



ARMY RESEARCH LABORATORY

BROAD AGENCY ANNOUNCEMENT

FOR

BASIC AND APPLIED SCIENTIFIC RESEARCH

W911NF-12-R-0011-03  
15 May 2012 – 31 March 2017

ISSUED BY:

U.S. Army Contracting Command-Aberdeen Proving Ground  
Research Triangle Park Division  
P. O. BOX 12211  
Research Triangle Park, NC 27709-2211

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## **I. OVERVIEW OF THE FUNDING OPPORTUNITY:**

### INTRODUCTION

This Broad Agency Announcement (BAA), which sets forth research areas of interest to the Army Research Laboratory (ARL) Directorates and Army Research Office (ARO), is issued under the paragraph 6.102(d)(2) of the Federal Acquisition Regulation (FAR), which provides for the competitive selection of basic research proposals. Proposals submitted in response to this BAA and selected for award are considered to be the result of full and open competition and in full compliance with the provision of Public Law 98-369, "The Competition in Contracting Act of 1984" and subsequent amendments.

Research proposals are sought from educational institutions, nonprofit organizations, and commercial organizations for research in materials sciences; ballistics and aeromechanics sciences; information sciences; human sciences; survivability, lethality, and vulnerability analysis and assessment; chemistry; electronics; physics; environmental sciences; life sciences; mechanical sciences, mathematical sciences, computing sciences and network sciences. Proposals will be evaluated only if they are for scientific study and experimentation directed toward advancing the state of the art or increasing knowledge and understanding.

ARO has primary responsibility for ARL's extramural basic research programs, with specific research interests as described in Part II.A.2. The ARL Directorates, while having primary responsibility for ARL's in-house research programs, also manage select extramural basic research programs. The research interests of the Directorates are described in Part II.A.1. Although ARL Directorates will consider funding proposals for extramural research programs, they can fund only a modest number of proposals in a single fiscal year. It should be noted that the ARL Directorates are highly interested in performing research in collaboration with other scientists and engineers. So, in addition to funding select external research projects, the ARL Directorates also have a strong interest in performing joint research with other organizations in ARL's core competency areas as described in this BAA. Collaboration is a central tenet of ARL's new Open Campus Initiative. Information regarding the Open Campus Initiative can be found on the ARL website (a summary at: <http://www.arl.army.mil/www/default.cfm?page=2357> and details regarding specific opportunities at: [http://www.arl.army.mil/www/pages/2357/ARL\\_Open\\_Campus\\_Opportunities.pdf](http://www.arl.army.mil/www/pages/2357/ARL_Open_Campus_Opportunities.pdf)). Inquiries regarding funding and/or collaborations should be directed to the listed Technical Point of Contact (TPOC).

Foreign owned, controlled, or influenced firms are advised that security restrictions may apply that could preclude their participation in these efforts. Before preparing a proposal, such firms are requested to contact the ARL Security and Counterintelligence Branch (301) 394-2444 concerning their eligibility. Pursuant to the policy of FAR 35.017 and supplements, selected Federally Funded Research and Development Centers may propose under this BAA.

PART II, Other Programs, addresses specific contributions to Conferences and Symposia and Historically Black Colleges & Universities and Minority-Serving Institutions (HBCU/MI) support.

The Army has a long history of advocating and supporting research at HBCU and MIs. We actively seek research proposals from HBCUs and MIs in full competition with all offerors who may submit proposals under this BAA. Proposals may be submitted at any time. We also encourage the inclusion of HBCUs and/or MIs as part of a consortium proposal or as subcontractors/ subgrantees to prime recipients.

In order to conserve valuable offeror and Government resources and to facilitate determining whether a proposed research idea meets the guidelines described herein, prospective offerors contemplating submission of a whitepaper or proposal are strongly encouraged to contact the appropriate technical point of contact (TPOC) before submission. The TPOCs' names, telephone numbers, and e-mail addresses are listed immediately after each research area of interest. If an offeror elects to submit a whitepaper, it must be prepared in accordance with the instructions contained in PART III Section 3. Upon receipt, a whitepaper will be evaluated and the offeror shall be advised of the evaluation results. Offerors whose whitepapers receive a favorable evaluation may be contacted to prepare a complete proposal in accordance with instructions contained in PART III Section 5.

The costs of whitepapers and/or complete proposals in response to this BAA are not considered an allowable direct charge to any award resulting from this BAA or any other award. It may be an allowable expense to the normal bid and proposal indirect costs specified in FAR 31.205-18.

In accordance with federal statutes, regulations, and Department of Defense and Army policies, no person on grounds of race, color, age, sex, national origin, or disability shall be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving financial assistance from the Army.

Offerors submitting proposals are cautioned that only a Contracting or Grants Officer may obligate the Government to any legal instrument involving expenditure of Government funds. This BAA also applies to research proposals submitted to the RDECOM International Technology Centers.

For ARL Directorate Research Areas II.A.1, offerors should discuss the preferred performance period with the Technical Point of Contact (TPOC). For ARO's Research Areas II.A.2, it is preferred that proposals are submitted to cover a 3-year period and include a brief summary of work contemplated for each 12-month period so that awards may be negotiated for an entire 3-year program or for individual 1-year increments of the total program.

All administrative inquiries regarding this BAA shall be addressed to voice mailbox number 919-549-4375. Technical questions should be referred to the TPOCs shown following each research area of interest. When an inquiry is made, please clearly state your name, correct spelling, and telephone number.

This BAA is available on the following websites:

<http://www.arl.army.mil/www/default.cfm?page=8>

<http://www.grants.gov>

[www.fbo.gov](http://www.fbo.gov)

This BAA is a continuously open announcement valid throughout the period from the date of issuance through 31 March 2017, unless announced otherwise, and supersedes the ARL BAA dated October 2007. Amendments to this BAA will be posted to the FedBizOpps web site and published at the above websites when they occur. Interested parties are encouraged to periodically check these websites for updates and amendments.

DR. THOMAS P. RUSSELL  
Director  
Army Research Laboratory

## **A. Required Overview Content**

### **1. Agency Name:**

U.S. Army Research Laboratory

### **Issuing Acquisition Office:**

U.S. Army Contracting Command-Aberdeen Proving Ground, Research Triangle Park Division

### **2. Research Opportunity Title:**

ARL Core Broad Agency Announcement for Basic and Applied Scientific Research for 15 May 2012 – 31 March 2017

### **3. Announcement Type**

Initial Announcement

### **4. Research Opportunity Number:**

W911NF-12-R-0011-03

### **5. Catalog of Federal Domestic Assistance (CFDA) Number and Title:**

12.431 – Basic Scientific Research

### **6. Response Dates:**

This BAA is a continuously open announcement valid throughout the period from the date of issuance through 31 March 2017, unless announced otherwise, and supersedes BAA W911NF-07-R-0001 (including all modifications) dated October 2006. Amendments to this BAA will be posted to the FedBizOpps web site and published at the above-mentioned websites when they occur. Interested parties are encouraged to periodically check these websites for updates and amendments.

## **II. DETAILED INFORMATION ABOUT THE FUNDING OPPORTUNITY**

### **A. Funding Opportunity Description**

The funding opportunity is divided into three sections: 1) Army Research Laboratory Core Competencies; 2) Army Research Office Division Research Areas; and 3) Other Programs.

### **1. ARMY RESEARCH LABORATORY CORE COMPETENCIES**

#### **a. CORE COMPETENCY 1: MATERIALS SCIENCES**

##### **1.1 Structural Materials and Components**

1.1.1. Composite Materials. Proposals are requested involving fundamental and applied research of advanced materials in relation to polymer-, metal-, and ceramic-matrix composites and their hybrids, and extending theory and experimental methodology where current theory and techniques are not adequate for modeling, analyzing, or characterizing the synthesis, processing, microstructure, and properties of these materials and material systems. The broad areas of interest include dissimilar material bonding, adhesion, interpenetrating networks, thermosetting-thermoplastic adherent interfaces, multilayer composites, and hybrid fiber systems; synthesis and thermo chemical and mechanical analysis of constituent material forms; surface analysis techniques; energetic and chemical interphase/interface development/properties; cure behavior and modeling; transport and degradation properties including thermal, oxidation, electrical, and chemical; effects of additives and fiber treatments on formation and properties of the fiber-matrix and hybrid system interphase/interface; failure modeling and analysis; special thermoplastic composite issues including intimate and healing mechanisms and modeling; interactions of composite and hybrid systems with electromagnetic and radioactive fields; modeling/analysis of void formation and effects of voids and other defects on strength, modulus, microcracking, etc.; composite-specific testing and analysis technique development and utilization including mechanical and electromagnetic property tests, fiber and matrix property tests, environmental exposure tests, etc.; statistical analysis of composite properties; assessment and analysis of industry-reported composite material property data; fundamental concerns and mechanisms for novel curing including electron beam, dielectric, microwave, etc.; physical property analysis; hygrothermal effects testing and analysis; thermal and oxidative stability; impact and delamination resistance; viscoelastic effects; analysis of process-induced properties; micro- and macromechanical analysis of fracture, buckling, delamination, etc.; mechanics of laminated forms; numerical analysis; material durability and performance; and fundamental research in new material developments including fiber forms and surface modifications, low-density core materials, low-viscosity thermosetting resins, and processable phenolic resins, etc. Special emphasis should be placed on composite materials supporting personnel and vehicular armor; on low-observable and ultra-lightweight, multi-functional materials for aircraft, flight body, ground vehicle, and on soldier systems; on materials for munitions, ordnance, cannons, armaments, and their sub-components, and on the characterization of polymer/hybrid materials surfaces and interphase phenomena, adhesive bonding, durability/life extension, and smart/intelligent material systems. Reporting of scientific results and conclusions will be



incorporated into scientific meetings and publications including general literature (conference proceedings, journals, etc.), technical reports, and standardization documents.

Technical Point of Contact: Ms. Pauline Smith, [pauline.m.smith.civ@mail.mil](mailto:pauline.m.smith.civ@mail.mil), (410)306-0899.

1.1.2. Advanced Materials and Materials Processing. ARL is seeking proposals for high quality research and development in advance materials and materials processing approaches that are critical to Army applications. The Army requirements are driven by the need for lighter weight, lower cost, environmentally friendly, and enhanced durability. Reduced weight / ultra-lightweight is the goal for all weapon systems and logistics support items including ground and air vehicles, missiles, munitions, etc. Major future weapon systems include the Future Force and the Ground Soldier System. There is an interest in materials and manufacturing processes that will reduce the cost of weapon systems, and increase capability without additional cost. Army weapon systems are being extended beyond original design lifecycle. Accordingly, there is an interest for materials and processes that will help lower the operating and support costs of weapon systems. Environmentally friendly materials and processes will impact disposal and cleanup costs. Processing technologies of interest include those that will be applicable during high rate production and also for rapid prototyping. The objective of rapid prototyping is to reduce lead-time and, where possible, to make cost independent of order size. Proposals may impact materials currently in use within existing systems or look forward to future systems, subsystems, or support items. A few areas of interest includes: (i) materials such as bulk and composite amorphous materials, nanomaterials, advanced metal matrix composites, polymer materials, DoD strategic materials research including rare earth elements, biomaterials, metamaterials, etc. Some goals are to discover, synthesize and process bulk and amorphous metallic alloys for potential applications such as kinetic energy applications; novel processing for refractory metal and alloy warhead liners for shaped charge and explosively formed projectile applications; other example uses include structural, armor, coatings, multifunctional, etc. applications, (ii) processing methods include joining, bonding, laser processing, shaping, etc. Objectives include: weld characterization, successful joining of difficult to weld materials, dissimilar metals; rapid prototyping, direct metal deposition techniques, processing to enhance surface properties, etc.

Technical Point of Contact: Ms. Pauline Smith, [pauline.m.smith.civ@mail.mil](mailto:pauline.m.smith.civ@mail.mil), (410)306-0899.

1.1.3. High Rate Deformation and Failure of Materials. Proposals are requested to investigate the high rate behavior of materials undergoing deformation beyond the elastic limit to include fracture and failure. Materials of interest include polymers, high-density metals, ceramics, materials used for constructing urban structures, and materials capable of energetic response to mechanical stimuli. The broad area of interest covers experimental, computational, and theoretical investigations with an emphasis towards the development of a computational predictive capability of high rate deformation and failure of materials subjected to ballistic impact conditions. Advanced constitutive characterization and modeling, equation of state, dynamic fracture (both experimental and computational), material decohesion, and thermomechanical coupling are included in this wide area of interest. Also included are experimental and computational issues associated with the bridging of length scales ranging from microstructural to macroscopic. Reporting of scientific results and conclusions may be

incorporated into scientific meetings and publications including general literature (conference proceedings, journals, etc.), technical reports, and standardization documents.

Technical Point of Contact: Dr. Todd W. Bjerke, e-mail: [todd.w.bjerke2.civ@mail.mil](mailto:todd.w.bjerke2.civ@mail.mil), (410) 278-5819

1.1.4. Structural Mechanics. Research proposals are requested for physics-based first principle and advanced computational methods for thermodynamically consistent fatigue and fracture models; advanced design methodologies for lightweight structures through enhanced quantification of uncertainty (e.g., structural-health-monitoring-based design) ; analysis and characterization of novel durable and damage tolerant composites; and advanced structural concepts based upon additive manufacturing of novel multifunctional composite structures that exhibit hierarchical ordering, to advance the development of extremely lightweight, adaptive, durable, and damage tolerant structures.

Technical Point of Contact: Dr. Jaret Riddick, email: [jaret.c.riddick.civ@mail.mil](mailto:jaret.c.riddick.civ@mail.mil), 410-278-9831.

1.1.5. Multifunctional Structures. Capabilities for revolutionary multifunctional structures embedded with combinations of power, electrical, actuation, or biological properties to increase system-level capability, performance, efficiency and mobility.

Technical Point of Contact: Dr. Mark Bundy, email: [mark.l.bundy2.civ@mail.mil](mailto:mark.l.bundy2.civ@mail.mil), 410-278-4318.

1.1.6. Adaptive Structures. Innovative adaptive structures integrated with smart materials having shape memory characteristic for morphing, healing capability for self-repair, or nanoconductive sensing ability for structural health monitoring.

Technical Point of Contact: Dr. Mark Bundy, email: [mark.l.bundy2.civ@mail.mil](mailto:mark.l.bundy2.civ@mail.mil), 410-278-4318.

1.1.7 Nanomaterials Processing. The ARL is seeking proposals for high quality research and development in furthering the science and application of nanotechnology to enhance weapon systems and warfighter capabilities. Encompassing nanoscale science and technology includes imaging, measuring, modeling, manipulation and control of nanostructural matter from the atomic level to the macroscopic, including the nano, micro and mesoscales. The challenges that impede the rapid transition of nanotechnology to applications and fielding are materials and manufacturing processes. There is a lack of transformational technologies for manufacturing nanostructures and nanomaterials in large quantity and low cost. Whether the product is nano-structured materials for armor or nano-particles for protective coatings, the pervasive technical challenge in processing and manufacturing of nano-materials is the ability to control their disbursement, distribution, stability, morphology and microstructural design throughout the synthesis and consolidation phases. There is a need to resolve the fundamental barriers to achieving the unique properties and capabilities available from nanotechnology. Significant challenges are nucleation, phase transformation, equilibrium and non-equilibrium crystal

structures, thermodynamics, diffusion, kinetics, oxidation and grain growth and particle agglomeration that arise from processing and manufacturing techniques. There is a need to enhance the development and understanding of the synthesis, characterization and design of nanoscale materials with superior mechanical, functional and environmental behavior based upon predictive modeling of their properties.

Research to develop tools and methodologies to create and retain unique nano-derived properties from nano-synthesis through component processing will allow for the insertion of higher strength, higher toughness, with high-temperature stability of nanostructured metals and alloys for structural and other niche applications. Of interest are the development of processing science, novel fabrication techniques, or scale up for the fabrication of powdered precursors and bulk products, including near-net formed from them. Specific materials include organic and inorganic materials, refractory metals and alloys, ultra lightweight metals and alloys, as well as more conventional alloy systems. Additional focus areas relate to the use of integrated computational methods designed and implemented to reduce the development and insertion timeline from conception to production and include the growth and characterization of embedded nano-sized constituents designed for material and multi-functional performance, including health monitoring (i.e. fatigue, corrosion); and investigations of novel methods leading to large-scale, large-quantity processing of nano-materials. The goal of this research is the rational design of safe, yet high performance nanoscale materials, efficient and inexpensive manufacture of these materials and the incorporation of the nanoscale materials into microscale or larger components. The submission of proposals that combine or integrate these phenomena is encouraged.

Technical Point of Contact: Victor K. Champagne, email: [victor.k.champagne.civ@mail.mil](mailto:victor.k.champagne.civ@mail.mil), (410) 306-0822.

