•Closed Loop EM Signature Reduction System<br>•Envelopes of Wakeless Operation<br>•Auxiliary Machinery System Design Optimization Capability | • Adv. Machinery Rafts Systems With Integrated Shock/Acoustic Performance<br>• Hull Acoustic Design Capability<br>• Integrated Stern Design Capability |
| Unmanned Maritime Vehicles | • Demonstration of Mine Warfare Technologies: Sonar Based Precision Navigation; 3-D Mapping<br>• Demonstration of Al/O2 Fuel Cell<br>• Transition MCM Technologies: Torridal Volume Search Sonar; Laser Imaging | • Rechargeable Li Battery<br>• Synthetic Aperture Sonars for MCM<br>• Adaptive Controllers for Fault Tolerance / Environmental Conditions<br>• Small, Composite Hulls<br>• Acoustic/Magnetic Signature Reduction<br>• Robust Acoustic Communications Data Rate<br>• Geophysical Navigation for Precision / Stealth | • Energy Dense Systems for Small Vehicles<br>• Technologies for Tactical Oceanography<br>• Sensors/Hydrodynamics for Surf Zone Mine Hunting<br>• Technologies for Surveillance and Intelligence Collection |

# 17b. GROUND VEHICLES

## A. SCOPE

This Technology Area incorporates technologies to support the basic Army and Marine Corps land combat functions: shoot, move, communicate, survive and sustain. Covered here are propulsion and power, track and suspension, vehicle subsystems, hydrodynamics, signature reduction, fuels and lubricants and integration technologies related to land combat vehicles, including amphibious vehicles with a ground combat role. Funding for this area is $131M in FY94 and $107M for FY95.

## B. VISION

Develop and transition superior technology to current and future ground and amphibious vehicles, enabling deployable, affordable, decisive, sustainable land systems and enhancing the economic industrial base.

## C. RATIONALE FOR INVESTMENT

The ground forces' most critical deficiency in the post cold war era is the rapid deployment of forces for world-wide contingency missions. Current heavy forces are capable but take too long to be deployed, have a large logistics tail, and have problems with the third world infrastructure. A lighter "heavy" force is required that can be sea deployable in half the time with half the ships, and be lethal, survivable and affordable. Such forces would be particularly well suited to actions at the lower end of the full range of military operations. Rapid and decisive response of amphibious forces is critical to power projection of U.S. interests abroad. Marines are most vulnerable during movement from ship to shore. Exposure time to enemy fire will be reduced by a factor of four. Current combat vehicles rely on traditional materials for construction, manual operation of subsystems, passive armor to defeat threat armament and conventional mobility. The result is large, expensive and vulnerable to an increasing number of threat weapons. The strategy is to:

- Reduce size and weight by 40-50% through application of advanced lightweight materials; task automation to reduce number of crew; development of compact mobility components; development of new survivability techniques.
- Reduce cost by 35-45% through application of Integrated Product and Process Development (IPPD); application of virtual prototyping; sharing of electronic subsystems between vehicles.
- Reduce vulnerability by 20-100% (scenario dependent) through application of countermeasures, signature management and high mass efficiency; increased engagement ranges; target size reduction; exposure time reduction; blast/energy management.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Vehicle Chassis

**a.** *Goals and Timeframes.* Vehicle Chassis program will reduce its structural weight by a minimum of 33% by application of state-of-the-art lightweight materials. The program uses IPPD to address cost, producibility, reliability, ballistic protection, repairability, non-destructive evaluation. Key to this demonstration is the integration of often competing technologies at a system level.

| | |
|---|---|
| 1995 | Initiate Lightweight Vehicle IPPD |
| 2000 | Demo reduced structural weight by 33% |
| 2005 | Reduce system weight by 33% |

**b.** *Potential Payoffs and Transition Opportunities.* A significantly lighter (minimum 33%) chassis is key to future development of a strategically mobile combat force. Technologies are applicable to all future vehicle systems and tactical bridging. Technologies have dual use potential for civilian transportation. 75% of FY95 investment is dual use.

**c.** *Major Technical Challenges.* Use of composite materials in the combat vehicle chassis is new. Issues include durability, producibility, repairability, and inspectability. Through an IPPD approach, all issues relating to the successful fielding of a composite vehicle, including cost, are being addressed.

**d.** *Performing Organizations.* In House 19%, Industry 79%, University 2%

**e.** *Related Federal and Private Sector Efforts.* Comanche helicopter, ARPA Technology Reinvestment Program

**f.** *Funding.*

| | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| DoD | 34 | 19 | 19 | 5 | 5 |

### 2. Non-Traditional Survivability

**a.** *Goals and Timeframes.* Non-traditional survivability will demonstrate that a lightweight combat vehicle, with reduced reliance on traditional armor protection can survive on the post year 2000 battlefield. Demonstrate the signature management and countermeasure technologies by FY98.

| | |
|---|---|
| 1995 | Evaluate competing active protection technologies |
| 2000 | Reduce probability of hit 20-100% |
| 2005 | Demo Hit Avoidance against 21st Century Threat |

**b.** *Potential Payoffs and Transition Opportunities.* Applying armor based on threat has resulted in unacceptable weight, yet the vehicle remains vulnerable to numerous threats. Countermeasures, blast and signature management can successfully address most threats, resulting in a vehicle with the lethality of the current fleet at 2/3 the vehicle weight.

These technologies are applicable to existing system upgrades and to new vehicle systems. For example, the top attack defense system being developed will also be equally applicable to the AFAS, Abrams, and Bradley vehicles. Some dual use potential exists for crash avoidance. 25% of FY95 investment is dual use.

**c.** *Major Technical Challenges.* Cost of the currently identified technologies are prohibitive for application to all vehicles. This demonstration looks at combined arms rather than individual vehicles and shares combat identification, fire control, target acquisition, and survivability assets to provide area versus point protection.

**d.** *Performing Organizations.* In House 20%, Industry 80%

**e.** *Related Federal and Private Sector Efforts.* Air Force and Army Aviation, Commercial Vehicle Crash Avoidance.

**f.** *Funding.*

| Funding ($M): | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| DoD | 23 | 25 | 24 | 21 | 28 |

## 3. Crewman's Associate

**a.** *Goals and Timeframes.* Crewman's Associate automates functions and exploits cockpit display, control, ergonomic and cognitive technologies to double crew effectiveness.

| | |
|---|---|
| 1995 | Demo 2 man crew station on DIS |
| 2000 | Demo 2 man crew station on vehicle |
| 2005 | Demo 1 man operated capability |

**b.** *Potential Payoffs and Transition Opportunities.* Analysis shows that reducing crew size is the single greatest contributor to reducing combat vehicle size and weight. Therefore, crew size reduction will reduce vehicle size and weight, and increase deployability. These technologies will improve the effectiveness of weapon systems by amplifying human perception and decision making. Application is to new and existing systems: ABRAMS, AFAS, FMBT, AAA-V Technologies have dual use potential in industrial work aides and transportation. 50% of FY95 investment is dual use.

**c.** *Major Technical Challenges.* Computer software, display technology, human factors and the electronic integration within the vehicle.

**d.** *Performing Organizations.* In House 20%; University 3%; Industry 77%

**e.** *Related Federal and Private Sector Efforts.* Over fifty efforts for the combined services, ARPA Technology Reinvestment Program, commercial vehicle driver aides.

**f.** *Funding.*

| Funding ($M): | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| DoD | 13 | 13 | 10 | 10 | 4 |

## 4. Mobility

**a.** *Goals and Timeframes.* This program will (1) double the ride-limited cross country speed of ground combat vehicles (2) cut the size and weight of mobility components by half (3) cut operations and support costs by half.

| | |
|---|---|
| 1995 | Demo semi-active suspension, Light Track |
| 2000 | Demo double cross country speed |
| 2005 | Demo forward sensing active suspension |

**b.** *Potential Payoffs and Transition Opportunities.* Markedly enhanced mobility, combined with driver aids and position location increase overall tactical mobility by more than 100%.