1.1.8 Coatings and Corrosion Science. The Annual Cost of Corrosion for Army Aviation and Missile Equipment report published in September 2010 estimates the total corrosion cost per year for Army ground vehicles to be \$2.4 billion. Factoring in other DoD ground, aviation and infrastructure related corrosion these costs rise to an excess of \$22 billion annually. The proper maintenance of deteriorating assets such as tanks, vehicles and ground support equipment with superior corrosion resistant coatings is needed to mitigate these costs. Organic coatings are used throughout all DoD organizations to protect valuable assets such as vehicles, munitions and ground support equipment from the effects of weathering, abrasion and corrosion. Recent environmental regulations have impacted the Army's ability to use certain chemicals to mitigate corrosion and prepare coatings, such as hexavalent chromium, lead, toluene, and other toxic metals and hazardous air pollutants. In addition, future regulations may impact the chemistry of the binders, potentially regulating the ability to use isocyanates to make polyurethanes, which are used in formulating chemical agent resistant coatings (CARC) and other coatings used by the Army.

Corrosion and materials degradation occurs in all aspects of coatings systems. Water infiltration reduces the mechanical performance of coatings and increases the likelihood of delamination, scratches, and other damage. Furthermore, water infiltration can cause significant issues to the composite substrates, reducing mechanical and thermal performance. Water also is a key component of corrosion of the metallic substrates, but can also enable the function of various

corrosion inhibitors. Thus, the ability of a coating to protect against water infiltration plays an important role in corrosion protection. The metal oxide is a key component of metallic corrosion. Water, ions, and other conditions can significantly impact the stability of the oxide. The porosity of this oxide also plays a significant role, whereby ions can directly attack the underlying metal of porous oxides. Pretreatments play a role in affecting oxide stability and perhaps porosity.

This BAA seeks to develop environmentally sustainable solutions to preparing high performing durable coatings that further reduce corrosion rates relative to existing coatings. To make effective breakthroughs, this BAA is not simply requesting solutions, but more importantly, is seeking an understanding of the corrosion mitigation mechanisms and how they function in pretreatments, according to TT-C-490, and primers, according to MIL-DTL-53022 and MIL-DTL-53030. Regarding the organic binders, this BAA is seeking non-isocyanate based coatings and high performing coatings derived from renewable resources (other than alkyds and other relatively low performing plant oil-based coatings), including novel methods to prepare these, and characterization of these polymers via structure property relationships and coatings as per applicable Army specifications and standards, including MIL-DTL-64159, MIL-DTL-53039, MIL-DTL-53022, MIL-DTL- 53030. Furthermore, computational methods to enable prediction of coating morphology, properties, and performance are also sought to help enable a materials by design approach for Army coatings. Computational and experimental methods to understand water infiltration, water-induced degradation of coatings, and water-enabled migration of ions are also needed. Other important areas of study include interactions of pretreatments with metal and metal oxide substrates, structure of deposited inorganic/organic pretreatments on the substrate, stability of this coating as a function of conditions, stability of the underlying oxide, and oxide morphology and porosity changes as a result of pretreatment.

Technical Point of Contact: John La Scala, [john.j.lascala.civ@mail.mil](mailto:john.j.lascala.civ@mail.mil), 410-306-0687.

## **1.2 Electronic Materials and Devices**

1.2.1. MicroElectroMechanical Systems (MEMS). ARL is interested in receiving proposals on novel materials, devices, and integration approaches for MEMS sensors and actuators. ARL is also interested in integration approaches for nanoenergetic materials on a chip, as well as MEMS devices and structures that either benefit from the presence of an energetic material or enable initiation, characterization, or control of the energetic reaction. Technical areas of interest include, but are not limited to, the following:

- a. Low or no power MEMS sensors and actuators
- b. Shock, acceleration and angular rate sensors and switches
- c. Bio-inspired and bio-mimetic sensors and actuators
- d. Size, weight and power constrained solutions for soldier born sensors and micro autonomous systems
- e. MEMS grippers and reversible adhesives
- f. Mechanical or electromechanical structures that respond to changes in environmental conditions, such as temperature, acceleration, pressure, light intensity or wavelength, etc.
- g. Materials and methods for integration of energetic materials on chip

- h. Methods and devices for conversion of energy from energetic reactions to other useful forms on chip (heat, light, pressure, electrical current, etc)
- i. Novel microactuators based on energetic chemical reactions

Technical Points of Contact: Dr. Chris Morris, [christopher.j.morris58.civ@mail.mil](mailto:christopher.j.morris58.civ@mail.mil), (301) 394-0950.

1.2.2. Nanoelectronics and Nanosensors for Army Applications. ARL is interested in receiving proposals addressing the technical barriers and advancing the state of the art for nanoelectronic devices. Technical areas of interest include, but are not limited to, the following:

- a. Theoretical and experimental studies of nanodevices
- b. Novel concepts for multifunctional electronics and sensors, including design, fabrication and testing approaches
- c. Graphene, BN, Diamond Like Carbon, MoS<sub>2</sub> and Nano carbon and other ambipolar class of electronics, devices and circuit and components
- d. Graphene/CNT micro-supercapacitors and hybrid system integration and packaging
- e. Novel 2-D and 3-D materials for full spectrum IR Imaging and Thermal Photo Voltaic (TPV) devices
- f. Plasmonics and Nano-Photonic devices, integration, testing, and circuit design
- g. Transparent, printable and stretchable electronics
- h. Ultra compact low power and high frequency RF communications
- i. High frequency RF devices
- j. Beyond CMOS electronics
- k. Integration with MEMS, NEMS, nanoenergetics, and other technologies

Technical Point of Contact: Dr. Madan Dubey, [madan.dubey.civ@mail.mil](mailto:madan.dubey.civ@mail.mil), (301) 394-1186.

1.2.3. Piezoelectric MicroElectroMechanical Systems (PiezoMEMS) Technology. ARL is interested in receiving novel proposals that address the technical barriers associated with improving the current state of the art in piezoelectric thin film materials, devices, and components used as sensors, actuators, and micro-mechanical structures. Technical areas of interest include, but are not limited to, the following:

- a. Theoretical and experimental studies of electro-mechanical interactions in solids.
- b. Studies of micro-mechanics that impact materials and device reliability, reproducibility, and device design.
- c. Investigation of piezoelectric thin films including texture, ferroelectric, dielectric, piezoelectric, and elastic properties under a variety of conditions including electric field, temperature, stress, and strain.
- d. Fabrication technologies to improve materials reliability and reproducibility, to enable 3-dimensional processing of actuators and sensors, and to achieve extremely large piezoelectric coefficients.
- e. RF MEMS technology including switches, phase shifters, resonator and filters, transformers, tunable microwave components, and integrated package and assembly strategies.
- f. mm-Scale Robotics including actuator and proprioceptive sensor design and modeling, fabrication and integration strategies for achieving high force, large

displacement actuation, and design and integration strategies for power, power management, control, and communication systems.

Technical Point of Contact: Dr. Ronald Polcawich, [ronald.g.polcawich.civ@mail.mil](mailto:ronald.g.polcawich.civ@mail.mil), (301) 394-1275.

1.2.4. Emerging Technologies for Semiconductors. Innovative research is sought in the areas of modeling, processing and fabrication of advanced electronic materials & devices for integrated systems that are critical to Army applications. The major focus in this request includes flexible electronics, multi-scale modeling, and novel characterization technologies that can be used to aid the understanding, development and fabrication of advanced materials and technologies for next generation microelectronics. Fabrication and processing of semiconductors, interconnects, device structures, 3D and heterogeneous integration, and the characterization and control of trace impurities, defects and interfaces in semiconductors and masks are of interest, particularly for sub90-nm devices and circuits. Principal emphasis is on surface or interface control during processing of these materials, characterization of their near-surface transport behavior and surface properties, and modeling or theoretical predictions of their properties.

Technical Point of Contact: Dr. Glen Birdwell, [Anthony.g.birdwell.civ@mail.mil](mailto:Anthony.g.birdwell.civ@mail.mil), (301) 394-0601.

1.2.5. Small RF (micro-sensor) Systems. The Army is interested in lightweight, affordable radar systems that are suitable for and have the ability to sense, locate, and identify targets from any of a variety of surveillance sensor platforms such as robots, UAVs or future micro-sensor platforms. The development of such a system may include phenomenology (signature) measurements in an effort to optimize the hardware and software. The systems or techniques proposed must have the high speed necessary to perform in real time, coupling with peripheral processors.

Technical Points of Contact: Mr. Edward Viveiros, [Edward.a.viveiros2.civ@mail.mil](mailto:Edward.a.viveiros2.civ@mail.mil), (301) 394-0930 or Mr. Eric Adler, [eric.d.adler.civ@mail.mil](mailto:eric.d.adler.civ@mail.mil), (301) 394-0933.

1.2.6. Microwave Device and Analog Signal Processing Research and Development. The Army requires improved microwave devices that are reliable and cost effective, as well as lightweight, reliable signal processing components to handle large volumes of data on a real-time basis. Desired are novel proposals that address the technical barriers associated with improving the state of the art of such devices and components. Technical areas of interest include, but are not limited to, the following:

- a. Physics-based modeling of microwave devices, components, packages, and radiating structures using semiconductor analysis and computational electromagnetics.
- b. The research and/or novel application of low-cost analog signal processing components based on acoustic wave technology, acoustic charge transport, magnetostatic waves, or high-temperature superconducting materials, either singly or in combination.
- c. Emphasis should be directed toward achieving larger bandwidth, reducing insertion loss and power consumption, or lowering fabrication costs.

- d. Novel linearization techniques.

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1.2.7. Broadband Analog, Microwave, Millimeter-wave and Mixed-signal Integrated Circuits and Processing Architectures. The Army requires the generation and analysis of broadband complex-modulated vector-waveforms for applications in communication, radar and electronics warfare. The Army is also looking for innovative digital signal processing circuits and architectures to process the large amount of data associated with the increased bandwidth.

Technical areas of interest include but are not limited to the following:

- a. High-speed low-power digital-to-analog converters (DACs) and analog-to-digital converters (ADCs).
- b. Circuits and techniques to generate and distribute highly stable and low jitter clock signals for DACs and ADCs. Techniques to synchronize converter clocks with front-end local oscillators.
- c. Novel broadband high-frequency circuits and techniques for modulation and demodulation of complex waveforms.
- d. High capacity and parallel digital signal processing techniques. These may include both ASIC and FPGA approaches.

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1.2.8. Frequency Control. The Army requires study and research of frequency control device technology since the accuracy and stability of RF sources and clocks are key determinants of the performance of radar, C3I, navigation surveillance, EW, missile guidance, IFF systems and sensors.

- a. High purity quartz and new piezoelectric materials.
- b. Gun Hardened RF oscillators and clocks for smart munitions.
- c. Low-noise vibration resistant RF sources and clocks for radar, communications, navigation surveillance, EW, missile guidance, IFF and sensors.
- d. Low-jitter clocks and low phase noise RF sources from HF (1 MHz) to W-band (100GHz).
- e. Resonator theory, modeling and computer aided design of resonators and oscillators including 3-d finite element models of resonators with improved algorithms to reduce super computer calculation times.
- f. Processing and packaging of high stability resonators and RF sources, including mode suppressant techniques to limit degradation of filters and RF sources, mounted in below cut-off wavelength size modules.
- g. Resonators and oscillator theory leading to optimum performance.
- h. Ultra-low-noise measurement techniques of SAW and bulk resonators, piezoelectric material parameters calculation, modeling and measurement, diagnostic analysis and probing techniques, including fundamental noise studies involving 1/f noise.
- i. Thin film piezoelectric resonators and micro-resonators (MMIC compatible) for resonators filters and RF sources.

- j. Hardware and software development of low power, high-stability clocks.
- k. Design of miniature low loss (<2dB) piezoelectric resonators for compact size, narrow bandwidth bandpass filters (.01%-5%).

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1.2.9 High Power RF Sources and Amplifiers. The Army requires study and research in the areas of the following high-power RF technologies for communications, radar systems, electronic warfare (EW), and countermeasures. Solid-state III-V materials and devices, free-space and circuit based power combiners, microwave power modules, vacuum electronic devices. Solutions are sought for the above sources with regard to the following characteristics: compact size and low weight, improved high reliability, low cost, increased life, reproducibility, reparability and simplicity of fabrication, long shelf life, broad bandwidth (or tunability), high power, high efficiency, high gain, high voltage stand-off capability and low noise. Proposed designs must show the potential for meeting one or more of the above requirements. Solutions are also sought for test and evaluation techniques for the characteristics listed. Innovative simulation/computer techniques for the proposed design approaches are encouraged.

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1.2.10 RF-to-THz Devices and Integrated Circuit Technology. The ARL is interested in research on innovative electronic substrate and epi-materials, devices, monolithic circuits, and integration techniques for digital, mixed mixed-signal, and RF- to-sub-millimeterwave-to-TeraHertz applications. Work should involve devices and ICs integrated circuits, and subsystems built upon new Si-based, III-V, III-nitride, and II-VI materials, novel device structures, innovative circuit topology, nano technology, and multi-level, and/or heterogeneous integration technology.

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1.2.11 RF Wide Band Gap Semiconductors, Devices, and Circuits. The Army requires advanced wide bandgap RF semiconductor devices such as HEMTs, varactors, and Gunn diodes for high-frequency and/or high-power applications in the GHz regime and beyond. Materials of interest include group III-nitride semiconductors, SiC, diamond, ZnO, or other materials. Researchers should propose novel device structures, material growth, fabrication and characterization techniques as well as device modeling concepts for advancing the state of the art. Areas of interest include:

- a. New structures such as III-nitride based devices containing tertiary and quarternary compounds to take advantage of polarization and band gap engineering concepts. Also of interest are other lower dimensional devices structures such as nanowires and constrained structures entailing multi-scale modeling.
- b. Advanced material growth techniques that reduce defects to improve device efficiency and modulation / switching performance.
- c. Characterization techniques to qualify and quantify traps and other defects, carrier transport characteristics, hot spots, strain, surface charge, material composition, etc.



- d. Computational electronics techniques including technology computer aided design, Monte Carlo carrier transport simulation, or density functional theory techniques to accurately describe material characteristics and device performance and explain measured results.
- e. New methods to assess device reliability and determine cause of lifetime reduction.
- f. Model extraction techniques to obtain lumped element models for circuit designs up to the GHz to THz frequency range.
- g. Devices support RF/power applications for Army systems operating in extreme environments such that high temperature performance and thermal management and packaging issues become critical.

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1.2.12. Antenna Front End and Receiver Technology for Multi-Function Radio Frequency Architectures. The Army has an interest in researching affordable shared aperture, single system architectures which could implement radar, radiometric, combat ID, command and control, target acquisition, communications, signals intelligence (SIGINT), satellite on the move (SOTM), and communications on the move (COTM) functions – depending on platform requirements. Supporting technologies include, but are not limited to, electronically scanned antennas, multi-beam antennas, multi-band/broadband antennas, and wafer level antennas. Specific areas of interest are broadband antenna elements, low loss phase shifters, low loss delay lines, true time delay architectures, low loss splitters and combiners, planar technologies, issues associated with polarization switching, instantaneous bandwidth, low-loss high performance switches, simultaneous multiple beam formation, wide-bandwidth RF components and modules (LNA's, PA's, Mixers), and high performance design tools. Other supporting technology includes digital receiver technology, high performance A/D converters, high performance filters, programmable synthesizers and signal processing architectures.

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1.2.13. Conformal Antennas. The Army has an interest in integrated antennas and antenna arrays that are platform conformal. Such platforms are broadly defined and can be as diverse as the side of a vehicle, the wing of a UAV or the backpack of a soldier. The antennas should exploit novel techniques (e.g., metamaterials, artificial ground planes, electrically small antennas on a chip, etc.) to achieve comparable performance with traditional antenna architectures such as whip, dish, and slots. An important metric is comparable performance to legacy antennas while reducing cost and increasing affordability.

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1.2.14. Vehicle Integrated Antenna Technologies. ARL is soliciting innovative research proposals in the area of vehicle integrated antenna technologies. The proposed research should investigate novel approaches that enable advances of in-situ antenna designs for application to covert RF systems on military vehicles. Such advances are required to allow transmitting and

receiving antennas on vehicle platforms to be concealed or completely covert. All technologies ranging from camouflaged to embedded antennas are solicited. Both high and medium gain wideband antennas are required with polarization diversity from circular to dual polarization being highly desirable. Primary design considerations shall be to reduce the visual signature of ultra wideband antennas that exhibit similar EM performance to current state of the art solutions. Antenna concepts for three frequency bands of interest are sought: 100MHz to 1 GHz, 1 GHz to 3 GHz, and greater than 3 GHz with emphasis on circular polarization approaches. Overlapping frequency bands are also of interest. Proposals ranging from multiple covert antennas to multifunction RF systems with simultaneous transmit and receive functions are solicited for application to complex detection and geolocation systems.

- a. Applications of such integrated antennas for covert operations fall into two general classes: 1) sensitive receiver systems and 2) high power radar transmitters. The host platform for these antennas can be a full size tactical vehicles requiring broad beamwidth ( $>40^\circ$ ) or omni-directional or small robotic vehicles (Talon or unmanned aerial vehicle requiring directional antennas with reduced size.
- b. The Vehicle Integrated Antenna Technologies program will establish the feasibility and demonstrate new and innovative antenna designs that have the potential to enhance the way that the Department of Defense (DoD) installs antennas on vehicle platforms. The scope of this BAA is limited to demonstrating the innovative designs proposed, providing sufficient antenna details to allow antenna simulation verification, and describing the opportunity that exploitation of the approach could provide the DoD. Antenna performance must be compared to commercially available equivalents to demonstrate advantages of the proposed design. The as-installed antenna on the host vehicle must have similar performance while providing reduced visual signature compared to COTS alternatives. Efforts that successfully demonstrate feasibility of the antenna design may lead to future, longer term efforts that fully investigate and develop the technology necessary to exploit integrated antennas for ground vehicle applications.
- c. Examples of research topics that are of interest include, but are not limited to, the following:
  - 1) Use of Artificial Magnetic Conductors to Reduce Ground Plane Effects for Wideband Antennas – provide usable bandwidth over an octave or more for antennas fully integrated into ground vehicles.
  - 2) Platform RF Systems – Innovative antenna concepts that replace vehicle structural elements such as a bumper that serves as an antenna. Novel applications of camouflaged antennas such as antenna elements embedded in glass or composite structures will also be considered. Antenna systems that can be integrated into the platform structure during the manufacturing process are of interest.
  - 3) Platform Feed Systems – Innovative feed systems that improve performance (multi-function / reduced co-site / improved gain and pattern) and reduce the impact on platform integration. Feed systems that allow a single RF cable to feed multiple antennas and feed systems that can be integrated into the platform structure during the manufacturing process are of interest.
  - 4) Integrated Platform-Enhanced Aperture Design – Aperture design research to improve performance by incorporating the platform as part of the aperture design to obtain omni-directional pattern coverage.

- 5) Metamaterial Aperture Design - Volumetric characterization of antennas with metamaterial apertures integrated into the vehicle structure is of interest. In addition, further research into the application of metamaterials in antenna design, to include embedding them in armor, is also of interest.
  - 6) Leaky Wave Antennas - Research into Leaky Wave antennas that can be fully integrated into the vehicle structure and scanned electronically are of interest. The approaches should consider the ability for vehicles to radiate in all directions and at different frequencies (VHF is of interest).
  - 7) Wideband, Multi or single element, Multi-function Platform Antenna/RF Distribution Systems: Development of RF distribution and antenna technologies that reduce visibility are of interest.
- d. Proposals that describe integrated antenna technologies that could substantially reduce the visual impact of RF systems on ground vehicles but do not directly fit into one of the topics listed above can be submitted under this BAA.

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#### 1.2.15. Millimeter-wave and Sub-millimeter-wave Sensor Technology.

ARL has an interest in active and passive millimeter (MMW) and sub-MMW sensors and sensor technology for detection, surveillance, targeting and imaging. Sensors in this frequency regime offer better spatial resolution in a form factor that is often smaller than microwave systems, which enables their use in space-constrained applications. Areas of particular interest include:

- a. scattering and emission phenomenology including polarimetry at frequencies from 30 to 500 GHz
- b. packaged devices that improve the function of MMW sensor circuits including amplifiers, detectors and passives, either as discrete elements or integrated circuits
- c. novel radar and radiometer architectures with operation in the MMW and sub-MMW regime
- d. synthetic aperture sensors for high resolution imaging or sensing
- e. novel devices and techniques for the calibration of MMW sensors
- f. quasi-optical elements and architectures for beam steering and polarimetric sensing
- g. signal processing techniques such as compressive sensing or computational imaging to reduce data collection times or increase the information content of the data
- h. the electromagnetic modeling of MMW scattered or emitted signals

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1.2.16. Next Generation Digital Imaging. ARL is actively engaged in research leading to next generation digital imaging systems. Although several critical technologies, including image collection optics, solid state detectors, digital post-detection processing, and image display, impact critically the performance of digital imaging systems, traditional approaches to specifying these components for such systems do not pay sufficient attention to the interplay between them

and the subsequent impact that has on overall system performance. In contrast, our integrated approach optimizes the design of the component technologies in parallel. Such an approach provides improved performance while also addressing size, weight, cost and power issues. Recent developments in detector technology, computational capabilities, and the manufacture of optical surfaces facilitate an integrated imaging design approach. We are interested in proposals that address two or more of the following topics: image reconstruction, aspheric optical design, information theoretic imaging metrics and numerical optimization techniques. Topics may be submitted on imaging systems for the visible, infrared, millimeter wave, and terahertz regimes.

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1.2.17. Electronic Warfare/Electronic Attack (EW/EA). ARL is the designated leader for the Army's directed-energy weapon (DEW) technology base program. These efforts are expanding into the EW/EA area to include technologies in susceptibility investigations for high-power microwave (HPM), non-nuclear electromagnetic pulse (EMP) (NNEMP), electronic jamming technology, and electronic neutralization. ARL has a continuing interest in a broad spectrum of research in these areas, including, but are not limited to:

- a. A better understanding of the susceptibility of developmental and fielded systems to attack by an RF DEW threat.
- b. Improved methods and technologies for hardening systems against that threat.
- c. The development of new components (sources, pulsers, and antennas) for possible future application in an RF weapon system:

(1) Generation of microwave power/energy--Novel pulsers/sources are needed that have programmable pulse characteristics so that rise time, pulse width, repetition rate and frequency bandwidth can be changed electronically, along with frequency-sweeping capability over octave bandwidths. Design considerations of low-cost compactness and high efficiency are of particular interest. Switch technologies that convert dc to RF directly with picosecond rise time capability are of interest. Radio frequency oscillators/amplifiers that use picosecond electronics to obtain programmable RF outputs are desired, along with picosecond RF exiters to drive amplifiers. Portable kilowatt and megawatt RF/microwave amplifiers with octave bandwidths are sought. Frequencies of interest are from 0.3 to greater than 10 GHz, with microsecond pulse durations and high duty cycles. Efficiencies should exceed 30 percent and gain should exceed 30 dB. Novel technologies suitable to extend high-power pulse amplifiers to 40 GHz or higher are also sought. Bandwidths should be multi-gigahertz and gains should exceed 20 dB. Emphasis will be placed on efficiency, compactness, and portability. Source technology that is based on solid-state transmitters using phased array antennas is of increasing interest.

(2) The effects of RF and microwave power/energy--Material susceptibility is the primary area of concern. Included are composite materials, electro-optical systems, computers, communications, displays, receivers, sensors, monolithic microwave integrated circuits (MMIC), very high speed integrated circuits, and other sophisticated electronic systems, subsystems, and devices. Upset and damage to electronic devices and their failure mechanisms, caused by RF transients, are of interest. RF coupling and failure mechanisms that are affected by such parameters as frequency, pulse width and shape, repetition rate, amplitude, and polarization are also of interest. Novel schemes are solicited for techniques that can be used for protection against

the RF and HPM threats. Advanced methods and techniques are needed for housing composite materials. Methods for the theoretical understanding and prediction of RF effects from transients with a wide range of pulse characteristics are of great interest.

(3) Hardening to RF energy--Army system survivability is enhanced using hardening techniques that are readily verifiable, reliable, and maintainable in the RF environment. ARL needs improved interactive models that yield statistical parameters of the source/system environment for complex scenarios. Models are sought that are suitable for understanding the mechanisms of device susceptibility and leading to improved devices. Detailed models have been developed that use excessive computer resources. New approximate techniques need to be developed to readily accommodate complex scenarios. Models are needed for composite materials, including both resistive and inductive effects. Innovative techniques for hardening front- and back-door entry ports of systems are sought. Hardening includes techniques to limit the throughput of the path or to raise the susceptibility threshold of devices subject to burnout or upset from RF energy. Hardening devices are of interest that:

- a. Can handle large average and peak powers.
- b. Can limit or switch unwanted HPMs in protecting the system or subsystem.
- c. Have frequency and amplitude selectivity. Vacuum microelectronics, semiconductor, and magnetic technologies are all of interest.

(4) RF microwave diagnostics--Novel, non-perturbing RF/microwave diagnostics are sought. Such devices should be able to measure RF/microwave power for microsecond durations and have rise times in the 0.1- to 10-ns range. The diagnostics should be mountable inside enclosures near complex structures. High-frequency probes that can operate above 2 GHz are also of interest. Quality measuring techniques are needed for seams, joints, and contracts for composite materials. The Army has a great interest in testing military systems in a microwave environment. Research topics related to the Army's system testing effort include instrumentation and measurements, anechoic chamber design and characterization, microwave source development, novel testing techniques to allow a military system to be quickly evaluated in a microwave environment, experimentation to determine microwave effects, modulations of microwave signals, and high-power sources.

(5) Battlefield effectiveness of RF-DEW--The Army, as well as DoD in general, is involved in the impact of RF effects on the battlefield. Novel approaches are sought to develop techniques/models that can describe the effects of system degradation on battlefield systems and how the systems may impact the outcome of the battlefield-appropriate measures of effectiveness must be defined for various types of weapons and sensors that could be affected by RF energy.

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1.2.18. Prognostics & Diagnostics. The Army has an interest in the area of Prognostics and Diagnostics (P&D) health monitoring systems as applied to current/future weapons platform and the Soldier. The paradigm of time-based maintenance currently employed across the massive platform inventory is too costly and drains resources. A cost savings can be obtained in shifting the paradigm from time-based to condition-based maintenance. In term of physical platforms

and hardware, embedded monitoring units will provide increased readiness and enhanced awareness of materiel condition. The soldier is recognized as the Army's most important asset. Being able to monitor and diagnose the Soldier's current condition is extremely valuable. Using environmental along with specific application sensors, signal processing will be necessary to predict the remaining operational life expectancy and the operational status of this range of diverse platforms. Understanding of the Physics of Failure and reliability engineering are crucial in the development of predictive algorithms. Establishing the appropriate algorithms to specific applications will be necessary for realization of P&D. P&D covers multiple areas such as ground and aerial vehicles, mechanical and electro-mechanical devices, electronic components, electronic communication and control systems, and biomedical systems. Areas of significant interest include, but are not limited to, the following:

- a. Framework/methodology in the development of prognostics and diagnostic routines
- b. Prognostics prediction algorithms and diagnostic routines
- c. Data acquisition systems with small form factor and minimal power consumption that are wirelessly networked & interrogable and extensible to existing platform diagnostics and readily available sensors. Compatibility with an open common architecture such is preferred.
- d. Techniques for Built-in Self-Test (BiST)
- e. Efficient techniques/processing of sensor data to reduce data storage requirements and methods of sensor fusion
- f. Novel design and integration of environmental and application specific sensors that provides smaller footprint, power and ease of integration for P&D applications

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1.2.19. Prognostics and Diagnostics for Material State Awareness. Research proposals are invited to develop novel prognostics and diagnostics (P&D) methods for material state awareness to enable ultra-reliability to support the Army's zero-maintenance vision for Future Vertical Lift. In order to achieve zero-maintenance operation of rotorcraft, conditions that lead to fatigue failure must be captured and controlled prior to the onset of failure, thus enabling fatigue-failure-free operation. The areas of technical interest include, but are not limited to, identification and capturing of precursors to damage; prognostic methods for the prediction of remaining useful life of a component and/or system based upon the existence of damage precursors and their progression to failure initiation; and real-time component and/or system level life prediction incorporating data fusion, risk assessment, and multi-scale modeling to reduce the logistics footprint, maintenance burden, and life-cycle costs while increasing vehicle availability.

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1.2.20. Bio-/Neuro-inspired Sensing and Information Management. The Army requires research investigations in the area of arrayed, bio-inspired and/or biocompatible microscale sensors, and bio-/neuro-inspired approaches for extremely low power information management and control. This research is anticipated to establish a revolutionary new pathway for optimizing the

coordination of orthogonal fused-sensing with computation in extremely size-, weight-, and power-constrained, arrayed heterogeneous sensor systems. Envisioned future applications range from autonomous control of mm-scale robotic platforms, to helmet- or textile-integrated physical health monitoring or situational awareness flexible sensor network arrays. This research strives to determine a set of minimalist solutions for information management and decision making in constrained heterogeneous sensor systems. In particular, it seeks to 1) determine the lower limit of sensor resolution required to achieve a high probability decision, 2) rigorously incorporate error and probability into sensor processing and decisions, 3) exploit orthogonal data streams to reduce uncertainty and enhance decision/actuation fidelity, 4) optimize control logic to the specific temporal dynamics of a system, and 5) incorporate information management logic directly into novel sensor nodes and arrays. Key research areas include, but are not limited to, the following:

- a. Investigation of bio/neuro-inspired control theory and multi-sensory perception algorithms for arrayed sensor information processing, actuation, and/or information management in relevant time scales. These algorithms may include multi-scale calculation approaches to modeling.
- b. Design, simulation, fabrication, test, and evaluation of electronic, electromagnetic, and electromechanical microsensor devices required to effect required actuation, communications, navigation, or information processing on extremely size-, weight-, and power-constrained systems.
- c. Design, simulation, fabrication, test, and evaluation of biocompatible microsensor devices for applications including helmet- or textile-integrated physical health monitoring or situational awareness flexible sensor network arrays.

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1.2.21. Quantum, Bio, and Flexible Materials for Next Generation Electronics: ARL is interested in receiving proposals toward the development of materials and processes for revolutionary changes to modern electronics. Specific areas include organic and inorganic materials for flexible/conformal electronics; true quantum materials, devices, and electronic structures; and bio-electronics.

A. Flexible opto-electronic materials and devices: ARL requires research investigations into novel materials and devices for opto-electronic applications that includes, thin film transistors, diodes, and electronic components for flexible electronic applications. In addition, materials and device research is sought for photovoltaic and other energy harvesting electronic applications. The research in materials and devices shall include relevant basic physics studies that couple electrical, optical and mechanical properties of these materials and devices. Research and analysis are needed to ensure that the opto-electronic devices for the current and new systems will provide improved performance that is required to carry out complex military missions. ARL is interested in receiving novel proposals that address the technical barriers associated with improving the current state of the art in flexible opto-electronic materials, devices, and components used as the basis for Army systems. Technical areas of interest include, but are not limited to, the following:

- 1) Theoretical and experimental studies of electronic properties including; carrier transport, carrier mobility, carrier injection, electronic performance and stability. The device shall be based on organic materials, inorganic materials and/or organic/inorganic hybrid materials.
- 2) Investigations on the materials, devices, and tools that will lead to the development of thin film transistors, diodes, electronic components (capacitors, resistors) required to enable electronic architectures on flexible substrates. The device shall be based on organic materials, inorganic materials and/or organic/inorganic hybrid materials.
- 3) Investigations on the materials, devices, and tools that will lead to the development of photovoltaic devices solar cells, and related energy harvesting devices on rigid and flexible substrates. The device shall be based on organic materials, inorganic materials and/or organic/inorganic hybrid materials.
- 4) An area of interest is the integration of high-performance electronics and opto-electronic devices on flexible substrates.
- 5) Studies of micro-mechanics that impact the opto-electronic devices.

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B. Quantum and Nano-electronics: ARL is interested in exploring the promise of nanoelectronics and quantum devices for the development of next generation and new capability electronic systems. Research should be related to the quantum mechanical effect of few atom systems and not be defined by bulk material properties. Research related to material development, processing, and modeling are welcome. Specific areas of interest include, but are not limited to, topological insulators, spintronics, quantum dot structures, nanowire based devices, and single electron devices.

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C. Bio-electronics: ARL is interested in the emerging science of bioelectronic and quantum biology for the development of next generation electronic materials. This fundamental research should address issues related to design, modeling, fabrication, testing, and characterization to include the ability to individually address, control and assemble structures across the nano through macro scale regimes. Technical areas of interest include, but are not limited to, the following:

- 1) Theoretical and experimental studies of the quantum phenomena of bioelectronic structures in the nano and sub nano regime
- 2) Theoretical and experimental studies of bioelectronic structures and assembly through the macro-scale enabling functional materials
- 3) Investigations on the materials, devices, and tools that will lead to the development of hybrid bio-electronic materials
- 4) Bioelectronic materials that are built from biological structures or assembled/enabled by biological structures.