Transition opportunities include Advanced Field Artillery System, Abrams and Bradley improvements, and Advanced Amphibious Assault Vehicle. An MOU exists between Army, Marine Corps and ARPA covering electric drive technology. All Technologies have dual use potential in civilian transportation. 75% of FY95 funds are dual use.

**c.** *Major Technical Challenges.* Technical challenges include energy management among the increasing number of high power users in the vehicle, active control of suspension spring and damping to control cross country speed-limiting-shock, improve electric drive technologies to meet the demands of the combat vehicle, decrease power required to move landing forces over water at high speed.

**d.** *Performing Organizations.* In House 20%; University 10%; Industry 70%

**e.** *Related Federal and Private Sector Efforts.* ARPA Electric, Hybrid and Natural Gas Vehicle Technology Program, ARPA Vehicle Technology category of Technology Reinvestment Program, commercial investment in electric drive technology, defense company Independent Research and Development, DoE and DOT. This area is particularly well suited to dual use, industry/Government programs.

**f.** *Funding.*

| Funding ($M): | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| DoD | 24 | 26 | 38 | 55 | 59 |

## 5. Amphibious Operations

**a.** *Goals and Timeframes.* The goal is to allow rapid, beyond the horizon deployment of landing forces and increase water and surf zone mobility by a factor of four.

| | |
|---|---|
| 1995 | Demo Electric Water Propulsors |
| 2000 | Demo rapid response amphibian |
| 2005 | Demo 4x current water speed |

**b.** *Potential Payoffs and Transition Opportunities.* Increase survivability of Marine forces while transitioning water to land. Transition opportunities include the Advanced Amphibious Assault Vehicle Program and improvements to the current landing craft fleet. Commercial use is possible for high performance water craft. Approximately 20% of FY95 funds are dual use.

**c.** *Major Technical Challenges.* Integration of high performance components for water operation conflicts with land survivability (armor, size, volume). Power required to achieve high water speed exceeds land combat engine requirements by 1000hp.

**d.** *Performing Organizations.* In House 18%; Industry 82%

**e.** *Related Federal and Private Sector Efforts.* Commercial development in high performance water propulsion and ARPA Electric and Hybrid Vehicle Technology Program.

**f.** *Funding.*

| Funding ($M): | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| DoD | 5 | 7 | 10 | 4 | 8 |

## 6. Robotics

**a.** *Goals and Timeframes.* The goals are to demonstrate combat operations with minimum casualties through automating and remoting combat and tactical vehicle control.

| | |
|---|---|
| 1995 | Demo autonomous convoy |
| 2000 | Demo remote minefield neutralization |
| 2005 | Demo remote Hunter Vehicle |

**b.** *Potential Payoffs and Transition Opportunities.* Remove the soldier from high risk military operations such as mine clearing and reconnaissance of NBC contaminated environments. Facilitate anti-fratricide and urban warfighting. Revolutionize combat vehicle mobility through intelligent navigation, powertrain/ride control and inter-vehicle coordination. Technologies have dual use potential for Intelligent Highway and hazardous duty vehicles. 75% of FY95 funds are dual use.

**c.** *Major Technical Challenges.* Development and integration of electronics, sensors, intelligent control software and hardware architectures and communication systems that facilitate real-time automated management of complex ground vehicle systems.

**d.** *Performing Organizations.* In House 15%; Industry 58%; University 27%

**e.** *Related Federal and Private Sector Efforts.* Department of Transportation, Intelligent Vehicle Highways System (IVHS), National Highway, Traffic Safety Administration (NHTSA), Automobile manufacturer R&D for occupant safety, collision detection, accident prevention.

**f.** *Funding.*

| Funding ($M): | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| DoD | 23 | 17 | 19 | 13 | 12 |

## 7. Future Vehicle Integration

**a.** *Goals and Timeframes.* Future Vehicle Integration brings together the accomplishments of three demonstrations and advanced technology demonstrations into a single system level advanced technology demonstration.

| | |
|---|---|
| 1995 | Complete user-developer study |
| 2000 | Demo survivable, deployable 40 ton tank |

**b.** *Potential Payoffs and Transition Opportunities.* This program will demonstrate highly deployable, readily transportable, lethal, survivable future main battle tank in the 40-50 ton class. Integration of complex electrical technologies have commercial application to heavy duty industrial machines. 25% of FY95 funds are dual use.

**c.** *Major Technical Challenges.* Integration of technologies into an integrated battlefield force demonstration. It brings together technologies from Hit Avoidance, Crewman's Associate, Target Acquisition.

**d.** *Performing Organizations.* In-house 75%; Industry 25%. By FY97, with the onset of the first ATD, in-house will be 20% and industry will be 80%.

**e.** *Related Federal and Private Sector Efforts.* Integration of complex electrical systems in industrial and transportation systems.

**f.** *Funding.*

| Funding ($M): | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|
| DoD | 4 | 8 | 15 | 14 | 25 |

## 8. Roadmap of Technology Objectives

See Table 17b-1.

# E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

Ground Mobility technologies have strong ties to air vehicle crew and stealth technologies, ship electric drive, aerospace propulsion, C3, human system interface, materials and structures.

# F. TECHNOLOGY TRANSFER AND DUAL USE

Of all areas, ground vehicle technology is perhaps the most adaptable to dual use. The Army and Marine Corps, with the assistance of dedicated ARPA programs, have taken great strides to involve the passenger car industry in a program that historically was heavy duty truck and industrial. Technology Reinvestment Program, vehicle technology category and National Automotive Center are new initiatives dedicated to technology transfer. Examples of technologies with high dual use application are electric drive, advanced engines, active suspension, crash avoidance and crash worthiness, autonomous driving, and lightweight structures.

Table 17b-1. Roadmap of Technology Objectives for Surface Vehicles

| Sub-Area | By 1995 | By 2000 | By 2005 | Sys Insertion Potential |
|---|---|---|---|---|
| Vehicle Chassis | • Demo minimum weight lightweight structural design<br>• Demo lightweight vehicle virtual prototyping<br>• Initiate lightweight vehicle IPPD | • Demo reduced structural weight by 33%<br>• Reduce cost of lightweight hulls by 50% | • Reduce system GVW by 33% | FMBT<br>Future Cbt & Tactical Vehicles<br>Product Improvements |
| Non Traditional Survivability | • Demo optimized active protection against smart horizontal munitions<br>• Demo countermeasure pairs to defeat laser designated threats<br>• Evaluate competing active protection technologies | • Reduce probability of being hit 20-100% scenario dependent<br>• Demo 150% increase in vehicle survivability against smart munition<br>• Demo tactics model to provide high-fidelity emulation | • Integration of an optimized survivability package<br>• Demo effectiveness of hit avoidance technology against 21st century threats<br>• Demo tactics in DIS | AFAS<br>M1A2+<br>M2A3<br>FMBT |
| Crewman's Associate | • Demo 2 man crew station thru DIS simulations<br>• Demo embedded Battlefield Digitization<br>• Demo Soldier-in-the-Loop Simulation<br>• Demo 50% crew workload reduction | • Demo large area flat panel displays<br>• Demo Automated Intelligent Crew Station Info Mgt<br>• Demo decision support systems<br>• Demo 2 man crew station | • Demo 1 man crew capability<br>• Demo virtual reality soldier-in-the-loop simulations<br>• Demo embedded virtual training | AFAS<br>M1A2+<br>M2A3<br>FMBT |
| Mobility | • Demo semi-active suspension<br>• Demo 22 Ten Band Track–1 ton weight savings<br>• Demo advanced variable gap drive motors | • Demo fully active suspension<br>• Demo 20 Ten Band Track–1.5 ton weight savings<br>• Demo double cross country speed<br>• Reduce size/weight of components by 1/2 | • Demo proactive suspension<br>• Demo 40 Ten Band Track–2.5 ton weight savings<br>• Demo 600hp Electric Gun Integration | AFAS<br>MIA2+<br>M2A3<br>FMBT |
| Amphibious Operations | • Demo Electric Propulsion track and waterjet drive<br>• Demo reduced diameter, high efficiency waterjet propulsors | • Demo rapid response, amphibious support vehicle<br>• Demo reduced length integral steering waterjets | • Demo very high speed over water 4 X current capability | AAA-V |
| Future Vehicle Integration | • Complete FMBT user-developer studies<br>- Digitization<br>- Force Protection<br>- Deployability | • Demo a main battle tank with 2 man crew<br>• Demo total force real-time situational awareness<br>• Validate virtual Prototyping process | | FMBT |
| Robotics | • Demo autonomous convoy<br>• Demo Crew aids<br>• Remote Mine Breeching | • Demo Remote NBC Recon<br>• Demo remote mine detection/neutralization<br>• Demo Remote Scout function | • Demo Remote Hunter vehicle (target acquisition)<br>• Automated Driver | Future Scout<br>Future NBC Recon<br>Future Counter-mine<br>Tactical Unmanned Ground Vehicle |

# 18. MANUFACTURING SCIENCE & TECHNOLOGY (MS&T)

## A. SCOPE

Affordability is a key concern in every technology area. The MS&T area is focused on cross-cutting engineering and manufacturing process technologies beyond those developed in conjunction with new product technologies in the other technology areas. The MS&T area includes ARPA 6.2 and 6.3 programs in information technology for manufacturing applications, Service/DLA Manufacturing Technology (ManTech) programs, advanced technology demonstrations for affordability, and advanced industrial practices to demonstrate the combination of improved process technology and improved business practices. These programs encompass process technologies at all manufacturing levels (enterprise/factory/cell/machine/unit process). Funding for this area is $187 million in FY94, not including TRP funding.

## B. VISION

Expand DoD access to a capable, responsive multi-use industrial base and achieve affordability improvements comparable to those experienced by world class commercial firms.

## C. RATIONALE FOR INVESTMENT

Advanced manufacturing technologies are vital to affordable defense systems and economic security. DoD needs access to manufacturing capabilities that meet world class benchmarks for cost, cycle time, and quality. Compared to current defense manufacturing this means, for selected products, a 30 to 50 percent reduction in development and production costs, commensurate reductions in cycle times, near-perfect quality even for items produced in small lots, and designed-in life cycle supportability.

The maturity level of processes employed to produce defense weapons systems has a telling effect on the ability of those systems to meet schedule and cost targets as they transition through development and into production. Immature manufacturing processes represent a major source of risk and uncertainty that is often translated into system cost growth and schedule slippage. MS&T's work in maturing factory processes as well as promoting effective Integrated Product and Process Development are critical elements in understanding and resolving risk early.

The MS&T strategy is to target defense-driven process technologies with the greatest leverage on costs, and to accelerate progress toward commercial viability where feasible. Life cycle costs are determined to a large extent by early design decisions, so design is one important leverage point. Figure 1 shows additional leverage opportunities and the relationship of MS&T sub-areas to manufacturing costs.

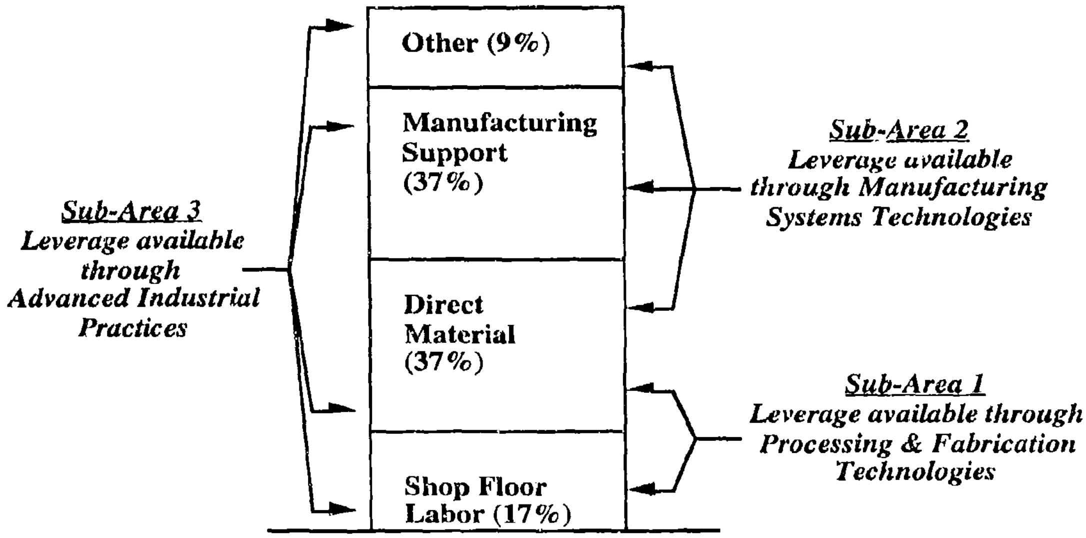


**Figure 1. Distribution of Weapon System Manufacturing Costs**

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Manufacturing Processing and Fabrication (Factory Floor)

MS&T's traditional role in accelerating shop-floor manufacturing process maturation at every stage of product development will be revitalized to attack cost, time, and quality risks in transition. As widely used by successful companies, Process Capability Index (Cp) will be adopted as a universal measure of process maturity to support low-risk transition to production. Where mature processes are not available, laboratory-developed initial process capabilities will be matured to the point where they can be used with confidence in weapons system design or for insertion of new technologies into existing systems. Processes for electrical and mechanical products from all tiers of industry will be addressed.

a. *Goals and Timeframes. "Lot size of one with first pass success."* Develop factory processes and tools that make unit production costs independent of lot size over a range of 1-500 items for composite structures, printed wiring assemblies, precision optics, and metalworking parts. Provide the same the flexibility for low volume production as is achieved in higher volumes, as for example, for combat rations and military uniforms. Some of the success in achieving these goals will result from the capability—resulting form concurrent efforts—which will, by the year 2000, allow the production of custom military items on high volume commercial production lines. Similarly, implementation of six sigma quality and unit process models will reduce scrap and rework by a factor of ten, reduce direct labor and material costs by 30%, and improve factory floor cycle time by a factor of two.

b. *Potential Payoffs and Transition Opportunities.* Factory floor process technologies will be demonstrated in an initial application of military importance, but in most instances will have spin-off potential for commercial applications. Transition opportunities for DoD include systems that will be in production in the 1998-2005 timeframe, such as F-22, ASTOVL, and JAST aircraft technology programs, JSOW, JDAM, Javelin, EFOG-M, TACAWS, AMRAAM and AIM-9X missiles, upper-tier theater missile defense, Composite Armored Vehicles, and maritime platforms and systems. Manufacturing technologies for composites will have broad application to airframe and engine structures for military and commercial aircraft, seeker housings for missiles, structure and armor for ground vehicles, maritime systems, and depot repair of composite structures. Manufacturing technology for electronics will be applied to printed wiring assemblies for both new production and spare parts in multiple military and commercial applications. The application focus for precision optics will be forward looking infrared systems (FLIRs) and optical sensors for military use, and lenses for advanced lithography in dual use applications. For metalworking and machined parts, transition opportunities include just-in-time manufacturing of spare parts, rapid prototyping, and precision machining of tools, dies and molds for military and commercial uses of all types.

**c.** *Major Technical Challenges.* The major challenge is to decouple cost from lot size, which requires process models and closed-loop process control algorithms to ensure process accuracy and repeatability, and reconfigurable tools and fixtures to reduce setup and changeover time. Additional specific technical challenges are defined within each application area. For Composites, challenges include automated processes for layup to reduce labor costs and improve quality, low cost tooling, tool-less assembly, and reduced inspection and test requirements. For Electronics, the challenges include environmentally benign processes for circuit board fabrication; soldering and parts emulation or substitution for obsolete parts; and integrated designs and materials for microwave and digital multi-chip module packaging. The major challenge for Precision Optics is elimination of hand polishing operations. For Machined Parts, the technical challenge is to develop physics based process models, near net shape forming and casting processes to reduce finishing requirements, generative process planning, and open architecture machine controllers.