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### **1.3 Photonic Materials and Devices**

1.3.1. Photonic Devices and Modules. Research is encouraged pertaining to active and passive devices as well as fiber based technology for sensing, communication including microwave, data and telecommunication and optical signal processing, Active device research includes the development of bulk and integrated sources, modulators, detectors and waveguides, and the development of technologies for their integration into processor architectures. Laser-based Terahertz systems are also sought. Active interface devices include semiconductor light emitting diodes (LED), lasers, vertical cavity surface emitting laser (VCSEL), photo detectors, solar cells, modulators, amplifiers and waveguides, with operation in the UV to IR spectral region, as well as integrated drivers and receivers. Also of interests are novel RF-Photonic devices, components, modules, and subsystems. Integrated array research should include on-chip processing, layout, mounting, and device cooling for one- and two dimensional arrays as well as the driver and receiver circuitry. Parameters of interest include number of elements, readout speed, noise levels, and dynamic range.

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1.3.2. Novel Optical Processing Algorithms and Techniques. Proposals relating to ideas for new processing systems and configurations are welcome. Methods for modulating light beams with signals of appropriate nature are of interest here. Also of interest are methods for realizing certain processing algorithms (e.g., multi-spectral image processing) and methods for detection using elaborate photosensitive devices (e.g., charge-coupled devices and CMOS detectors). Also of interest are algorithms and architectures for high speed data and telecommunications and networking as well as new concept and architectures to generate, transmit and processing RF-microwave signals in optical domain to improve the current RF systems including antennas and Radars. Important factors are speed, reasonable laser power requirements, insensitivity to lens aberration, small size, noise and environmental immunity, and other aspects of high performance. Both pre- and post-processing electronics are among the system components subject to possible improvement, with interfaces and coprocessors.

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1.3.3. EO/IR Sensors. Research proposals are desired that will lead to the ability to sense, locate, identify, and engage targets at tactical ranges. These sensors must reliably discriminate between targets and clutter and detect targets in the presence of counter-measures. For example, it is desired to detect a camouflage-netted vehicle partially obscured by foliage. Electro-optical and infrared sensors, both passive and active, and covering the spectrum from the ultraviolet to the far infrared, are of interest. Small size and gun or missile launch survivability are required for some applications and low cost is always important. Another area of interest is surveillance (UAV) and fighting platform (rotary wing and ground vehicle) based systems. Critical components of sensors, such as high-power eye-safe laser sources for laser radar, are of interest. Methods for fusing the outputs of various sensors and signal propagation modeling are also of

interest. Applications include surveillance and target acquisition, target engagement for smart munitions, and navigation and obstacle avoidance.

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1.3.4. Infrared Detectors & Power Sources. ARL's research and development goal is to advance the technology for producing technologies for smart, multi-spectral, active and passive, focal plane arrays (FPAs) in ultra-violet to sub-millimeter wave spectral regions, with particular emphasis on the infrared region. Effort is also made to develop new concepts for photovoltaic and thermoelectric for power generation. Examples of areas of interest include, but are not limited to, the following:

- a. Materials research, thin film growth, nano/bio-materials and device processing for fabricating single and multi-spectral detectors/arrays for active and/or passive sensors covering the major infrared bands. New materials development for power sources etc. Improvement in photovoltaic devices using: (i) Broadband operation with strong harvesting and conversion of below-bandgap photons; (ii) Nano-patterned structures for advanced light trapping schemes via holographic lithography;(iii) Nano-enhanced absorbers in the IR range; (iv) Advanced windows based on novel transparent conductors; (v). Bandstructure nano-engineering for high conversion performance; (vi). Nano-engineered electron processes for suppression of thermalization and recombination losses; (vii). Advanced passivation schemes for reducing surface recombination.
- b. Epitaxial growth processes of materials on compliant and non-compliant substrates (e.g. HgCdTe, GaAs, InGaAs, etc.) for detectors, solar cells, thermoelectric and other optoelectronic applications. Research spectrally flexible hybrid thermophotovoltaic conversion consisting of optimized emitters, optical filters, cavity geometry and low bandgap, conformable thermophotovoltaic cells. Significant improvements can be achieved by (i). Optimizing photon recycling schemes for enhanced absorption; (ii). Bandstructure engineering for high conversion performance; (iii). Utilizing conformable photovoltaic cells for improving thermal heat management; (iv). Advanced materials and techniques to control spectral emission and transmission including photonic crystals and metamaterials.
- c. Novel Uncooled FPA technology.
- d. Computer simulation and modeling of single and multi-color detectors and systems.
- e. Biologically inspired techniques for IR detectors and power source devices.
- f. Development of advanced readout circuits including neuromorphic and bio-inspired circuit designs.
- g. Development of Novel III/V materials and devices.

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### 1.3.5. Novel and Highly Scalable Diode-Pumped Solid State Lasers

- a. Novel Solid State Lasers and Laser Materials: The Army is interested in research on innovative gain media, for example laser-quality ceramics with emphasis on engineerable doping and index profile (e.g., gradient doping, sharp-step waveguiding structures with sub-10-micrometer layering precision); solid-state materials for high-gain stimulated Brillouin scattering (SBS); specialty fibers and fiber lasers suitable for high average powers and power scaling (e.g., fibers with compositions for ultra-high SBS threshold; fully crystalline double-clad, i.e., crystalline core/crystalline cladding, fibers; non-circular, high aspect ratio, fiber designs with developed mode selection mechanisms or self-mode selection); and advanced laser materials for diode-pumped eyesafe lasers (e.g., based on high and ultra-high thermal conductivity hosts, environmentally stable low-phonon hosts, or exceptionally high emission/absorption cross-section laser materials).
- b. Techniques for Power Scaling of Diode-Pumped Solid State Lasers: The Army also has interest in innovative highly efficient pump-coupling techniques; innovative pump diode and active medium cooling techniques (e.g., cooling via optically transparent highly thermo-conductive materials); passive and active laser beam/aperture combining methods; laser wavelength shifting techniques for achieving high average powers with optimum eye-safety; active and passive wavefront distortion compensating/OPD reducing techniques.

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1.3.6. Hyperspectral/Multispectral/Polarization Imaging. ARL is engaged in the research and development of high performance compact, field-portable hyperspectral and multispectral imaging systems from the vacuum ultraviolet (UV) to the long wave infrared (LWIR) using tunable filter technologies including acousto-optic tunable filter (AOTF), Fabry-Perot etalon, diffractive optics, Michelson interferometer, liquid crystal, and other promising approaches. There is considerable interest in designing miniature sensors using micro electromechanical systems (MEMS) approach. Development of high performance hyperspectral/multispectral/polarization imager technology is critical to the Army's needs in chemical and biological agent detection as well as for target detection including buried mine detection. The range of applications includes spectroscopic remote sensing of biological and chemical agents, detection of explosives, detection of chem/bio agents on surfaces, pollution monitoring, detection of plumes, condition-based management, and polarization imaging for detection of targets and backgrounds, etc. System designs for compact automated hyperspectral/polarization imagers from UV to long IR incorporating suitable detectors, optics, image collection and processing software incorporating automated target detection algorithms and on chip preprocessing capabilities including biological inspired algorithms, electronically tunable polarimetric elements, suitable high sensitivity focal plane arrays, compact cooling systems, and schemes to improve the noise equivalent spectral radiance (NESR) of such imagers are of critical interest. Research in automatic processing algorithms for spectroscopic and spectropolarimetric imaging data including data storage techniques and data compression is encouraged. Topics of interest include efficient spectral dispersing elements; design of AOTF cells and transducers including designs to facilitate operation over two or more octaves in

frequency; MEMS-based tunable etalons including materials, processing, fabrication, and packaging; diffractive optic elements including cooled lenslet arrays; design and fabrication of electronically tunable compact polarizing elements; higher sensitivity focal plane arrays with high dynamic range, fast efficient readout circuits, etc.; and compact packaging of such imagers for field portability and UAV and UGV operations.

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1.3.7. Luminescent Materials and Devices. The ARL requires research investigations into luminescent materials, devices, and components, and relevant basic physics studies that couple luminescence, electrical, optical and mechanical properties of these materials and devices. The luminescent materials and device application areas of interest include, but limited to, displays, luminescent sensors, tags, excitation sources from visible to x-ray. Research is needed to ensure that the devices available for the current and new applications will provide improved performance that is required to carry out complex military missions. ARL is interested in receiving novel proposals that address the technical barriers associated with improving the current state of the art in luminescent materials, devices, and components used as the basis for the applications above in Army systems. Technical areas of interest include, but are not limited to, the following:

- a. Theoretical and experimental studies of luminescence including electroluminescence, (organic and inorganic) cathodoluminescence, and photoluminescence.
- b. Investigations on the materials, devices, and tools that will lead to the development of devices on flexible substrates.
- c. Studies of micro-mechanics that impact display devices.
- d. Investigation of light modulation materials and devices.
- e. Investigation of electron sources for electronic devices and luminescent emitters from visible to x-ray
- f. Components and technologies that enable excitation sources from visible to x-ray

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1.3.8 Nonlinear Optics. The ARL requires research investigations and proposals in nonlinear optical (NLO) materials, components and devices that can reduce their optical transmission across the visible and NIR (400-900nm) wavelength range passively when subjected to an incident laser beam within that wavelength range. Reductions of optical transmission on the order of 1000X or greater is desired. The speed at which such materials, components, or devices switch from transmissive to non-transmissive states needs to be on the order of <1ns. Materials and devices must be highly transmissive in the initial state. Concepts need to be able to be incorporated into low F/# optical viewing systems, yet must not greatly impact the normal performance of those systems. Technical areas of interest include, but are not limited to, the following:

- a. Development of optical materials with large nonlinearities and a broad wavelength and/or pulsewidth response. This can include molecular modeling, material synthesis,

and characterization of nonlinear parameters as well as nonlinear transmission studies.

- b. Modeling efforts to relate nonlinear material properties to their ability to effectively reduce transmission. Modeling effort should include details on how the nonlinear materials affect the propagation of incoming laser beams.
- c. Development of optical viewing systems and components that incorporate the materials and devices above.

Proposals utilizing solutions other than NLO materials that suggest novel methods of reducing transmission will also be considered.

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1.3.9. Biologically Inspired and Biologically Derived Sensor, Power, Device and Materials Research. This effort is characterized by three main core competencies: the study of biological systems, synthetic biomaterials and biotic/abiotic interface science. These areas are used to build future technologies designed to increase situational awareness, reduce logistic loads and provide new capabilities in extreme operational environments.

Goals include the development of revolutionary biological, photonic, electronic and organic-electronic hybrid devices and sensors. In an effort to capitalize on these advances, targeted investigations will be conducted in the following areas:

- a. Biosensors to either sense biology or sense with biology.
- b. Biomimetic sensors.
- c. Synthetic recognition discovery tools including engineered biomolecular scaffolds through low cost cell sorting technologies.
- d. Natural and synthetic metabolic network analysis including metabolomics, regulation, tools for building synthetic networks and predictive modeling.
- e. Photonic and electronic devices that replicate/mimic or harness biology to function.
- f. Biologically derived or inspired power generation and storage.
- g. Biological waste to energy conversion.
- h. Bioelectronics that are built from biological structures or assembled/enabled by biological structures.

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1.3.10. Advanced Concepts for Hazardous Material Sensing Applications. The ARL is exploring new enabling detection technologies for hazardous material sensing applications. The ultimate goal of our research efforts is to develop sensors (both point and standoff) of hazardous substances for field use. The areas of potential application include, but are not limited to, food/water safety and defense, toxic industrial chemical (TIC) and toxic industrial material (TIM) sensing, improvised explosive devices (IED) detection, unexploded ordinance (UXO) and chemical and biological defense. Desirable features of sensor systems include: high specificity in analyte identification, small in size for field portability, low power requirements, low cost, and stability for long periods of time under various environmental conditions. The several key sensor research thrust areas are transduction technique, biological or chemical recognition, and direct spectroscopic methodologies. Our current research interests include development of both point

and remote sensing for hazardous materials using synthetic molecular recognition elements, and optical and electrochemical transduction technologies. The desired sensor technologies are not limited to these methods, but may use mechanical or other novel detection methods. Recognition technologies include, but are not limited to, molecular imprinting, ssDNA hybridization, dsDNA hybridization, aptamers, peptides and phage or cell surface display technologies. Optical technologies include, but are not limited to, new optical sources and detectors for sensors, fiber optics, interferometry, non-linear optics, photonics devices, Raman techniques, and fluorescence.

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1.3.11. Technology Demonstrations and Assessments for Special Operations and Low Intensity Conflict (SOLIC). ARL is interested in proposals that focus on demonstrating (prototype level) or assessing (unique facilities) across any of the technical areas described in the Army Research Laboratory Directorates portion of this BAA for SOLIC applications. Demonstrations and assessments should be at least at the brass board prototype level. The focus is to demonstrate the transition of technology for the application of advanced systems and equipment to the U.S. Army, United States Special Operations Command, and other unique missions related to transformation of the U.S. military and the Global War on Terrorism in the following mission areas:

- a. Direct Action Support: Development and demonstration of advanced technology supporting small team and transformational combat units (interim brigade, objective force, and future combat systems) combat operations. This includes close quarters combat and fire support (laser target designation, etc.)
- b. Intelligence, Surveillance and Reconnaissance Support: Development and demonstration of technology supporting enhanced situational awareness and real-time intelligence for small team and transformational combat units (interim brigade, objective force, future combat systems) and their tactical support elements at forward operating bases and joint special operations task force locations.
- c. Special Reconnaissance Support: Development and demonstration of technology supporting dismounted, long term reconnaissance into non-permissive areas.
- d. Psychological Operations: Development and demonstration of equipment providing production and dissemination and assessment of Psyop media. This includes leaflets, RF broadcasts, and text messaging and other formats.
- e. Expeditionary Warfare/Unconventional Warfare: Development and demonstration of technology and systems supporting rapid deployment operations. This involves the rapid build-up of lethal and sustainable forces in remote areas.
- f. Military Operations in Urban Terrain: Development and demonstration of technology and systems supporting a range of military operations in urban terrain. This includes enhanced situational awareness and use of unmanned systems.
- g. Network Centric Warfare: Development of technology and systems for engaging enemy network systems, and protecting friendly networks.
- h. Knowledge Superiority: Development, application and demonstration of hardware and software to provide and apply knowledge superiority to U.S. Army and Special Operations Forces objectives.

- i. Counter-drug Operations: Development and demonstration of technology and systems supporting counter-drug operations. This includes equipment that is able to detect and identify the presence of drugs in any form, or in any container.
- j. Deployable Force Protection: Development and demonstration of technology and systems supporting deployable force protection on both maritime (ocean and riverine) and land. This includes equipment that is able to provide entry control, surveillance, cover/reinforcement, active defense, communications and power.

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#### 1.3.12. Technology Demonstrations and Assessments for Department of Defense Biometrics.

The use of biometrics as an enabling technology has grown recently due to its success in various military applications. Biometrics has an important role as an enabling technology in Department of Defense (DoD) mission areas such as intelligence (e.g., tagging, tracking, locating), access control (both physical and logical), and forensics (e.g., latent matching). In addition, biometrics can be leveraged to support various other missions within DoD to include Identity Management.

As biometrics matures within DoD, the requirements and needs of the user are becoming increasingly complex and require specific solutions that have not yet been developed. It is DoD's intent to advance the state-of-the-art in a targeted approach to provide users with new and enhanced biometrics capabilities. The U.S. Army Research Laboratory (ARL), on behalf of the DoD Biometrics Task Force, solicits proposals focused on the development and demonstration of functional models and the assessment of biometric functionality across the two (2) Focus Areas indicated below that can lead to a demonstration in a relevant environment, at the brass board level, within 18 months. Demonstrations and assessments will be performed in coordination with the DoD Biometrics Task Force. Results are to include technical performance measurements and analysis from actual testbeds and laboratory environments that indicate the effectiveness of the technology to advance the state-of-the-art in current biometrics capabilities across and/or within the following two (2) Focus Areas.