**d.** *Performing Organizations.* Industry - 90 percent; Academia - 6 percent; In-House - 4 percent.

**e.** *Related Federal and Private Sector Efforts.* Planning in all MS&T sub-areas is coordinated with other agencies (DoE, NSF, NASA, DOC) through NSTC and various interagency working groups. The 1994 NSTC report on Advanced Manufacturing Technology lists the major complementary programs. DoD accounts for about half of all Federal funding for manufacturing technology.

**f.** *Funding.*

| Funding ($M) | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| | 111 | 86 | 96 | 85 | 78 | 75 |

## 2. Engineering and Manufacturing Systems (Above the Shop Floor)

This sub-area focuses on improving the support functions associated with planning, scheduling and controlling functions for manufacturing cell, factory, and enterprise level activities, including all manufacturing operations and customer and supplier interface activities. It also includes computer aided design and engineering tools that will make Integrated Product and Process Development (IPPD) for six sigma quality a practical reality from the earliest stages of design.

**a.** *Goals and Timeframes. "The Integrated Enterprise".* The Principal targets to address are the leverage on total life cycle costs available through integrated product and process development, the reduction in overhead costs available through manufacturing system integration, and the ability to respond effectively to change through reconfigurable enterprise systems and organizations. Specific goals: reduce the indirect costs of production by 30 percent and shorten the transition time from design to production by 30 percent for key defense subsystems and components by 2000; demonstrate in 1995-2000 an annual doubling in scale of networked data exchange among prime contractors and suppliers, including the interoperability of information system products from multiple vendors.

**b.** *Potential Payoffs and Transition Opportunities.* The principal payoffs for defense are the reduction of production and life cycle costs through designed in producibility and supportability, reduced overhead costs through more efficient enterprise level processes and supplier interfaces, and access to a broad base of multi-use manufacturing capabilities. Simulation based design and virtual manufacturing simulations will improve the operations of multi-product factories, increase supplier and inventory efficiency, and provide for first pass success, thus shortening the transition from design to production. Electronic commerce, including enterprise control and market intelligence will play a major role in the manufacturing sector, not only speeding routine procurement transactions, but also facilitating "instant partnerships" and enabling a new electronic marketplace for engineering and manufacturing services accessible over wide area networks. The transition strategy in this sub-area is generally to avoid defense-unique solutions and promote commercial implementation. Spin-off potential is particularly high for manufacturing applications of the National Information Infrastructure (or information superhighway), which will exploit new capabilities for electronic commerce and enterprise control and market intelligence (the industrial counterpart to military C3I).

**c.** *Major Technical Challenges.* Development of integrated tools for IPPD, involving tradeoffs among product parameters, process parameters and cost; networked collaboration capability that makes distributed teams as effective as co-located teams; the function of the complexity, scope and investment required for enterprise level integration of market intelligence systems and the development of "virtual factory" simulation with enough granularity for pre-hardware validation of processes are major technical challenges.

**d.** *Performing Organizations.* Industry - 90 percent; Academia - 6 percent; In-House - 4 percent.

**e.** *Related Federal and Private Sector Efforts (see D.2.e).*

**f.** *Funding.*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| | 36 | 51 | 47 | 46 | 47 | 18 |

## 3. Advanced Industrial Practices

This sub-area will leverage the combined effects of technology advances and the use of new manufacturing systems with and advanced business practices to demonstrate new industrial base capabilities. Projects will validate defense-critical aspects of commercial/military integration, agile manufacturing, lean production, and business practices. Barriers that stop defense producers from using commercial practices or sources will be attacked.

**a.** *Goals and Timeframes. "Combined effects of technology and world class business practices".* Advanced Industrial Practices combine advanced process technologies, at both the factory floor and enterprise levels, with advanced business practices. These programs are structured as "pilot factory" demonstrations with the critical mass to set new benchmarks for cost, cycle time, and quality in industrial sectors that are critical to defense products. The technology emphasis and specific goals depend upon the products. Specific goals include: flexible, one-wafer-at-a-time processing capability for Infrared Focal/Plane Arrays that can reduce cost and manufacturing cycle time by 50 percent, for DoD small lot production; for signal processors, integrated design tools and dual use manufacturing capabilities for signal processors that can shorten development and upgrade times by 75 percent; flexible factory systems for Interferometric Fiber Optic Gyroscopes (IFOGS) that can produce navigation grade gyroscopes for $1,500 per axis (less than 20 percent the cost of current products), opening possibilities for new affordable precision guided weapons; a multi-missile factory with dual-use component suppliers for Missile Seekers that can reduce unit costs by 10-30 percent; demonstrations in ongoing programs (such as F-22 and C-17) for manufacturing 2005, matching world class benchmarks for lean manufacturing, with reductions of 30 percent or more in direct and overhead costs for structures and sub-assemblies produced on a commercial production line.

**b.** *Potential Payoffs and Transition Opportunities.* Advanced Industrial programs are structured to have a pervasive impact in the industrial sector by setting new benchmarks and by including new tool vendors who can make the resulting technology widely available in the market. Initial implementation is assured by choosing real defense applications as the demonstration targets such as F-22, C-17 and IAST, and establishing partnerships with weapon system program managers who will implement the resulting technology in future production, upgrade or sustainment programs such as AMRHAM, JSOW and JDAM. The programs in composite aircraft structures, IFOGs, and dual-use Agile Manufacturing pilots are dealing with products with near term commercial spin-off potential. Even though some pilot applications, such as missile seekers, have no appreciable commercial market potential. The design tools, factory equipment, market intelligence capabilities, and advanced business methods validated in these pilot programs can be applied to a broad class of commercial and military products that goes far beyond the products selected for initial demonstrations. Payoffs include rapid product mix conversion with little distinction from defense to commercial, rapid insertion of manufacturing technologies for new or existing products, fully integrated manufacturing functions using information and communication systems, and improved design process for existing and new hardware due to knowledge of process performance during product definition.

**c.** *Major Technical Challenges.* Reconfiguration of military production into dual-use factories with common inspection standards, material applications, inventory controls, and activity-based costing will require implementation of acquisition reform. The development of dynamic multiple enterprise ventures ("virtual corporations") requires demonstration of agile manufacturing technology solutions, including innovative business concepts and efficient, enterprise-wide communications.

**d.** *Performing Organizations.* Industry - 90 percent; Academia - 6 percent; In-House - 4 percent.

**e.** *Related Federal and Private Sector Efforts (see paragraph D.2.e).*

**f.** *Funding.*

| Funding ($M): | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| | 40 | 95 | 130 | 136 | 130 | 100 |

### 4. Roadmap of Technology Objectives

See Table 18-1.

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

A guiding principal of the Science and Technology strategy is to reduce costs by investing in process (as well as product) technologies in all technology areas. MS&T will establish tools, benchmarks, and models that can be replicated throughout the other technology areas to influence system development toward affordability. In addition, MS&T shares responsibility with two other technology areas (Electronics Devices and Materials and Processing) in developing new process technologies. MS&T concentrates on process technologies with broad application, while the other areas concentrate primarily on specific processes associated with new product technologies. Close coordination is maintained among these areas through Project Reliance. Of the total FY94 funding for manufacturing process technologies (approximately $1 billion), 30 percent is in the Technology Reinvestment Project, 25 percent is in MS&T, 35 percent is in the Electronic Devices area, and 10 percent is in the Materials and Processing area.

## F. TECHNOLOGY TRANSFER AND DUAL USE

Our Manufacturing Science and Technology program has been, and will continue to be, driven by defense needs for technologies and systems that provide a superiority edge. The nature of our business dictates we be on the leading edge of creating technologies and products that, in the early development state, have no commercial market and are beyond the normal risk acceptable to industry. Often, years later after these technologies have been demonstrated, they are employed in the commercial market.

What is new in today's environment is a proactive strategy to involve the commercial industrial base as soon as possible. We do this by first insisting on use of commercial processes and practices, where possible, in our manufacturing programs, and later by incentivizing commercial market investments through programs such as the Technology Reinvestment Project.

For example, consider the military need for superiority leading the commercial demand is in radar transmit-receive modules. Since the 1960's, there have been three generations of phased array radar technology funded by the military services. Commercial production of transmit-receive modules is not starting in the auto industry, with school bus radar sensors booking a few hundred deliveries to date. Although military demand will continue to outstrip commercial demand for the balance of the decade, we are now at a point where cost-shared investments in dual use production capabilities make good business sense. We recently announced a TRP project to accelerate automotive insertion for anti-collision applications.

Across the government, the manufacturing development, deployment, and education programs at the Department of Commerce, Department of Energy National Labs, National Science Foundation, and the National Aeronautics and Space Administration are elements of a strengthening partnership among the Federal agencies. In particular, MS&T programs are working closely with the National Institute for Standards and Technology to transfer the results of military technology to small and medium sized contractors, via Manufacturing Extension services network.

## Table 18-1. Roadmap of Technology Objectives for Manufacturing Science and Technology Goals*

| Sub-Area | Goal | By 1995 | By 2000 | By 2005 |
|---|---|---|---|---|
| Manufacturing Processing and Fabrication<br>(Factory Floor) | Scrap/Rework: | Reduction of 20% | Reduction of 50% | Reduction of 90% |
| | Unit Cost: | Reduction of 10% | Reduction of 20% | Reduction of 30% |
| Goal: make unit production cost independent of lot size for: | Setup/Changeover Time: | Reduction of 15% | Reduction of 30% | Reduction of 50% |
| 1. Metalworking Parts | Manufacturing Cycle Time: | Reduction of 10% | Reduction of 25% | Reduction of 50% |
| 2. Printed Wiring Assys<br>3. Precision Optics | Quality control capability 1-6 | Statistical process control (SPC) | Closed loop model-based control (A few parameters) | Closed loop model-based control (All critical parameters) |
| 4. Composite Structures | | | | Custom military products from commercial lines |
| 5. Military Apparel | Envelope of Flexibility 1-6 | Military variants of commercial products | | |
| 6. Combat Rations | Flexible tooling Capability 1, 4 | Production using soft tooling | | Eliminate need for jigs, dies, fixtures |
| Engineering and Manufacturing Systems (Above the Shop Floor) | Changes to correct design errors | Reduction of 10% | Reduction of 30% | Reduction of 60% |
| | Indirect production costs | Reduction of 5% | Reduction of 30% | Reduction of 50% |
| Integrated Product/Process Design | Transition time from ATD/ACTD to production | Reduction of 10% | Reduction of 30 % | Reduction of 40% |
| Enterprise Integration | Supplier transaction costs | | | |
| | Integration methodology | Reduction of 10% | Reduction of 20% | Reduction of 30% |
| | Engineering support tools<br>Simulation and modeling | Product data standards for composites, PWAs<br>Design tool interoperability<br>Simulate manufacturing flows - paperless factories | Integrated production data base, distributed factory C3<br>Design to cost - tools and knowledge base<br>Automated manufacturing process planning and simulation (Cell level) | Enterprise-level C3I<br>Product/process design synthesis<br>"Virtual factory" integrated simulation and control (machine/cell/ factory) |
| | Electronic Commerce capabilities | Procurement transactions, on-line catalogs | Easy access to engineering/manufacturing services on the NII | Interactions as of colocated (Virtual Company) |
| Advanced Industrial Practices<br>Achieve combined effects of technology and world-class business practices | Pilot factory ATDs | Reduction of 25% in product realization time for signal processors | Reduction of 75% for signal processors | Reduction of 75% for wide range of defense electronic systems |
| | | One wafer at a time processing for IRFPAs | Reduction of 50% in cost and cycle time for family of IRFPAs | |
| | | Tactical grade IFOGs for $6,000/axis | Navigation grade IFOGs for $1,500/axis | |
| | | Reduction lines sub-optimized for individual missiles | Reduction of 15% in cost through multi-missile factory systems | Reduction of 30% in multi-missile production |
| | Lean Manufacturing Pilots | | 30% reduction for total cost of major aircraft structures (C-17) and circuit card assy's (F-22) | |
| | Agile Manufacturing Pilots | Initiate demonstrations to make production of defense products comparable in costs to world class commercial development | New benchmarks of excellence for cost, quality and ability to respond rapidly to change in major industrial sectors | |

* Goals are fiscally constrained, and apply to product areas selected for initial demonstrations.

# 19. MODELING AND SIMULATION (M&S)

## A. SCOPE

This technology area includes development, integration, and implementation of tools and applications to apply M&S more broadly and with greater validity across DoD. Efforts are directly dependent on enabling technologies such as high speed computing, communications and networking, human systems technologies such as high speed computing, communications and networking, human systems interfaces, and software. Major sub-areas are: (1) architectures (software, data/database methodologies, and interfaces with communications and networks); (2) environmental representations (terrain, weather, atmosphere, space, oceans, and others); (3) computer generated forces (systems representations, human behaviors, and their interactions).

M&S efforts include those focused on advancing the state-of-the-art in modeling and simulation and that exhibit features such as scalability, variable resolution, interactive use, and interoperability with diverse models. While significant DoD investments in M&S are embedded in other technology areas (C3; human-system interfaces; battlespace environments; and manpower, personnel, and training), those applications support a particular scientific or engineering problem area and are often not applicable for advanced distributed simulations. Hence, these classes of models and simulations are not included in this technology plan.

The Department will invest $325 million in M&S specific R&D in FY 94.

## B. VISION

In support of readiness, provide operationally valid M&S tools and synthetic environments for on demand use by DoD Components to: train jointly; develop doctrine, tactics, techniques, and procedures; assess courses of action; formulate operational plans; support technology assessments, system upgrade, prototyping, and full scale development; and conduct force structuring analyses and assessment.

## C. RATIONALE FOR INVESTMENT

The nation's long term security is largely dependent on DoD's ability to place the right equipment in the hands of warfighters, train them to use that equipment, and develop commanders who understand mission requirements in a changing geopolitical environment. Maintaining readiness in the face of evolving missions, rapidly developing technology, instantaneous global communications and the information it carries, and compounded by budgetary constraints is a daunting problem. Effective use of M&S from acquisition through training, development of doctrine and tactics, and mission rehearsal offers the best possibility for improving readiness at lower cost. In fact, M&S is often the only way to address DoD's increasingly complex problem sets.

Simulators are very cost effective to train warfighters to use their equipment. Where operations are too dangerous for peacetime training or where live operations pose ecological hazards, simulation is the only reasonable means of effective training and mission rehearsal. Focused investment in the emerging technology base can substantially improve the quality of synthetic environments and the ability to create large, complex simulations from repositories of models, data, and databases. Investments must produce better environmental models, more intelligent autonomous components, more realistic live participation, and the architectural structure for linking components reliably.

As warfighters require training with new or improved equipment, commanders must train for a wider variety of missions, many of which are not rooted in prior operational experience. Engagement simulations in which tactics and warfighting doctrine can be explored will allow commanders to master today's doctrine and evolve tactics for new types of engagements. Simulations will be viable to the extent that the entities on the battlefield are accurately modeled in synthetic environments that reflect realistic operational conditions.

M&S can provide repeatable, iterative experiments, with appropriate fidelity, from which data can be extracted and analyzed as a quantitative means of assessing capability and determining effectiveness. Such analyses are needed to assess the impact of new systems and direct the acquisition process to invest in the those systems that provide the most significant payoff. M&S also has the potential to allow force structure analysis at the Joint Task Force, Service, Component, and DoD levels.

In an era of rapidly evolving technology, the ability to move through the acquisition process in a timely and cost effective fashion is essential to maintaining the materiel readiness of our armed forces. Using M&S as a predictive tool and to focus test planning can have a significant impact on both the time required and the validity of operational testing. To do this, constructive simulations using high fidelity engineering models must be combined with live and virtual simulations in synthetic environments in a consistent fashion from design through test. To accomplish this objective, the architecture must support the interoperability of engineering models through analysis models to constructive and live models in the same environment.