- a. Single Sensor Capturing Multiple Modalities: The ability to collect biometric data is a critical step in the overall biometric process. Traditional biometric collection systems are able to collect a single biometric (e.g., fingerprint). In some cases, a single device can use multiple sensors to collect multiple modalities (e.g., finger, face, and iris). However, using multiple sensors to capture multiple modalities demands extra time and resources. The ability to capture multiple modalities with the same sensor, whether contact or contactless, would be a valuable asset for our Warfighters and users within DoD. Below are examples of possible multi-modal fusion sensor challenges that could be addressed:
  - Hand Capture – Could collect palm, hand geometry, fingerprint, and/or vascular biometrics with a single sensor
  - Face Capture – Could collect face, ear, and/or iris biometrics with a single sensor
- b. Multi-Modal Matching Capability: Several biometric systems rely on the use of a single biometric modality (e.g., fingerprint) for the verification and/or identification

of individuals to produce highly accurate results. However, with the advent of stand-off biometric collection and less than optimal samples due to the tactical environment, relying on only a single modality has the potential to limit the matching accuracy. Future biometric technologies must be able to combine multiple modalities (e.g., fingerprint, iris, face, voice, DNA, palm, vascular, ear) of varying quality and origin, and other non-biometric data, without sacrificing speed, to allow for improved matching and more robust identity analysis. Below are examples of possible multi-modal matching algorithm challenges that could be addressed:

- Algorithms that can adapt their matching capability to the types of biometric modalities available and their respective quality
- Algorithms that can execute on many processor architectures, from smaller/embedded devices to larger enterprise systems

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## 1.4 Energy Materials and Components

1.4.1. Electrochemical Power Production and Energy Storage. The areas of interest are:

- a. Active and Reserve Primary Batteries for Munitions Applications: Research of new battery chemistries, materials, and battery designs for improved thermal and liquid-electrolyte reserve batteries capable of supplying power densities from 20 to 400 Watts/liter after 10 or more years of storage. Primary areas of interest are: thin-film thermal battery chemistries, materials, components, or production methodologies for thin-film batteries with faster activation, higher power, smaller volume, more-flexible form-factor, greater mechanical robustness, or better production efficiency; and new forms of heat sources that would be compatible with the thin-film thermal battery technology. Storage and operation are required over the full military temperature range.
- b. Primary Lithium Batteries: Research of battery chemistries for cells and stacks of cells for man-portable applications using environmentally-friendly materials capable of providing better service than the Army's present general-purpose Li/SO<sub>2</sub> and Li/MnO<sub>2</sub> batteries. Emphasis is on modification of commercially-based chemistries to permit all-weather storage and use. This may include Li/air, Li/S and Li/CF<sub>x</sub> formulations. The development of manufacturing technology for these batteries is an area of interest.
- c. Rechargeable Li (Li Ion) Batteries: Research of electrode and electrolyte materials chemistries for cells and stacks of cells using liquid or polymeric electrolytes capable of providing, at the packaged cell level, specific energies greater than 250 Wh/kg, specific power greater than 50 W/kg continuous, and greater than 10 kW/kg pulse power over the full military temperature range. The development of manufacturing technology for these batteries is an area of interest.
- d. Advanced battery chemistries to include multi valent materials such as magnesium and aluminum. Research of components, especially electrolytes and cathodes to allow stable operation.



- e. Batteries for grid storage to include molten salt batteries and dual interaction materials.
- f. Fuel Cells: Research and development of improved low temperature alkaline and acid based polymer electrolyte membrane fuel cells and components including catalysts for use with alcohol and solid fuels. Use modeling and simulations to solve and improve fuel cells performance. The development of hydrocarbon fuel reformers and reformer components, including desulfurizers and sulfur tolerant reformer catalysts to provide hydrogen for fuel cells are areas of interest. The development of medium and high temperature fuel cells and components for the direct utilization of hydrocarbon fuels or impure hydrogen is also an area of interest.
- g. Fast Discharge Pulse Power Capacitors: Research of film capacitor technology including the development of high energy density dielectric films, impregnants, metallization and manufacturing technology for capacitors that can provide energy densities  $> 2.0 \text{ J/cc}$  with a DC life over 2000 hours, and discharge time is the microseconds range.
- h. High Temperature Capacitors for Power Electronics: Research and development of high temperature polymeric dielectrics including process development for high temperature thin film manufacturing. The capacitors made of such thin film dielectric should be operable at temperatures over 125 degrees C, preferably over 150 degrees C. The capacitors shall have the following characteristics: a dissipation factor below 0.5 percent, insulation resistance greater than 105 ohm-farad at 125 oC, operational life of greater than 10,000 hours at frequency greater than 20 kHz and rms current greater than 1.0 A/microfarad.
- i. Energy Science: Research and development of novel materials and routes to energy. These could include development of alternative routes to fuel such as direct photoelectrolytic routes to hydrogen or energy, photovoltaic devices that have very high efficiency for development of devices suitable for portable power, can also include metamaterials that could be used in catalysis, high efficiency solar or waste heat to energy. Other routes for waste heat to energy include thermoelectric and thermophotovoltaic devices.

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1.4.2. Power Conditioning. The Army is searching for innovative technologies and techniques for reducing the size, weight, cost, and logistics footprint of power conditioning systems across the full range of Army applications. High efficiency and high temperature operation (for reduced cooling) are also critical requirements. Some specific areas of interest include:

- a. Novel power converters.
- b. Novel materials and designs for high-temperature power conditioning capacitors and inductors.
- c. High performance components such as switches and capacitors.
- d. Pulse Forming Network (PFNs) and power conversion technology for electric guns, directed energy, electromagnetic armor and other high power and high voltage loads.

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1.4.3. Wide Band-Gap Power Devices. ARL is seeking proposals for research of wide band gap devices in the following areas:

- a. Device design and fabrication of monolithic and hybrid voltage-controlled SiC or GaN high-temperature high-field power devices.
- b. Circuit design and fabrication of highly-efficient Si-based and SiC- or GaN-based high-temperature power electronics for power conversion and motor-control applications.
- c. Circuit simulation to allow topology and device trade off studies for the design of high-temperature power conversion circuits for specific Army Future Combat Systems applications.
- d. High-temperature high-field insulator materials for use as gate dielectric and field passivation layers for application to SiC and/or GaN power devices.
- e. High-temperature packaging and thermal management systems for wide bandgap power electronics ( $T_j = 225$  to  $400$  C).

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1.4.4. Microsystems Technology for Power Generation and Energy Conversion Components.

The areas of technology of interest to ARL include, but are not limited to, the following:

- a. Microfabricated combustors and components for micro fuel cells and small thermal-to-electric converters: research and modeling in catalytic and homogeneous combustion for extreme energy dense, high temperature heat sources.
- b. Heat transfer and thermal management: Research and modeling in materials and techniques to remove high heat fluxes from power electronics, improve efficiency of small energy converters, recuperate & repurpose waste heat energy, improve thermal system packaging, improve environmental control units, and understand multi-phase heat transfer fundamental mechanisms.
- c. Balance-of-plant component for small heat engines and fuel cells: research in fuel technologies including liquid atomization and micro-fuel pumps. Research in high efficiency air delivery including blowers, fans and pumps.
- d. Technologies to support microfabricated rotary systems including bearings, motors and similar components.
- e. Microsystems power components and conversion: research in high power density, multifunctional components and sub-systems for capturing, transforming, converting and delivering power to microsystems.

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1.4.5 Ultra-Energetic Materials and Energy Storage. The areas of technology of interest to ARL include, but are not limited to, the following:

- a. Radioisotopes and Nuclear Isomers: Develop and study approaches to the control of nuclear emission and/or nuclear decay rates. Investigate nuclear structure of isomeric nuclei, particularly focused on long-lived isomers from which gamma or charged-particle emission could be utilized for power sources.
- b. Radioisotope/Nuclear Isomer Energy Conversion: Develop and study improved concepts for conversion of nuclear decays into usable electrical power. Techniques using liquids or novel materials are of interest for long-lived micro-power sources.

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1.4.6 Nuclear Detection and Sensors. Develop and study approaches that include compact sensors that can be arrayed for large area survey and data fusion. Investigate sensor element architectures that enhance system energy efficiency supporting 100 microwatt power level sources and increased performance of compact devices.

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1.4.7 Superconducting Materials. The areas of technology of interest to ARL include, but are not limited to, the following:

- a. Materials development of high temperature superconductors. Research for better understanding on structure-property relationship in critical superconducting temperature, superconducting critical current density, and the interaction with external magnetic field. Investigation of pinning effect on superconductivity, transient phenomena of electric current in the superconductor, and the associated ac losses.
- b. Investigation of superconductor materials growth mechanism at the interface of the joint. Development of related superconductor processing technology.
- c. Devices and applications of superconductors for Army utility.
- d. Electronic device development with superconducting materials as component for function and performance enhancement.

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1.4.8 Energy Materials and Components. Tactical Energy Networks. The areas of interest are:

- a. Power lines sensing technologies to determine types and specifications of loads and sources that cannot or do not provide the information directly. Primary interest areas are sensors to collect information from the power line, techniques to analyze power line data, methods to interrogate loads and sources through passive or active methods.
- b. Advanced cognitive techniques to allow real time adaptive operation and longer term predictive modeling to provide energy informed operation of tactical micro grids. Primary interest areas are technologies to enable machine based decisions for tactical grids systems that utilize heuristics and cognitive techniques. A key goal is to

- provide learned behavior with input from external sources such as operational data, weather, maintenance and other factors.
- c. Novel power conditioning components and control research in technologies to allow efficient conversion of power between frequencies and voltages with the ability to scale system power levels based on need.

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#### 1.4.9 Tactical Energy Networks/Microgrids

The areas of interest are:

- a. Power lines sensing technologies to determine types and specifications of loads and sources that cannot or do not provide the information directly. Primary interest areas are sensors to collect information from the power line, techniques to analyze power line data, methods to interrogate loads and sources through passive or active methods, and load source health monitoring.
- b. Advanced cognitive techniques to allow real time adaptive operation and longer term predictive modeling to provide energy informed operation of tactical micro grids. Primary interest areas are technologies to enable machine based decisions for tactical grids systems that utilize heuristics and cognitive techniques. A key goal is to provide learned behavior with input from external sources such as operational data, weather, maintenance and other factors.
- c. Novel power conditioning components and control research in technologies to allow efficient conversion of power between frequencies and voltages with the ability to scale system power levels based on need.
- d. Research in tactical energy communications and control technologies to include layered architectures comprising physical, data, and communication; exploration of technologies that interact between the information, energy, and warfighter domains. Key areas to include interfaces for microgrids; hardware, distribution boxes; modeling and simulation of operation and performance in multiple domains.

Technical POCs: Mr. Bruce Geil, [bruce.r.geil.civ@mail.mil](mailto:bruce.r.geil.civ@mail.mil); Dr. Tsvetanka Zheleva, [Tsvetanka.s.zheleva.civ@mail.mil](mailto:Tsvetanka.s.zheleva.civ@mail.mil)

## **b. CORE COMPETENCY 2: BALLISTICS & AEROMECHANIC SCIENCES**

### **2.1 Energetics and Propulsion Science**

2.1.1. Novel Insensitive Energetic Materials. ARL is seeking proposals for high quality research and development in novel energetic materials technology. There is interest in low cost, higher performance, and insensitive novel energetic materials technologies to enable energy release tailoring, performance, and acceptable vulnerability characteristics for a wide range of future gun, missile, and warhead munitions. Novel energetic materials formulations and associated technologies support insensitive munitions requirements that will enable munitions to reliably fulfill their performance, readiness and operational requirements on demand, but minimize the probability of inadvertent initiation and severity of subsequent collateral damage to weapon platforms, logistic systems and personnel when subjected to unplanned stimuli. Proposals may impact munitions currently used within fielded systems or future munitions, subsystems, or support items. Some examples of areas of interest and emphasis include, but are not limited to, the following: novel propellant and explosive formulations, new crystals/molecules, nano-technology material, advanced binders and energetic polymers, desensitization technologies, metastable compounds, reactive materials, energetic structural materials, activated metal powders, hydrides, novel energy releasing processes and mechanisms, ignition and initiation, wear and erosion, modeling and simulation, advanced diagnostics and testing methods, and detection methodologies. Proposals are also sought that address novel energetic materials and formulations in conjunction with munitions system design and packaging. Some examples of areas of interest and emphasis include, but are not limited to: liner materials, passive/active venting, coatings, thermal protection materials, and barrier/ballistics material.

Technical Points of Contact:

Dr. Brad E. Forch, e-mail: [brad.e.forch.civ@mail.mil](mailto:brad.e.forch.civ@mail.mil), (410) 306-0929;

Dr. Betsy Rice, email: [betsy.rice.civ@mail.mil](mailto:betsy.rice.civ@mail.mil), (410)306-1904.

2.1.2. Laser-matter Interactions. In conjunction with other Army and DoD efforts into studying directed energy (DE), nonlinear optics (NLO) and ultrashort pulse lasers (USPL), ARL seeks to prepare the basic understanding of physical processes for future applications of these developing technologies. These technologies are approached from two viewpoints: application of energy, and protection from effects. Interests include, but are not limited to:

- a. Extension of studies, experimental and theoretical, into developing regimes of USPL radiation sources. Specifically, we seek to advance the knowledge from 800 nm to 1.5-2.5  $\mu\text{m}$  and UV wavelengths while comparing advantages and disadvantages. This will include differences in nonlinear propagation, propagation in adverse conditions, and solid target interactions.
- b. Interaction of USPL and short pulse lasers with air molecules. This research entails theoretical and experimental analysis of intense electromagnetic (EM) fields with diatomic molecules below, at, and above the ionization threshold. As well, examine the role of different wavelengths and pulse durations on these effects.

- c. Design and performance of novel nonlinear optical devices to enhance imaging, laser direction, laser contrast, and laser beam quality. Utilizing new concepts, materials, and applications we look for the physical understanding to radically alter how we are able to sense, protect from, and direct EM radiation with the emphasis on higher efficiencies, lower cooling demand, and smaller and lighter devices.
- d. Coupling of DE with other forms of EM and mechanical energy. Examine the interaction of DE, USPL and solid matter to produce enhanced effects in air and target materials. This research seeks to resolve how different energy types couple and interact, and how the combined effect of coupled energy influences the material properties of the media in which the energy is combined. Examples include enhancement of NLO effects in air by heating with a second, coupled laser source, or weakening target materials with lasers to render them less resistant to mechanical impact. An understanding of the timescales of interaction events and material changes produced in the target media (both chemical and physical) by different types of combined energy as well as a strong theoretical understanding is required to tailor energy interactions with various media to achieve desired effects.

Technical Points of Contact:

Dr. Anthony Valenzuela, email: [anthony.r.valenzuela6.civ@mail.mil](mailto:anthony.r.valenzuela6.civ@mail.mil), (410) 278-9876

2.1.3. Innovative Engine Technologies. ARL is seeking research proposals on innovative engine technologies to enable higher power density, higher efficiency, reduced signatures, multi-fuel capable, reduced cooling capacity, and more durable and reliable air and ground engines. The areas of research interest include, but are not limited to, the following: advanced engine cycles, innovative new engine concepts, innovative component technologies, and engine analysis tools and modeling to advance the state-of-the-art technologies

Technical Point of Contact: Dr. Chol-Bum “Mike” Kweon, email: [chol-bum.m.kweon2.civ@mail.mil](mailto:chol-bum.m.kweon2.civ@mail.mil), 410-278-9319.

2.1.4. PROPULSION TRIBOLOGY AND DRIVETRAIN RESEARCH. The ARL is seeking proposals in the area of vehicle power transfer, encompassing propulsion components, systems, and tribological interfaces transferring power from powerplants to thrust-producing devices for Army ground and air vehicles. At the fundamental level, interface science probing nanoscale composition, properties and behavior of surfaces and solid interfaces in power transfer devices is of interest. Also of keen interest is power transfer tribology investigating solid, liquid, gas, and mixed phase lubrication and wear phenomena enabling high performance, robust and reliable mechanical component technologies. Research is sought in novel material systems and treatments applied to mechanical components to provide enhanced life and step-function changes in power density. Proposals are also sought in innovative component improvement technologies, including principles derived from the above, enabling radical improvements to bearings, gears, seals, shafts, splines, couplings, clutches, etc. Finally, proposals are sought addressing new system-level power transmission configurations advancing the feasibility of missions and alternative vehicle architecture through paradigm shifts in power density, packaging, and constraints.

Technical POC: Dr. Anindya Ghoshal, email: [anindya.ghoshal.civ@mail.mil](mailto:anindya.ghoshal.civ@mail.mil), 410-278-7358.

2.1.5. Rotorcraft Research. Advanced gas turbine engine and mechanical power transfer system technologies and concepts for improving performance & reliability while reducing weight & cost of propulsion systems for rotorcraft vehicles. Analysis code & algorithm development supported by experimental validation testing of components.

Technical POC: Ernest Chin, [ernest.s.chin.civ@mail.mil](mailto:ernest.s.chin.civ@mail.mil), (410) 278-9986.

2.1.6. High Temperature Propulsion Science. The Army has unique materials challenges to enable discovery to revolutionize small-engine class (<15,000 shp) and innovation in transfer power density that will enable future Army unmanned systems, ground and rotorcraft propulsion systems. ARL propulsion materials research focuses on achieving Army unique goals in conjunction with engine and power transfer sciences. High-temperature materials and structures research for advanced propulsion concepts to improve engine performance and reliability while reducing weight and cost. Analysis and experimentation with candidate high-temperature materials and structures including evaluation of processing and lifing of sub-elements and components.