## D. TECHNOLOGY SUB-AREAS AND INVESTMENT STRATEGIES

### 1. Architectures

**a.** *Goals and Timeframes.* The cornerstone for realizing the DoD vision for simulation on demand to support the operational readiness of forces is an open, object-oriented, simulation architecture supported by consensus based standards and protocols. The architecture defines system design principles, interfaces, standards, protocols, correlation and conformance requirements and communication requirements. The architecture must be able to incorporate constructive, live and virtual simulations, seamlessly linking all systems with acceptable latency. It must be the vehicle through which component representations with differing fidelity and granularity are incorporated into a single consistent synthetic environment. As M&S technology develops, the architecture must be able to support the introduction of evolving network and software capabilities, replacing older modules and systems with their successors without undue redevelopment costs.

The goal of this sub-area is interoperability, that is providing "plug and play" on demand in synthetic environments. The overall investment will result in models, simulators, and instrumentation systems which allow users to easily select and adjust parameters for scenario development; automatically register model capability to prevent invalid coupling of entities; mix constructive, virtual, and live simulations; and ensure commonality of data and databases. The architecture must include a user friendly, intelligent, object-oriented, graphical environment. Concurrent with the development of an architectural specification, cost effective methods for model VV&A must be developed without which the models and simulations will have, at best, limited applicability. The Joint Simulation System Joint Program Office has initiated an effort to produce a new scalable architecture for constructive wargames. Once fielded, the architecture will be extended to include engineering and analytical applications.

**b.** *Potential Payoffs and Transition Opportunities.* A common architecture is the key for providing simulation on demand with the diversity of complex entities required for readiness, mission rehearsal, analysis, and acquisition. Implementing a standard architecture will enable interoperability of models and simulations horizontally and vertically. Availability of accredited models and certified data will foster broader use of M&S and reduce start-up costs for new simulations. DOT, DOJ, and the FAA have all demonstrated an interest in DoD M&S efforts and an intent to adopt, where appropriate, common architectures, standards, and protocols. There will be a migration of architectures among DoD, other government, academic, and commercial members of the M&S community.

**c.** *Major Technical Challenges.* Principal technical challenges are in the realms of software and database design, e.g. standards and procedures for: (1) variable resolution databases that assure consistency when higher resolution models are aggregated, (2) verification, validation and accreditation for aggregated, variable resolution models and "knowledge-based" models, (3) adaptable scenario generation, and (4) implementing multi-level distributed security access and dynamic multicasting.

**d.** *Performing Organizations.* Service labs - 15%, industry - 70%, and academia - 15%.

**e.** *Related Federal and Private Sector Efforts.* USAF - JMASS, IEEE Standard 1278 - Distributed Interactive Simulation, Four Service - Joint Simulation System, Navy - MARS, ARPA - Synthetic Theater of War (STOW), Army - WARSIM 2000.

**f.** *Funding.*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Funding ($M): | 15 | 22 | 24 | 24 | 23 | 23 |

## 2. Environmental Representations

**a.** *Goals and Timeframes.* The goal is to provide common, authoritative environmental representations with adequate resolution, fidelity, and user friendliness, applicable across a wide variety of M&S. Only with such representations for terrain, ocean, air, space, weather, electromagnetic, and other environments can simulations support applications in war fighting, training, test and evaluation, research and development, and acquisition with the necessary accuracy and validity. Representing environments in simulations is complicated by the fact that each entity playing in the simulation must experience critical environments at the requisite fidelity; the environments must react to changes occasioned by the presence of the entities; and there must be a consistent global view maintained throughout the simulation scenario. For example:

terrain must be geo-spatially accurate in X, Y, and Z axes to ensure correct correlation, changes in terrain caused by one entity (creation of a bomb crater) must be immediately available to all entities using terrain, and all players in the same weather phenomenon on the same terrain must experience the same impact on visibility and trafficability.

The critical importance of environmental representations has been recognized and in response DoD has specifically addressed their life-cycle management. Common- and general-use representations will be managed and life-cycle support provided through executive agents designated by USD(A&T). Data and databases for environmental representations supporting M&S will fall under the oversight of the Defense Modeling and Simulation Office (DMSO) as M&S Functional Data Administrator.

**b.** *Potential Payoffs and Transition Opportunities.* Having dynamic, interactive authoritative environmental representations will make the whole of M&S more valid and therefore more acceptable to users. With the availability of such environmental representations the performance of warfighters; their supporting systems; and their tactics, techniques, and procedures can be tested over a far wider range of conditions than would be available in real-world trials. There are major opportunities for commercialization and application to other government department projects such as the DOT's Driver Simulation Program, FAA applications, education, and the entertainment industry.

**c.** *Major Technical Challenges.* Technical challenges include: (1) eliminating the long lead times and cost for database development, (2) harnessing computational speed required for dynamic environmental play, (3) maintaining global consistency across a simulation composed of models of differing resolutions.

**d.** *Performing Organizations.* Service labs 40%, industry 30%, and academia 30%.

**e.** *Related Federal and Private Sector Efforts.* Work being done by DMA, Services, DoD Agencies, Universities, and industry.

**f.** *Funding.*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| Funding ($M): | 22 | 21 | 21 | 23 | 22 | 9 |

## 3. Computer Generated Forces (CGF)

**a.** *Goals and Timeframes.* CGF include representations of human behaviors as the full range of systems and their performance in the hands of humans and groups of humans. A CGF may be an individual soldier, a single weapons platform, the weapons platform with crew, or the aggregation of entities into large maneuver formations. The goal of CGF development is to enable mission specialists & training developers to capture and represent adaptive, interactive, "intelligent" behaviors of military personnel and units, weapon systems, and smart weapons, which are suitable for use in variable scale synthetic environments.

Interoperable entity representations are currently available for a number of ground systems, for some rotary and fixed wing aircraft, and a variety of missiles and improvements are ongoing. Programs have been initiated to develop the complex aggregates of warfighters, sensors and weapons typical of Naval systems. Plans to develop C2 representations (information flow, decision making processes and command structures) are in the requirements stage. Prototypes for these new entities should be available in the 1995-1997 time frame.

**b.** *Potential Payoffs and Transition Opportunities.* While environmental representations provide a synthetic physical world, CGF provide the realistic systems performance and human interactions needed to move M&S from "cookie-cutter" textbook exercises to interactive exploration of the complex activities characteristics of all human endeavor. The exploration will be accomplished with far fewer live troops depicting large scale operations. The methodologies used to develop and integrate both systems and human representations are directly transferable to other areas like air traffic control, manufacturing, driver training, delivery of emergency services, law enforcement, and operations in hazardous environments.

**c.** *Major Technical Challenges.* Principal challenges are in providing accurate behavioral representations computable in near real time and include: (1) advanced models defining human cognitive, phychoperceptual and psychological behaviors; (2) models for C2 across echelons from theater to unit level; and (3) evaluation methods and standards of behavior for various mixes of constructive, live and virtual simulations.

**d.** *Performing Organizations.* Service labs - 30%, industry - 60%, academia - 10%.

**e.** *Related Federal and Private Sector Efforts.* ARPA -I4-WISSARD, IFOR, CCTT-SAF, BFTT-SAF, Training development organizations in the public and private sectors.

**f.** *Funding.*

| | FY94 | FY95 | FY96 | FY97 | FY98 | FY99 |
|---|---|---|---|---|---|---|
| **Funding by ($M):** | 15 | 12 | 13 | 13 | 5 | |

## E. RELATIONSHIP TO OTHER TECHNOLOGY AREAS

M&S draws upon the advances in many of the other technology areas. In return, M&S provides the architectures and tools for developing and improving simulation applications unique to the other technology areas. Most importantly, the M&S technology area will provide the synthetic environments and the standards through which disparate simulations can be linked to enable wider applicability and increased validity. As the M&S technology area planning team chair and DoD focal point for M&S, DMSO will work with the various teams to ensure coordinated efforts and consistency of purpose for M&S related activities.

Table 19-1. Modeling and Simulation Technical Plan Sub-area Goals.

| Sub-Area | By 1995 | By 2000 | By 2005 |
|---|---|---|---|
| Architectures | • Evaluate expansion of scenario scripting tools like RASPUTIN for constructive M&S<br><br>• Tools and gateways to plan and execute interconnecting classified and unclassified networks for exercise<br><br>• 1.5-45 Mega Bits-per-Second (Mbps) Networks<br><br>• 1.5 Mbps Encryptors for simulation nodes | • Field constructive M&S scripting tools that accept V&V plug-in tools<br><br>• Constructive models & architecture operational (accepts live and virtual simulations)<br><br>• Module Reuse Common<br><br>• •Constructive models will connect to/replicate C4I systems<br><br>• 50-622 Mbps Networks<br><br>• Multicasting and Resource Reservation<br><br>• Standard Devices at Sites<br>• ATM cell encryptors for simulation nodes | • Extend scripting tools as architecture grows to handle live and virtual M&S<br><br>• Architecture extended to design & development of live and virtual systems (accepts C4I systems)<br><br>• Gigabit Networks<br><br>• Integrated DoD-wide Network<br><br>• Multicast Capable Key Management |
| Environmental Representations | • 10 m resolution -N hour X XXX sq mi database production<br><br>• Physics based environmental & electromagnetic effects | • 1 m resolution H hr ZZZ sq mi database production<br><br>• Micro-terrain models<br><br>•Dynamic environmental models | • Near-real-time, interactive environmental models<br><br>• Scalable terrain models (micro-to-macro) |
| Computer Generated Forces | • Realistic computer-controlled aircraft engagements (air-to-air/air-to-ground) | • Automated C2 entities (2 Levels)<br><br>• 50,000 heterogmsous entities interacting<br><br>• Develop/validate C2 simulation language | • Automated C2 Entities (2-3 Levels) Plus Human-in-the-Loop<br><br>• 100,000 heterogeneous entities interacting<br><br>• Libraries of Entity Models<br><br>• Develop/validate X2 simulation language |

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| 2-D | Two Dimensional (length/width) |
| 21 CLW | 21st Century Land Warrior |
| 3-D | Three Dimensional (length/width/height) |
| | |
| ACT | Advanced Concepts and Technology |
| ACTS | Advanced Communications Technology Satellite |
| ACTD | Advanced Concept Technology Demonstration |
| ADC | Analog-to-Digital Converter |
| ADS | Atmospheric Density Specification Satellite |
| AE | Acquisition Executive |
| AEAS | Advanced Environmental ASW Support |
| AFAS | Advanced Field Artillery System |
| AI | Artificial Intelligence |
| ABL | Airborne Laser |
| ALI | Alpha/LAMP Integration |
| AMLCD | Active-Matrix Liquid Crystal Display |
| AMPP | Advanced Materials and Processing Program |
| AMRAAM | Advanced Medium Range Air-to-Air- Missile |
| ANN | Artificial Neural Networks |
| Appr | Appropriation |
| ARM | Anti-Radiation Missile |
| ARPA | Advanced Research Projects Agency |
| ASB | Airbase Systems Branch |
| ASCM | Advanced Spaceborne Computer Module |
| ASIC | Application Specific Integrated Circuit |
| AST | Advanced Subsonic Technology |
| ASUW | Airborne Anti-Surface Warfare |
| ASW | Anti-Submarine Warfare |
| ATACMS | Army Tactical Missile System |
| ATCCS | Army Tactical Command and Control System |
| ATD | Advanced Technology Demonstration |
| ATP | Acquisition, Tracking, and Pointing |
| ATR | Automatic Target Recognition |
| | |
| B | Billions |
| BMDO | Ballistic Missile Defense Office |
| BST | Biomedical Science and Technology |
| B/T | Boost and Orbit Transfer Propulsion Systems |
| BTI | Balanced Technology Initiative |
| BW | Biological Warfare |

| | |
|---|---|
| $C^3$ | Command, Control, and Communications |
| $C^3CM$ | Command, Control and Communications Countermeasures |
| $C^3I$ | Command, Control, Communications, and Intelligence |
| $C^4I$ | Command, Control, Communications, Computers, and Intelligence |
| CAD | Computer-Aided Design |
| CAE | Computer-Assisted Engineering |
| CAM | Computer-Aided Manufacturing |
| CASE | Computer-Aided System Engineering |
| CB | Chemical and Biological |
| CCD | Camouflage, Concealment and Deception |
| CE | Critical Experiment |
| CECOM | U.S. Army Communications and Electronics Command |
| CERL | Civil Engineering Research Laboratories |
| CFC | Chlorofluorocarbon |
| CFD | Computational Fluid Dynamics |
| CGF | Computer Generated Forces |
| CIM | Computer Integration Manufacturing |
| COIL | Chemical Oxygen Iodine Laser |
| CONUS | Continental United States |
| COTS | Commercial Off-the-Shelf |
| CPB | Charged Particle Beam |
| CR | Cold Regions |
| CRDA | Cooperative Research and Development Agreements |
| CRREL | Cold Regions Research & Engineering Laboratory |
| CW | Chemical Warfare |
| CWS | Combat Weather System |
| DDR&E | Director, Defense Research and Engineering |
| DDS | Direct Digital Synthesizer |
| DE | Directed Energy |
| DEA | Data Exchange Agreements |
| DET | Dynamic Environment and Terrain |
| DEW | Directed Energy Weapon |
| DF | Deuterium Fluoride |
| DIRCM | Directed Infrared Countermeasures |
| DIS | Distributed Interactive Simulation |
| DISA | Defense Information Systems Agency |
| DLA | Defense Logistics Agency |
| DMA | Defense Mapping Agency |
| DMSP | Defense Meteorological Satellite Program |
| DNA | Defense Nuclear Agency |
| DoC | Department of Commerce |
| DoD | Department of Defense |
| DoE | Department of Energy |

| | |
|---|---|
| DoT | Department of Transportation |
| DRFM | Digital RF Memory |
| DSPO | Defense Support Project Office |
| E-O | Electro-Optical |
| EAST | EUREKA Advanced Software Technology |
| ECCM | Electronic Counter-Countermeasures |
| ECM | Electronic Countermeasures |
| EHF | Extra-High Frequency |
| EM | Electromagnetic |
| EngMat | Alloys and Composites for Engines |
| EO | Electro-Optics, Electro-Optical |
| EOD | Explosive Ordinance Disposal |
| EPA | Environmental Protection Agency |
| EPRI | Electrical Power Research Institute |
| ESM | Electronic Support Measures |
| ESSI | European Software and System Initiative |
| ESSM | Evolved Sea Sparrow Missile |
| ETC | Electro-Thermo Chemical |
| ETEC | Enterotoxic E. Coli |
| EW | Electronic Warfare |
| EXP | Expendable |
| FAA | Federal Aviation Administration |
| FBI | Federal Bureau of Investigation |
| FC | Fire Control |
| FCRC | Federal Contract Research Center |
| FDS | Fixed Distributed System |
| FEMA | Federal Emergency Management Agency |
| FFRDC | Federally Funded Research and Development Center |
| FHWA | Federal Highway Administration |
| FLIR | Forward-Looking Infrared |
| FMBT | Future Main Battle Tank |
| FO | Fiber-Optic |
| FPA | Focal Plane Array(s) |
| FSSVP | Former Soviet Union Ship Vulnerability Program |
| FY | Fiscal Year |
| GaAs | Gallium Arsenide |
| GBL | Ground-Based Laser |
| GIF | Guidance Integrated Fuzing |
| Giga- | Billion |
| GPS | Global Positioning System |