Technical challenges include the development of engine and power transfer materials to enable unprecedented maneuver capabilities. This refers to near-zero-wear/lubricant-free gears and bearing materials for drive trains as well as ambient to high- temperature (RT-3000F) thermo-mechanical fatigue and creep resistant materials for combustion engines. Development of theoretical, physics-based models and methods to assess the process-structure-property relationship in complex materials, such as ceramic matrix composites, fatigue resistant fiber/metal laminates, and engineered metal alloys, are required to achieve these goals. The Army thrust for damage tolerant structures and cost wise readiness requires high fidelity material state awareness. The research capabilities to detail mechanical, thermal, and chemical behaviors of propulsion materials at high-transient elevated temperatures and environment are in their infancy. High temperature sensors, thermal and chemical damage quantification and life cycle analysis including accurate and reliable material life prediction are lacking. Research efforts toward design, manufacturing and insertion of materials-by-design for tribological transmission components and high-temperature turbomachineries thus creating new design space for revolutionary propulsion systems

Technical Point of Contact: Dr. Anindya Ghoshal, email: [anindya.ghoshal.civ@mail.mil](mailto:anindya.ghoshal.civ@mail.mil), 410-278-7358

2.1.7. Spray and Combustion. ARL is seeking research proposals on spray and combustion science. The Army is interested in technologies to increase engine power density and efficiency, while operating on a single fuel. In order to realize these technologies, it is critical to understand the fundamental physics and chemistry in energy conversion from fuel to mechanical power. The areas of research interest include, but are not limited to, the following: high-resolution optical and laser diagnostics, conventional and alternative fuels, and high-fidelity modeling.

Technical Point of Contact: Dr. Chol-Bum "Mike" Kweon, email: [chol-bum.m.kweon2.civ@mail.mil](mailto:chol-bum.m.kweon2.civ@mail.mil), 410-278-9319.

## 2.2 Impact Physics

2.2.1. Warhead and Penetrator Technology. Proposals are sought for research and/or manufacture of technologies related to advanced warheads and penetrators. These include precision formed shaped charge liners, high density penetrator materials, explosive formed penetrators, and other novel material or technique for defeating threat targets.

Technical Point of Contact: Mr. Tim Farrand, email: [timothy.g.farrand.civ@mail.mil](mailto:timothy.g.farrand.civ@mail.mil), (410) 278-6065.

2.2.2. Human Incapacitation – Penetration of Soft Tissue. ARL conducts an extensive applied research program in human incapacitation and wound ballistics. There is interest in low cost, high performance materials and materiel for use in barrier and body armor applications. Proposals for modeling and simulation and/or experimental validation are sought that address ballistic interaction with metal, glass, composite, or other barrier materials, vehicle armor, individual body armor, and the penetration of, and trauma to, soft tissue(s). Proposals may impact lethality and/or survivability aspects of small caliber and medium/large caliber fragment-producing munitions currently in use within fielded systems or future munitions, subsystems, or support items, as well as the defeat of these threats by the individual warfighter.

Technical Point of Contact: Dr. Lee Magness, e-mail: [Lee.s.Magness.civ@mail.mil](mailto:Lee.s.Magness.civ@mail.mil), (410) 278-6022.

2.2.3. Armor Technology for Warhead Defeat. Proposals are sought for research and development of advanced armor technologies for warhead defeat. Warheads of interest include shaped charges such as seen in rocket propelled grenades (RPGs) and anti-tank guided missiles (ATGMs), as well as explosively formed penetrators (EFPs). Areas of interest include novel passive, reactive, and electromagnetic armor technologies.

Technical Point of Contact: Mr. John Runyeon, email: [john.w.runyeon.civ@mail.mil](mailto:john.w.runyeon.civ@mail.mil), (410) 278-6568.

### 2.2.4. Early Detection and Vehicle Response to Underbody Blast Events

- a. Advanced Methodologies and Instrumentation for the Detection of Underbody Blast Events. Conduct applied research and advanced development to create enhanced capabilities for detecting the occurrence of an underbody blast event prior to vehicle impingement. Areas of interest include methodology, sensors, data acquisition, signal conditioning, filtering, fusion techniques, modeling and simulation, all focused on providing a high probability of detect (PoD) combined with a low probability of false alarm (FA) across a wide range of operating conditions. Proposed technologies must be robust across a wide range of underbody threats.
- b. Advanced Methodologies and Instrumentation for the Measurement of Vehicle Response to Underbody Blast Events. Conduct applied research and advanced development to create enhanced capabilities for measuring vehicle reaction to an



underbody blast event. The area of interest includes the measurement of vehicle dynamics in response to underbody events. Due to the extreme environment coupled with a wide variety of time scales (from sub-microsecond shock loading to multiple second rigid body motion), traditional methods, such as IMUs, do not provide accurate positional tracking through these blast events. An absolute measurement technology is preferred as opposed to a method that relies upon numerical integration and should provide a high-fidelity state determination solution (6DoF) for the vehicle crew compartment during the entire blast event.

Technical Points of Contact:

Mr. Neil Gniazdowski, email: [neil.m.gniazdowski.civ@mail.mil](mailto:neil.m.gniazdowski.civ@mail.mil), (410) 278-6058.

Mr. David Lyon, email: [david.h.lyon.civ@mail.mil](mailto:david.h.lyon.civ@mail.mil), (410) 278-6800.

2.2.5 Ballistic Launch and Transitional Ballistics: ARL conducts research into the effects of launch dynamics on ballistic structures. There is interest in novel numerical and experimental techniques and approaches to quantify projectile, and missile systems, and the associated internal components and payload, subjected to the high g dynamic loading environment of launch. Areas of interest include projectile strength of design, projectile and barrel interactions, blow by of the interior ballistic gasses, transitional ballistics, accuracy and survivability of onboard components. Proposals may address system or subsystem effects and the relations thereof ranging from small to larger caliber and missile or mortar systems as well as experimental and/or numerical tools which further the understanding of such systems.

Technical Point of Contact: Dr. Joseph South, e-mail: [joseph.t.south.civ@mail.mil](mailto:joseph.t.south.civ@mail.mil), (410) 278-9077.

2.2.6 Munition systems research. All aspects of research towards developing highly efficient, low collateral damage, and multi-functional munition systems. Areas of interest include cluster munition replacement, collective-attack munitions, launch system concepts, software and robotic assistance for collective or assembled launch.

Technical Point of Contact: Dr. Müge Fermen-Coker, email: [muge.fermen-coker.civ@mail.mil](mailto:muge.fermen-coker.civ@mail.mil), (410) 278-6018.

2.2.7 Human Response to Ballistic Loading. ARL is developing technologies to protect the soldier from ballistic and blast loading. There is interest in experimental studies and theoretical modeling of the human body's response to these loading conditions. Proposals for experimental or theoretical studies are sought that address the human response to ballistic loading including projectile impact, overpressure from blast loading, and high rate accelerations (such as those encountered in mine blast loading) are sought.

Technical Point of Contact: Dr. Christopher Hoppel, e-mail: [Christopher.p.hoppel.civ@mail.mil](mailto:Christopher.p.hoppel.civ@mail.mil), (410) 278-8878.

## 2.3 Aeromechanics

2.3.1. Rotorcraft Aeroelasticity. ARL conducts foundational aeromechanics research to enable future Army rotorcraft with combinations of enhanced performance and low maintenance burdens that are currently infeasible. Research interests include novel approaches for enabling advanced concepts that may currently be considered to be “radical” from an aeromechanical/aeroelastic stability and/or response perspective. Novel concepts from a structural dynamics, aerodynamic performance, coupled fluids/structures, and/or nonlinear dynamics theoretic perspectives are relevant. In addition, analytical and experimental capabilities to support development of advanced numerical methods and computational codes for assessing aeroelastic, aeromechanical, and structural dynamics performance are of interest.

Technical Point of Contact: Dr. Bryan Glaz, email: [bryan.j.glaz.civ@mail.mil](mailto:bryan.j.glaz.civ@mail.mil), 410-278-8037 or Mr. Matthew Wilbur, email: [matthew.l.wilbur.civ@mail.mil](mailto:matthew.l.wilbur.civ@mail.mil), 757-864-1268.

2.3.2. Vehicle Dynamics. Analytical techniques for predicting structural dynamics and aeromechanical response of advanced vehicle concepts including real-time active, adaptive suspension system with preview sensor-driven control algorithms.

Technical Point of Contact: Dr. Muthuvel Murugan, email: [muthuvel.murugan.civ@mail.mil](mailto:muthuvel.murugan.civ@mail.mil), 410-278-7903

2.3.3. Vehicle Integrated Analysis Technologies. Fundamental technology analysis capabilities needed to model vehicles and their components. Research tools for understanding and developing the ability to couple physics-based analyses to assess full-spectrum military operations.

Technical Point of Contact: Dr. Rajneesh Singh, email: [rajneesh.k.singh.civ@mail.mil](mailto:rajneesh.k.singh.civ@mail.mil), 410-278-4022.

2.3.4. Affordable Precision Munition Technologies. ARL conducts an extensive applied research program in support of technologies that enable affordable precision munitions. Research interests include guidance laws, guidance sensors, navigation methods, control laws, maneuver actuators, aerodynamics, flight dynamics, experimental research, technology development, and prototype demonstrations that expand the body of knowledge and understanding in these areas.

Technical Point Contact: Dr. Mark Ilg, [mark.d.ilg.civ@mail.mil](mailto:mark.d.ilg.civ@mail.mil), 410-306-0780 or Dr. Paul Weinacht, email: [paul.weinacht.civ@mail.mil](mailto:paul.weinacht.civ@mail.mil), (410) 306-0800.

2.3.5 Weapon and Ammunition Accuracy. ARL conducts a fundamental theoretical, computation and experimental research program in support of weapon and ammunition accuracy. Research interests include technologies, techniques and devices for improving weapon and munitions accuracy, techniques for guiding man portable munitions, improved trajectory prediction, fire control, wind sensing and target ranging devices. To support the research program, ARL is also interested in theoretical and experimental techniques and devices to improve the fundamental

understanding of munition launch and flight dynamics such as computational fluid dynamics and high speed and spark photography.

Technical Point of Contact: Dr. Paul Weinacht, email: [paul.weinacht.civ@mail.mil](mailto:paul.weinacht.civ@mail.mil), (410) 306-0800.

## **2.4 Ballistic Vulnerability**

2.4.1. Weapons Effectiveness. ARL is conducting an extensive fundamental research program in support of improving weapon effectiveness. This topic encompasses a diverse spectrum of weapons and systems, including small, medium, and large caliber gun-launched systems; rocket and missiles; hybrid gun-missile concepts; direct-fire and indirect fire weapons (LOS, NLOS, BLOS); smart munitions, munitions guidance, navigation, and control (GN&C), and high g-hardened gun-launch technologies; energetic materials development; interior, transitional, and exterior ballistics; ballistic wear and erosion, defensive weapons and systems such as active protection and extended area protection; non-lethal weapons technologies; robotic platforms, unmanned aerial vehicles (UAV), unmanned ground vehicles (UGV), including hardware, command and control algorithm development, behavior modeling and simulation, and operations in semi-autonomous, near-autonomous, and fully autonomous modes. Proposals may address improving weapon effectiveness of existing systems or new concepts, as well as tactical use of weapons, such as under conventional battlefield conditions, in military operations in urban terrain, or in non-military homeland defense applications for Federal or local law enforcement agencies. Proposed research can be in modeling and simulation, experimental in nature, or both.

Technical Point of Contact: Dr. William Oberle, e-mail: [william.f.oberle.civ@mail.mil](mailto:william.f.oberle.civ@mail.mil), (410) 278-4362

2.4.2. Fundamental Basis for Survivable Systems Subjected to Multi-physics, Multi-phase Asymmetric Threats. For traditional force on force battlefields, the protection requirements for armored vehicles, soldiers, and other Army assets were based primarily on conventional war concepts and threats. However, asymmetric battles have shown that the protection is required on all types of military and civilian structures, and encompass a wide variety of both conventional and unconventional threats, such as kinetic energy projectiles, IEDs (roadside, buried, vehicle-born, and suicide Improvised Explosive Devices), grenades, missiles, and mines. In addition, the battlefield in which these assets operate includes complex urban terrains and the United States homeland. Proposals are requested to conduct a broad, interdisciplinary basic research program to develop advanced science and engineering based methodologies that afford advanced understanding of crew and vehicle survivability under unpredictable explosive-device induced blasts. To date the fundamental underlying mechanisms that challenge the survivability of critical Army/civilian structures and systems with respect to the unconventional explosive threats is not well understood. This highly multidisciplinary research area includes complex interactions between terrains, explosives, and extremely hard to extremely soft material systems. Modeling unconventional blast-effects on structures requires a two-step process:

- a. The first step is modeling of the blast itself resulting in a multi-phase flow, which requires improved physical understanding of detonation processes as well as their packaging and the environmental conditions. Modeling and characterization of the

- dynamic behavior of a wide range of explosive packaging methods including combinations of soils, pavement overlays, metal, and other encapsulations result in extreme spatial and temporal pressure gradients and fragment distributions. Fine scale temporal and spatial resolutions are needed to achieve a threshold level of predictive capability. It is essential to accurately model the explosion/combustion reaction chemistry to deal with the issues surrounding reacting multi-phase flow from metallized blast explosives (using aluminum, higher density metal fuels, and/or thermites, etc). Turbulent mixing, combustion, and reaction chemistry (both during the detonation and fireball formation) need to be addressed. The capability to independently represent both the fluid and solid components so they can be coupled to and applied to the structure in a realistic manner is essential.
- b. The second step of the two-step process is to model the effects of explosive systems on military and civilian structures. This requires parallel, explicit, Lagrangian codes with a library of continuum and structural elements, robust parallel contact algorithms capable of dealing with explosively driven deformations, and adaptive techniques to capture the physics of localization and subsequent failure. The design optimization of explosive systems and their effects involves problems that are geometrically and materially nonlinear. Fracture and fragmentation of large military and civilian systems involves a variety of spatial and temporal scales from nanometers to meters and microseconds to seconds. Two important effects of explosive systems and other kinetic energy penetrators on Army systems is the generation, and dispersion of stress waves through complex material configurations and the formation of highly lethal behind armor debris.
  - c. The final area of need is to develop tailored materials (novel metal laminates/ advanced metallic-composite) for enhanced survival from explosive systems. Finite Element tools need to be utilized to develop design guidelines that provide yield strength, ductility, modulus, etc. parameters necessary for fabrication. As materials are developed, test and evaluation methods need to develop methods for imbedded/organic diagnostics to monitor dynamic material properties as samples are evaluated in order to verify and improve material models.

Technical Point of Contact: Mr. Neil Gniazdowski, email: [neil.m.gniazdowski.civ@mail.mil](mailto:neil.m.gniazdowski.civ@mail.mil), (410) 278-6058.

### **c. CORE COMPETENCY 3: INFORMATION SCIENCES**

#### **3.1 Network Sciences**

3.1.1. Network Theory. The ARL is interested in receiving proposals addressing the technology and technical barriers for extending the state of the art of fundamental network science as it applies to tactical networks and communication requirements. This includes the study of interactions of communications, information, and socio-cognitive (CIS) networks, and the development of analytical models of dynamic network flows, resulting in novel theories and tools. Research interests include, but are not limited to advancing the state of the art in the following research areas:

- a. Novel mathematical representations and analysis of dynamic networks as a path to understanding and characterizing structure and evolution of network topologies.
- b. Establishment of fundamental limits and tradeoffs for information flows in multi-genre networks, and development and analysis of protocols.
- c. Models for the impact of dynamic network processes on network structure and vice-versa
- d. Controlling global topology and behavior of information flows via local interactions.

Technical Point of Contact: Dr. Brian Rivera, email: [brian.m.rivera.civ@mail.mil](mailto:brian.m.rivera.civ@mail.mil), phone: 301-394-2298 and Dr. Ananthram Swami, email: [ananthram.swami.civ@mail.mil](mailto:ananthram.swami.civ@mail.mil), phone: 301-394-2486.

3.1.2. Secure Wireless Mobile Communications. The ARL is interested in receiving proposals that address science and technology for mobile wireless communications networks, especially the mobile tactical domain, and including sensor networks. The objectives of this research are to enable secure, survivable and assured communications over wireless networks among highly mobile users, sensors, and robotic platforms under adverse channel conditions, with desired quality of service on demand. Research areas of interest include, but are not limited to, advancing the state of the art in the following areas:

- a. Bandwidth and energy constrained mobile transceiver design.
- b. Cross-layer designs, especially with respect to physical layer and media access layer interaction.
- c. Multi-antenna methods, including space-time processing, for mitigating multi-user and intentional interference, while achieving very high capacity.
- d. Techniques for overcoming electronic warfare and jamming threats.
- e. Dynamic spectrum access, and frequency agile systems.
- f. The combination of channel equalization and coding techniques.
- g. Wideband modulation methods such as orthogonal frequency division multiplexing.
- h. Ultra wideband systems, including coexistence issues and system overlays.
- i. Sensor networking systems, including signal processing and communications interactions, distributed detection and estimation, and networking protocols.
- j. Ad hoc mobile networking protocols and procedures.
- k. Survivable wireless and hybrid cell based ad hoc networks and networking.
- l. Key distribution and security in a mobile wireless ad hoc network.
- m. Automating creation and distribution of interoperable vulnerability knowledge bases.
- n. Network management and visualization tools that support real time planning and control of tactical networks.