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|---|---|
| HABE | High Altitude Beam Experiment |
| HAE | High Altitude Endurance |
| HAZTOX | Hazardous/Toxic |
| HCI | Human-Computer Interaction |
| HIV | Human Immunodeficiency Virus |
| HPC | High Performance Computing |
| HPCC | High Performance Computing and Communications |
| HPM | High Power Microwave |
| HSI | Human System Interfaces |
| HTS | High Temperature Superconductor |
| | |
| I/O | Input/Output |
| IC | Integrated Circuit |
| IFF | Identification Friend or Foe |
| IFOGS | Interferometric Fiber-Optic Gyroscopes |
| IHPRPT | Integrated High Payoff Rocket Propulsion Technology |
| IHPTET | Integrated High Performance Turbine Engine Technology |
| IHVS | Intelligent Vehicle Highways System |
| IM&D | Information Management and Display |
| IMETS | Integrated Meteorological System |
| IMF | Intelligent Mine Field |
| INFOSEC | Information Security |
| INS | Inertial Navigation System |
| IPES | Integrated Platform Electronics and Sensors |
| IPPD | Integrated Product and Process Development |
| IR | Infrared |
| IR&D | Independent Research and Development |
| IRCCM | Infrared Counter-Countermeasures |
| IRCM | Infrared Countermeasure |
| IRFPA | Infrared Focal Plane Arrays |
| IRST | Infrared Search and Track |
| | |
| JAST | Joint Advanced Strike Technology |
| JCS | Joint Chiefs of Staff |
| JDAM | Joint Deep Area Munition |
| JS-LIST | Joint Service-Lightweight Integrated Suit Technology |
| JSOW | Joint Stand Off Weapon |
| | |
| L/V | Lethality/Vulnerability |
| LADAR | Laser Radar |
| LAMP | Large Advanced Mirror Program |
| LIFE | Laser IRCM Flyout Experiment |
| LLNL | Lawrence Livermore National Laboratory |

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|---|---|
| LODE | Large Optics Demonstration Experiment |
| LOTS | Logistics-Over-The-Shore |
| LOTSOS | Logistics-Over-The-Shore Operational Simulator |
| LST | Landing Ship Tank |
| LWIR | Long-Wave Infrared |

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|---|---|
| M&R | Maintenance and Repair |
| M&S | Modeling and Simulation |
| MANTECH | Manufacturing Technology |
| MC&G | Mapping, Charting, and Geodesy |
| MCM | Mine Countermeasures, Multichip Module |
| Mega- | Million |
| MEA | More Electric Aircraft |
| MEMS | Microelectromechanical System |
| MIMIC | Millimeter Wave Monolithic Integrated Circuit |
| MLRS | Multiple Launch Rocket System |
| MLS | Multilevel Security |
| MMACE | Microwave and Millimeter Wave Advanced Computer Environment |
| MMIC | Microwave Monolithic Integrated Circuit |
| MMS | Merchant Marine Service |
| MMW | Millimeter Wave |
| MODIL | Manufacturing Operations Development Integration Lab |
| MOU | Memorandum of Understanding |
| MP&S | Materials, Processes, and Structures |
| MPM | Microwave Power Module, MMW Power Module |
| MPP | Massively Parallel Processor |
| MRE | Meals Ready to Eat |
| MRDE/OTSG | Medical Research Development Engineering / Office of the Surgeon General |
| MSI | Medium Scale Integration |
| MSTI | Minature Sensor Technology Integration |
| MSX | Midcourse Space Experiment |
| MTEDS | MCM Tactical Environmental Data System |
| MTI | Moving Target Indicator |
| MWIR | Microwave Infrared |

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|---|---|
| NAS | New Attack Submarine |
| NASA | National Aeronautics and Space Administration |
| NATO | North Atlantic Treaty Organization |
| NAVSEA | Naval Sea System Command |
| NAWC | Naval Air Warfare Center |
| NBC | Nuclear, Biological, Chemical |
| NCF | Naval Construction Forces |
| NCTR | Noncooperative Target Recognition |

| | |
|---|---|
| NDT | Non Destructive Testing |
| NFESC | Naval Facilities Engineering Support Center |
| NHTSA | National Highway, Traffic Safety Administration |
| NIST | National Institute of Standards and Technology |
| NOAA | National Oceanic and Atmospheric Administration |
| NPB | Neutral Particle Beam |
| NRaD | Naval Command and Control Ocean Systems Center, Research and Development Division |
| NRL | Naval Research Laboratory |
| NSF | National Science Foundation |
| | |
| O&M | Operations and Maintenance |
| O/S | Operating System |
| OCONUS | Outside of CONUS |
| ODC | Ozone Depleting Compounds |
| OGA | Other Government Agencies |
| OMCVD | Organo Metallic Chemical Vapor Deposition |
| OPAR | Optimum Path Aircraft Routing |
| OPSR | Optimum Path Ship Routing |
| OS | Operating System |
| OSD | Office of the Secretary of Defense |
| OTH | Over-the-Horizon (Radar) |
| | |
| PBR | President's Budget Request |
| PEO | Program Executive Officer |
| Peta- | Quadrillion ($10^{15}$) |
| PGM | Precision Guided Munitions |
| PM | Program Manager |
| POL | Petroleum Oil & Lubricants |
| PPM | Pulse Power Module |
| | |
| R&D | Research and Development |
| RAM | Random Access Memory |
| RCS | Radar Cross Section |
| RCRA | Resource Conservation and Recovery Act |
| RCVR | Receiver |
| RDT&E | Research, Development, Testing and Evaluation |
| RDTE&E | Research, Development, Testing, Evaluation, and Engineering |
| RF | Radio Frequency |
| RMC | Resin-Matrix Composites |
| RPV | Remotely Piloted Vehicle |
| RT | Real-Time |
| RWR | Radar Warning Receiver |

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|---|---|
| S&T | Science and Technology |
| SAM | Surface-to-Air-Missile |
| SBIR | Small Business Innovation Research |
| SBL | Space-Based Laser |
| SBR | Space-Based Radar |
| SD | Satellite/Divert Control Propulsion Systems |
| SDI | Strategic Defense Initiative |
| SDV | Swimmer Delivery Vehicle |
| SEAD | Suppression of Enemy Air Defenses |
| SEB | Staphylococcal Enterotoxin B |
| SEE | Systems Engineering Environments |
| SEI | Software Engineering Institute, Specific Emitter Identification |
| SEP/MEP | Soldier and Marine Enhancement Programs |
| SERDP | Strategic Environmental Research & Development Program |
| SFC | Specific Fuel Consumption |
| SHF | Super-High Frequency |
| SOE | Submerged Operating Envelope |
| SPC | Software Productivity Consortium, Statistical Process Control |
| SPO | System Program Office |
| SRAM | Static Random-Access Memory |
| SSTD | Surface Ship Torpedo Defense |
| STOW | Synthetic Theater of War |
| SW | Smart Weapon |

| | |
|---|---|
| T/R | Transmit/Receive |
| TACAWS | The Army's Combined Arms Weapon System |
| TAMPS | Tactical Air Mission Planning System |
| TBM | Tactical Ballistic Missile |
| TDA | Tactical Decision Aid |
| Tera- | Trillion |
| TES | Threatened and Endangered Species |
| TESS | Tactical Environmental Support System |
| TFSOS | Thin Film Silicone on Sapphire |
| TF/TJ | Turbofan/Turbojet |
| Ti | Titanium n Alloys |
| TM | Tactical Missile Propulsion System |
| TOW | Tube-Launched Optically Tracked Wire-Guided (Anti-Tank Missile) |
| TRP | Technology Reinvestment Project |
| TS/TP | Turboshaft/Turboprop |

| | |
|---|---|
| UAV | Unmanned Air Vehicle |
| UGV | Unmanned Ground Vehicle |

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|---|---|
| UHF | Ultra-High Frequency |
| UMOP | Unintentional Modulation on Pulse |
| USARIEM | U.S. Army Research Institute of Environmental Medicine |
| USDA | U.S. Department of Agriculture |
| USGCRP | U.S. Global Change Research Program |
| UUV | Unmanned Underwater Vehicle |
| UV | Ultraviolet |
| UXO | Unexploded Ordinance |
| V&V | Verification and Validation |
| VEE | Venezuelan Equine Encephalitis |
| VHF | Very High Frequency |
| VOC | Volatile Organic Chemicals |
| WDA | Weather Decision Aid |
| WES | Waterways Experiment Station |
| WL | Wright Laboratory |
| WMD | Weapons of Mass Destruction |