Technical point of contact: Dr. Brian M. Sadler, email: [brian.m.sadler6.civ@mail.mil](mailto:brian.m.sadler6.civ@mail.mil), phone: 301-394-1239 and Dr. Brian Rivera, email: [brian.m.rivera.civ@mail.mil](mailto:brian.m.rivera.civ@mail.mil), phone: 301-394-2298.

3.1.3. Sensor Network Communications. The ARL is developing communications devices and technologies for unattended sensors. These unattended devices must work for long periods on limited battery power, use Anti-Jam and Low Probability of Detection waveforms, perform ad-hoc networking for autonomous self-healing routing, and provide network security for authentication, data integrity and privacy. ARL is also interested in leveraging these technologies

for use in other energy constrained communications applications. Areas of interest include, but are not limited to:

- a. Ad-hoc network protocols.
- b. Security protocols.
- c. Robust AJ/LPD waveforms.
- d. Energy efficient modems.
- e. Energy efficient RF front-ends and components.
- f. Low power signal processing.
- g. Small broadband antenna.
- h. Forward-error-correction.
- i. Integration of sensor and communications processing.
- j. Efficient integration of sensor and communications into Unattended Sensors.

Technical Point of Contact: Mr. Ronald G. Tobin, e-mail: [ronald.g.tobin.civ@mail.mil](mailto:ronald.g.tobin.civ@mail.mil), phone: 301-394-2184.

3.1.4. Cyber Defense and Information Assurance. The ARL is interested in receiving proposals that address the technology and technical barriers for improving the state of the art of critical scientific areas that affect cyber defense and information assurance for wired/wireless networks. The objective of the research is to strengthen the underlying science of cyber defense and intrusion detection. Research interests include, but should not be limited to, advancing the state of the art in the following research areas:

- a. Applicability, impact, and implications of ensemble techniques to examine existing anomaly-based intrusion detection techniques at a fundamental level.
- b. Fundamentals of visualization for cyber security for the exploration, analysis, and situational awareness of network events to deal with the sheer volume and complexity of the data.
- c. Decision theory and online learning of intrusion detection for the minimization of costs to detect and prevent intrusions using network monitors by analyzing a more accurate model of the flows in and among networked hosts.
- d. Automating intrusion monitor placement for 1) dynamic probing and sampling for intrusion detection in large cyber systems under resource constraints and 2) anomaly localization based on a quickest detection approach.

Technical Point of Contact: Mr. Curtis B. Arnold, email: [curtis.b.arnold.civ@mail.mil](mailto:curtis.b.arnold.civ@mail.mil), phone: 301-394-0263 and Dr. Robert F. Erbacher, email: [robert.f.erbacher.civ@mail.mil](mailto:robert.f.erbacher.civ@mail.mil), phone: 301-394-1674.

3.1.5. Unattended Ground Sensor (UGS) Technology. Technology concepts, sensors, algorithms, sensor employment planning tools, and hardware modules that support:

- a. Wide-area detection and localization;
- b. Autonomous classification and discrimination between people, animals, vehicles, aircraft, and ammunition fire (e.g., gunshots, mortar, artillery, etc) with high probability of correct classification;
- c. Low false alarm rates;

- d. Autonomous determination of accurate position, orientation, localization and field position;
- e. Terra Harvest compatibility for sensor system interoperability;
- f. Communication, networking and distributed fusion of information among various UGS nodes to provide robust ISR information;
- g. Remote command and control;
- h. Remote emplacement capability, e.g. low-altitude air deployment;
- i. Low observability;
- j. Of particular interest are low-cost, low-powered and small-sized hardware modules that implement the functions listed above;

Sensors that require minimal personnel for employment, operation and maintenance

Technical Point of Contact: Mr. Tom Walker, [Thomas.w.walker68.civ@mail.mil](mailto:Thomas.w.walker68.civ@mail.mil), (301) 394-0756.

3.1.6. Disposable Sensor Technology. Research proposals are desired that can lead to a complete sensor system consisting of several disposable and interchangeable sensor nodes that can communicate with a remote display. Each disposable sensor node should include one (or more) transducer(s), a signal processor, and a communication device, all in a single package. Disposable sensor nodes should be extremely small, lightweight, and consume extremely low amounts of power. The projected unit cost for individual nodes should be less than \$10 each, based on production quantities in the millions.

The primary performance goal is the detection of personnel and/or human activities, especially in confined areas; e.g., buildings, caves, bunkers, tunnels, sewers, etc. False-alarm rates must be kept low, even in a dynamic battlefield environment. In general, overall network performance is more important than performance metrics for individual nodes: “the network is the sensor”. Other desirable performance goals include detection and/or classification of other targets and/or threats, including gunshots, mortar, artillery, and rocket launches and/or explosions; power line activity; telephone activity; chemical and/or biological threats; unattended air vehicles, micro-air vehicles, and other robotic or autonomous vehicles; etc. Low-bandwidth information, including context-oriented location information, should be exfiltrated via the sensor network to the end user in near-real time. Sensor modalities are not specified in this topic, but could include acoustic, seismic, magnetic, electric field, non-imaging passive infrared, passive RF, chemical/biological, and/or any other transducer(s) that could be used to detect any targets or threats of military significance. Sensors should be chosen and/or configurable for a wide variety of Intelligence, Surveillance, and Reconnaissance (ISR) missions, including self-protection for individual soldiers, surveillance by small groups of soldiers, perimeter security, and border monitoring.

Node-level computations are needed to reduce relatively high-bandwidth raw sensor data to immediately usable information that can be transmitted over extremely low-bandwidth ad hoc sensor networks. The sensor output should be as concise as possible, but include a node ID, timestamp, target type, and confidence level. Development of sensor fusion algorithms, including multi-modal algorithms that are independent of particular transducers, can be considered under this topic.

The communications source may be acoustic/ultrasonic, RF, or IR, or it may resonate or reflect "on command" from an external receiver. One-way communication may be used to exfiltrate data to end-users and/or more capable sensors, gateways, etc. The network should be able to infer node location information from some combination of the ISR sensors, the network topology, and/or programming during emplacement. The node reports should include contextual location information; localization should not depend on GPS. The problem of exfiltrating data from confined areas, e.g., through robust multi-hop networking, should be addressed.

Sensors should be deployable by hand, via UAVs, helicopters, and/or cargo rounds (artillery); however, high-G packaging techniques are not a focus of this topic. Similarly, proposals submitted under this topic should NOT focus on sensor information assurance, network-level information fusion, novel low-cost sensor technologies, low-power microprocessors, communications and networking theory, novel display technologies, haptic interfaces, low-cost packaging for high-volume production, and/or power and energy technology (i.e., batteries). These are important issues, and components using technology from all of these areas could be part of a proposed sensor system; however, funding to advance these technologies will generally not be funded under this topic.

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## 3.2 Decision Support Sciences

3.2.1. Information Science and Technology. The ARL is interested in basic and applied research resulting in technologies that support state-of-the-art capabilities for the Warfighter in the analysis, assimilation, and dissemination of battle space information. Research areas of interest include, but are not limited to, advancing the state of the art in the following areas:

- a. Natural language processing.
- b. Intelligent software agents.
- c. Automated information distribution.
- d. Information fusion and visualization.
- e. Knowledge discovery.
- f. Social network analysis.
- g. Computational social science
- h. Automated human language translation using text and speech data.
- i. Mixed small robot/soldier team collaboration and behavior.
- j. Autonomous platform software integration including manned and unmanned systems.

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3.2.2. Natural Language Processing (NLP). The ARL desires NLP and computational linguistics methods and algorithms to develop and improve technologies for machine translation, as well as for information extraction, automated summarization, and other text analytics. Also relevant are methods and algorithms for integration of text analytics with analytics for multimodal information such as imagery, video, and speech to enhance situation understanding as well as



human communication with information networks and autonomous systems. Additionally, ARL is interested in proposals to develop and improve technologies for OCR and speech recognition as input to machine translation, information extraction, and automated summarization. Finally, ARL requires development of language data in support of building these technologies and development of metrics to evaluate them.

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3.2.3. Software Technologies Targeting Interoperability for Systems of Systems. Emerging DoD systems represent a revolutionary leap ahead in the concept of “system of systems” and interdependent operations. Interoperability and the management of complexity is the chief challenge in harnessing technologies to meet the Army’s current and future information requirements. Software will provide the glue which ties together all the pieces, and in so doing, must be adaptable, flexible, and agile enough to accommodate the widely disparate and rapidly evolving systems. Research areas of interest include, but are not limited to, advancing the state of the art in the following areas:

- a. Domain-specific modeling languages and semantics.
- b. Model-based design and development/engineering for system of systems architectures and ultra large scale software intensive architectures.
- c. Models which support reflective (self-referential) capability.
- d. Principles and ontology development for organization of components, their design and construction.
- e. Verifiably correct generators and models.
- f. Re-engineering and Integration technologies (methods, tools, metrics, models, etc.) for legacy systems.

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3.2.4. Computational Social Science. The ARL is interested in proposals to discover and mine information from text, social media, and other sources, develop high-level information fusion, exploitation, socio-cultural concepts and tools for understanding human terrain and tactical situations. Areas of focus include sociolinguistics and social network analysis, along with innovative ways to visualize results.

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3.2.5. RF Phenomenology, Signal Processing and System Design. ARL is interested in RF techniques, concepts, models, algorithms, and hardware modules that support:

- a. All-weather, wide-area detection, location, and recognition of stationary tactical ground targets that may be behind walls or concealed in foliage and/or employing camouflage, concealment, and deception.
- b. All-weather, wide-area detection, location, and discrimination of surface and near surface buried mines and/or improvised explosive devices.

- c. All-weather, wide area detection, location, and tracking of moving targets (e.g., personnel, tactical vehicles and low flying aircraft) from a ground-based and/or airborne foliage penetrating sensor system.
- d. The detection of very small RF signals in highly cluttered environments, including active and passive techniques for man-portable, ground vehicle, and airborne platforms.

In particular, research proposals are desired in areas that address the technical obstacles associated with using an ultra-wide frequency band (UWB) synthetic aperture radar (SAR) for the detection, location, and possibly classification of subsurface targets (ranging from near surface to deeply buried objects). Further, proposals are desired to support low frequency radar models, techniques, and enabling component technology. In addition, proposals are sought to support passive and active RF techniques that can detect small signals in highly cluttered environments (i.e. natural and man-made clutter as well as electromagnetic interference). The proposals may address, but are not limited to:

- e. Radar component technology, including wide-bandwidth/ low-frequency antennas, high power transmitters, high-speed signal processors, and analog-to-digital converters.
- f. Radio frequency interference (RFI) extraction/avoidance techniques including cognitive techniques for interoperability of multiple RF systems in cluttered electromagnetic environments.
- g. High-precision position location systems.
- h. Radar imaging techniques to mitigate sources of artifacts.
- i. Beam-forming techniques.
- j. Self-aligning and calibrating arrays
- k. Target detection, tracking and classification algorithms.
- l. Cognitive radar.
- m. Non-linear radar.

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3.2.6. Image Processing (IP). This topic addresses research interests in algorithm development for image reconstruction, enhancement, detection, recognition, tracking, identification of objects-of-interest and spatiotemporal perception. In particular, the problem of big data analysis or data to decisions (D2D) where meaningful inference should be drawn through automated analysis is important. The data class of interest includes EO-IR-multi/hyperspectral imagery and video. These different types of imagery vary in resolution, wavelength, and sensor type that can be exploited individually or collectively. Applications of interest include persistent surveillance, perception in autonomous systems and decision support systems.

Specific topics include:

- a. Model based Automatic Target Recognition (ATR). Algorithms incorporate external knowledge related to the targets, scene, and sensor to perform one or more ATR functions such as detection, recognition, tracking, and identification.

- b. Scene understanding and spatiotemporal perception. Beyond conventional ATR in which isolated objects are detected and classified, there is need for identifying relationships among objects and entities in a scene in both space and time where applicable. Identification of behavior and activities is an area of interest. Studies to extend scene classification algorithms by exploiting additional sources of information should be considered.
- c. Multisensor IP algorithms. Passive video or FLIR ATR is frequently preferred in a battlefield scenario. However, the increased information content and the potential performance boost of combining passive and active sensors makes multisensor fusion approaches worth investigating. Proposals for the development of algorithms providing fusion of FLIR imagery with one or more sensors, such as ladar, or millimeter wave (MMW), will be considered if they represent a performance enhancement over current methods.
- d. Hyperspectral IP algorithms. Information content is potentially increased with use of hyperspectral imagery. Special problems arise because of the large amount of data. Novel methods by which to exploit the increased information content without sacrificing speed of computation are possible topics of research in this area.
- e. Image Synthesis and reconstruction. Algorithms for generating images from sensor array data such as antenna arrays, microphones, hyperspectral sensor systems etc. and from partial or incomplete information. Areas include 3D reconstruction, tomographic reconstruction, super-resolution and sparse-sampled processing, high dynamic range synthesis, image graphics, image rendering and display.

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3.2.7. Acoustic Technology. Proposals are requested for technology in acoustic sensors and signal processing. Specific areas of interest include (i) advanced acoustic sensors and sensor array designs for UGS and on mobile ground platforms including small robot vehicles and on aerial platforms such as aerostats and UAV's; and (ii) advanced signal processing techniques/algorithms for multi-target beam forming, target tracking, target classification and identification, reduction of wind noise reduction, reduction of platform noise reduction, etc. Required detection capabilities include continuous sources (vehicles, aircraft, etc.) and impulsive sources (gun fire, artillery impacts, etc.). Other areas of interest include, but are not limited to, long-range hearing, biomimetic acoustics, auditory enhancement of individual soldiers, acoustic signature data collection techniques and equipment, acoustic propagation modeling, novel data analysis techniques, and systems to employ acoustic sensors in new innovative ways, and multi-modal sensor fusion with acoustics and other non-imaging and/or imaging sensors. .

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3.2.8. Sniper and Artillery Location Technology. Proposals are requested for research in sensor technology for detecting, tracking and locating the source of hostile small arms, artillery, rocket, and mortar fire. Potential sensors include acoustic, seismic, radar, infrared, and ultra violet. Sensors proposed for this application should be capable of locating the source of enemy fire, and

may include other data such as the distance of the miss, the type and number of rounds fired, etc. Source bearing accuracy of better than +/- 10 degrees is desirable.

For small arms, location of the firing source at ranges of 300 m and beyond is desirable. For mortar/artillery/rocket fire, location of likely firing positions despite intervening terrain or non-benign environmental conditions is of particular interest. The capability to locate the source of mortar firings at ranges greater than 2 km and artillery/rocket firings at ranges greater than 10 km is desirable. Operation of sensors on individual soldiers, fixed sites, and moving vehicles are all of interest. Research into areas either directly addressing the sniper/mortar/artillery/rocket problem or supporting technologies will be considered.

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3.2.9. Electric Field Sensor Technology. Research proposals are desired that are related to small, rugged, low-power electric field sensors that can be deployed on a battlefield using artillery-based delivery systems, or scattered from air or ground vehicles, or emplaced by individual soldiers. These sensors should be passive or semi-active (i.e., with no local field-generating element), and may operate at low frequencies in the quasi-static zone (or "near field"), where the electric and magnetic fields are not coupled. These sensors should be characterized by exceptionally low power, size, weight, and cost, and/or by exceptionally high sensitivity and low noise (i.e., with performance limited by the background environment).

They should operate in an unattended mode, and should be able to detect, classify, identify, localize, and/or track tactically-significant targets, including ground vehicles (tanks and other tracked vehicles, and wheeled vehicles), air vehicles (fixed-wing, rotary-wing, UAV/MAVs, etc.), and/or other targets and events at tactically-useful distances. These other targets include, but are not limited to, armed individual soldiers, underground facilities, power and telephone lines, RF transmitters; other events including gunshots, mortar and artillery launches, and explosions.

These sensors may be used individually or as part of a wide-area sensor array for surveillance, target acquisition, and/or engagement. While individual sensors may or may not have exceptional individual performance, their low size, power, weight, and cost should permit them to be used on the battlefield in ways not previously contemplated. Moreover, arrays and/or networks of such sensors are expected to provide new sensing capabilities and levels of performance simply not available today.

Unattended surveillance sensors may be stationary or mounted on robotic platforms; these sensors will be integrated with local signal processing and communications capabilities, and should operate unattended for weeks or months after deployment. The sensor output should be quantitative: e.g., analog voltage level(s) or digital word(s); it should contain target information, and possibly a confidence level, suitable for low-bandwidth transmission and/or inter-sensor fusion.

Proposals related to the subject technology are also desired, to the extent that they are applicable to standalone sensors that can be used in proximity fuses, small-unit training and simulation devices, etc. In this case, sensors may operate for a much shorter period of time (typically seconds to hours), so extremely low-power operation is less important, and the final sensor output may be qualitative (yes/no).

Proposals will be accepted in five areas:

- a. Research on novel electric field sensor concepts leading to quantification of detection distance(s), classification, identification, localization, and/or tracking of various classes of targets.
- b. Research directed at environmental and/or platform noise reduction, and/or reduction of sensor front-end noise (particularly 1/f noise).
- c. Research related to filtering and/or signal processing techniques, which are expected to improve the detectability of targets in a battlefield environment.
- d. Computer-based modeling of targets and sensors that can provide a capability to perform trade-off analyses of sensor concepts during prototype design.
- e. Research of prototype design(s) of individual electric field sensors suitable for detecting tactically significant targets in battlefield environment.

There are several related topics in this BAA that are intended to complement each other. Proposals that focus on magnetic sensing should be submitted against the "Magnetic Sensor Technology" topic. Proposals that focus on low-cost sensor systems should be submitted against the "Disposable Sensor Technology" topic.

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3.2.10. Passive Magnetic Sensor Technology. Research proposals are sought for work that can lead to small, rugged, low cost, low power, highly sensitive passive magnetic sensors for use as part of unattended ground sensor systems. The sensors can be deployed using artillery, scattered from the air or ground vehicles, or hand emplaced. Since it is desired that they will operate unattended for weeks or months at a time, they must consume very little power. To provide surveillance over an area of a few square kilometers, many low cost sensors will have to be employed. The sensors may detect ferromagnetic material on vehicles or carried by armed personnel or the low frequency signals generated by vehicles or underground facilities. For most applications, the sensor output should have a digital output that can be used in a tracking/classification algorithm. Magnetic sensors used in some application such as in proximity fuses, small-unit training and simulation devices, etc. may consume more power. Other BAAs cover communications between sensors and to hubs.

Besides using stationary sensors, the sensors also may be employed on robotic platforms, UAVs, and UGVs. In these applications, the requirement of low cost is less severe, but there is a need for coping with noise generated by rotational vibrations. Total field magnetic sensors may provide a solution to this problem. Proposals are sought for:

- a. Low cost, energy efficient, high sensitivity vector and total field sensors.
- b. Methods for reducing geomagnetic noise.
- c. New efficient algorithms for identifying and tracking targets.
- d. Methods for reducing the cost and power consumption of magnetic sensors.

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3.2.11. Sensor, Data and Information Fusion: The Army is interested in data and information fusion algorithms that are robust and well grounded in phenomenology which can be implemented at the node and network levels. There is also interest in techniques and methodologies for determining the quality of information before and after fusion along with the notion of value of information for Intelligence, Surveillance and Reconnaissance (ISR) applications. Algorithms capable of information fusion from multiple types of intelligence sources (e.g.; SIGINT, ELINT, HUMINT, etc.) and soft data sources are desired. This includes machine processable contextual representations of quality requirements throughout the fusion chain for these ISR applications.

The Army is seeking holistic approaches to sensor and information fusion for linking physical sensors and information sources to users throughout and at the edge of the network. The Army is interested in flexible and scalable fusion architectures that can be used at node level and network level for situational awareness to fuse disparate, multi-modal multi sensor data/information. Fusion methodologies for hard and soft data fusion and algorithms for efficient data dissemination over the network are also sought. The Army is seeking research into sensing methodologies for information gathering rather than data gathering in order to improve situational awareness and mission effectiveness.

The Army is interested in fundamental theory of sensor processing and their models to provide the basis for data and information fusion to enhance the probability of detection/classification and tracking in order to minimize false alarms and to achieve a high level confidence in characterizing multiple targets. Research in robust target detection, classification and tracking based on multiple phenomenologies is sought.

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3.2.12. Quantitative Technology Assessment. Models to examine the total performance and potential payoff of new and evolving technology on Army vehicles and systems. Tools to assess the real benefits of evolving technologies and provide quantitative basis for strategic research decisions. Research in this area will provide a better, scientific understanding and technical foundation for developing technology solutions for the next generation of capabilities.

- a. Methods for including reliability, survivability, manufacturability, integration, etc. in a technology development tradespace.
- b. Methods to slice the design space and visualize multidimensional tradeoffs, beyond 2D Pareto front and 3D Pareto surface.
- c. Methods to increase confidence that a technology tradespace has been sufficiently bounded and populated.
- d. Automatically populating a technology tradespace with input from multiple databases that use differing schemata, hierarchies, and attributes.

- e. Visualizing multidimensional tradespaces in manners that enable human-in-the-loop manipulation and control.
- f. Predicting subsystem and system-level variances based on uncertainties at the technology component level.
- g. Ability to model and assess reliability and cost to provide insight into long-term product reliability and maintainability, for existing capabilities and future technologies.
- h. Assessing the sensitivity of design alternatives to changes in design parameters, requirements, and technologies.
- i. Removing or reducing the subjectivity associated with weightings on measures of performance and effectiveness, as well as assessing the sensitivity of these stakeholder desires to system capability.
- j. For a combination of preferred technologies, modeling and analysis capability to assess the technology tradespace that enables understanding of the magnitude and direction of affected capabilities, compliant requirements, and required funding.

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3.2.13. Technology Demonstrations and Assessments for Counter Insurgency Operations. The U.S. Army seeks proposals for the research and demonstration of technologies to detect, disrupt, degrade, and dismantle insurgent groups for future conflicts. The Army envisions that in the future, many areas of the world may be plagued by insurgencies which survive in some measure due to problems of poor governance, corruption, militant resistance, ethnic conflicts and criminality. The security problems for the Army are likely to be defined by insurgent groups attacking host nation government forces from within the population and exploiting the host nation government's challenges in providing security and enforcing their laws. These insurgencies are likely to be supported by terrorist groups, criminal groups, and gangs. The objectives of this effort are: researching and demonstrating a comprehensive information management methodology that may include both material (i.e. cyber defense capabilities, human terrain mapping, sensors, etc.) and/or nonmaterial solutions (i.e. doctrine, tactics, procedures, techniques, etc.); and, transitioning this methodology to organizations that have the responsibility of countering insurgent groups.

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### **3.3 Computational Sciences**

3.3.1. Simulation-Based Engineering Sciences. Proposals are required in the areas of multi-disciplinary computational sciences research exploiting high performance computers: associated computer science research; and development of leading-edge computing systems to address challenges in simulating practical Army applications. Specific areas of interest include:

- a. Innovative and scalable methodologies (including finite element methods, particle methods, meshless methods, etc.) for Computational Mechanics, Computational Fluid Dynamics (CFD), Computational Structural Mechanics (CSM), Computational

- Electromagnetics and Acoustics (CEA), and Computational Chemistry and Materials (CCM), etc.).
- b. Innovative and scalable methods for discrete event simulation (DES) that can be useful to a wide variety of problems within the Army (example: Communications Network Modeling, Scheduling, etc.).
  - c. Computational methods for interdisciplinary applications (example: structure-medium interaction, Eulerian-Lagrangian, etc.).
  - d. Multi-scale computational approaches over a wide range of length and time scales (example: Macro-meso-micro approaches, molecular dynamics-continuum mechanics coupled approaches, etc.).
  - e. Computational methods to address innovative structures for Army applications (designing, manufacturing, testing, verification and validation).
  - f. Data mining for scientific applications.
  - g. Large-scale data analytics.
  - h. Cloud computing and heterogeneous computing architectures.
  - i. Tactical high-performance computing.
  - j. Information visualization.

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3.3.2. Quantum Information Science. Recent advances in Quantum Information Science (QIS) and emerging technologies have opened up the possibilities for achieving improvement in computing, imaging, communications, navigation, and environmental awareness for the Army and DOD. The ARL research program explores new and/or improved quantum methods of entanglement, teleportation, quantum imaging, quantum computing, quantum information capacity and security communications, quantum sensing, and metrology that can achieve unprecedented resolution, information capacity and security beyond the capability of classical techniques. Quantum systems that are of interest include, but are not limited to photons, cold atoms, trapped ions, rare earth ions, diamond vacancies, and quantum dots. Enabling technologies for controlling quantum behavior and new methods to reduce size, weight, and power are also desired

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### **3.4. Autonomy**

3.4.1. Tactical Mobile Robotics. The ARL is interested in basic and applied research in intelligent robotic behaviors that enhance Soldier mission effectiveness. The objectives of this research are to provide Warfighters with intelligent autonomous aerial and ground mobile robots that remove the Warfighter from harm's way and to provide enhanced situational awareness on the battlefield. This research will lead to the development of intelligent, autonomous systems of robots that will make optimal use of limited resources and will act appropriately in uncertain environments. Research areas of interest include, but are not limited to, advancing the state of the art in the following areas:



- a. Localization, world modeling, navigation and exploration.
- b. Planning for persistent surveillance.
- c. Teaming of autonomous mobile robots with Warfighters.
- d. Maintenance of communication under adverse wireless radio channel conditions.
- e. Coordination of heterogeneous robots, including air/ground, large/small, tracked/legged, etc.
- f. Object detection, classification, recognition, identification and tracking.
- g. Learning and adaptation to improve system robustness in real-world environments.
- h. Tactically relevant behaviors inspired by concepts of operation of human Warfighters.
- i. Self-awareness and introspection for transparency in human-robot collaboration.
- j. Multi-robot coordination in any of the above areas of research

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3.4.2. Micro Autonomous Systems and Technology (MAST). The MAST strives for enhanced tactical situational awareness in urban and complex terrain by enabling the autonomous operation of a collaborative ensemble of multifunctional, mobile microsystems. To achieve this, fundamental research aims to advance fundamental science and technology along three key Thrust Areas:

**1) Mobility, Control, and Energetics for Size and Resource Constrained Systems:**

- Aeromechanics at small scales to enable the design of agile, efficient, gust-tolerant aerial platforms
- Terramechanics principles for body and appendage design for all-terrain mobility at small scales
- Novel algorithms for agile navigation in complex, 3-D, uncertain environments
- Technology for robust actuation and propulsion for small scale platforms

**2) Communication, Navigation, and Coordination for Size and Resource Constrained Systems:**

- Ensemble collaboration for persistent surveillance, relative localization, distributed mapping
- Enhanced ensemble networking through channel modeling, routing, and path planning
- Ensemble communication in complex environment through multi-channel, multi-protocol, and low power radios and radio repeaters

**3) Sensing, Perception, and Processing for Size and Resource Constrained Systems:**

- State estimation, goal recognition, and sensor fusion for navigation
- Obstacle detection and mapping for 3-D perception and navigation in cluttered environments
- Ultra-low power processor architectures targeted at implementing and accelerating critical MAST relevant algorithms
- Small scale, low power intelligence, surveillance and reconnaissance (ISR) sensors

The key to deploying microsystem technology is to consider the interplay between individual technologies. Radical design and engineering methodologies are envisioned in which system-level performance is emphasized over the optimization of individual functions.

The operational vision focuses on roughly the last 100 meters of travel from the Soldier to an objective, which may be a building, cave, or analogous above-ground or underground structure, followed by reconnaissance and surveillance operations at the objective, which may take systems indoors or underground. Mobility is critical to the operational effectiveness of the collection of platforms. This includes, but is not limited to, flying, hovering, crawling, climbing, and jumping. For the scope of current research, the total mission duration is considered to be less than an hour. The ability to fly or ambulate and work within heterogeneous (scale and functionality) robotic teams and at the operational tempo of the Soldier is advantageous to operations. This vision drives the major research themes of the program without introducing difficulties that are out of reach or irrelevant to the research. Four scenarios of progressive difficulty are used to derive technical capabilities required to enable such missions:

1. Small unit building search
2. Small unit cave or collapsed building search
3. Small unit perimeter defense
4. Small Unit mobile real time ISR

These scenarios are designed to address operation in realistic, real-world environments, progressing from relatively benign and structured conditions in scenario 1 to far more challenging and unstructured conditions in scenario 4.

Important research issues include:

- a. Methods, models and simulations, sensors, and platforms for increased operational speed, risk tolerance and platform collaboration in complex environments on MAST SWaP constrained systems
- b. Low complexity methods with sufficient accuracy for dealing with uncertainty in sensing and operating in complex environments
- c. Sensors for MAST Scaled Autonomous Navigation
- d. Methods, models and simulations, and sensors that exploit the collaborative and heterogeneous nature of MAST systems to enable new capabilities at larger scale than realizable by a single MAST scaled platform
- e. Novel actuation technology for MAST SWaP constrained systems
- f. Distributed control for state estimation
- g. Understanding of design and control of avian flight
- h. Dynamical systems theory for air and ground mobility
- i. Novel onboard power/energy technologies that could substantially increase mission duration
- j. Platform stability and control in high-disturbance environments.
- k. Vortex-dominated unsteady aerodynamics of flapping wings at low Reynolds numbers.

- l. Bio-inspired, bio-mimetic leg and wing concepts with integrated sensors and actuators.
- m. Autonomous and semi-autonomous navigation and control over a network.
- n. Group cooperative behavior and planning.
- o. Robust and scalable control and communications architectures

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3.4.3. Robotics Science and Technology. Fundamental Research is directed towards providing the Army with technological building blocks required to develop future generations of highly capable unmanned systems that will team with Soldiers to successfully conduct multiple missions and activities. Activities fall three distinct areas of robotics that have the potential to significantly impact the future military missions, from the organic intelligence required by the vehicles to autonomously maneuver through complex and dynamic operational environments, to the mechanisms and control schemes that are required to provide the raw mobility to maneuver in three-dimensional environments typical of urban areas or highly dangerous situations such as maneuver through pipes, tunnels, and culverts, to the ability to dexterously manipulate objects of varying size, shape, texture, and weight distribution, to the ability to create numbers of extremely small mobile sensors that can fly through interior spaces or crawl on the ground like insects, providing critical tactical intelligence to our Forces.

To successfully develop such future systems will require the development of key technologies, including:

- a. **Adaptive Tactical Reasoning** – The ability to generate tasks to accomplish the mission at hand, reacting appropriately to unforeseen events; to understand teammates, human or otherwise, and what the teammates need to know during the mission, to learn from experience and generalize appropriately from specific examples.
- b. **Focused Situational Awareness** – The ability to monitor friendly forces and neutrals and look for threats, to contribute to the general situational awareness of the unit, looking for any salient unexpected events, to continuously predict the future so that anomalies can be more readily detected.
- c. **Efficient Proactive Interaction with Humans** – The ability to receive, understand, and acknowledge orders, asking for clarification if needed in a natural fashion utilizing the same codes of command and control that Soldiers use.
- d. **Safe, Secure, and Adaptive Movement** – The ability to move on orders or their own initiative from one tactical position to the next with little or no reliance on metric inputs such as GPS..
- e. **Interaction with the Physical World** – The ability to pick-up and move objects, either upon semantic direction or their own initiative. And to maneuver in three dimensional terrain, possibly in places that Soldier cannot travel. These capabilities must be applicable to a broad range of scales, from micro-systems through larger tactical vehicles.

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### 3.4.4 Intelligent Systems

The ARL is interested in basic and applied research concentrated on the understanding and exploiting of interactions between information and intelligent systems, such as robots and software agents, wherein information is transformed between different levels of abstraction and roles within the intelligent system's cognitive processes – recognition, prediction, reasoning, and decision making. Research areas of interest include, but are not limited to, advancing the state of the art in the following areas:

- a. World modeling, including loop closure and localization
- b. Scene understanding
- c. Inference of unknown areas or conditions, based on previous experience
- d. Task/resource allocation and distributed planning for multi-agent systems
- e. Search and exploration techniques

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## 3.5 Atmospheric Sciences

3.5.1 Atmospheric Sensing and Characterization. Improving the measurement of battlespace weather variables and the characterization of atmospheric processes through observations applied to critical scientific areas that affect atmospheric modeling, soldier battlefield awareness, survivability, and tactical decision-making.

The successful implementation of such sensing and characterization systems will require the development of key technologies, including:

- a. Army atmospheric observing systems for various applications such as, but not limited to, atmospheric processes, bio-warfare and chemical warfare threats, battlefield logistics (e.g. soil moisture, flooding), and human behavioral and social effects of the weather.
- b. The methodology, infrastructure, and application framework for the simulation of sensor performance in various battlefield environments. The implementation of this framework may involve, but is not limited to the following:
  - (1) Optimizing sensor system performance
  - (2) Developing decision support tools (DSTs) for use by various sensors
  - (3) Developing optimal simulation modules for sensor performance and distribution. These modules may include, for example, artificial intelligence and modeling techniques for state of the art computer architectures.
  - (4) Conducting trade-off studies. For example, determining the optimal quantity, distribution, type, frequency of measurement, and accuracy of meteorological

(MET) sensors for use on the battlefield or other denied geographic regions to provide appropriate environmental analyses and forecasts;

(5) Developing methodologies and applications for the use of satellite remote sensing of boundary layer environmental conditions with emphasis on smaller scales, that is, the meso-gamma scale and microscale.

- c. Innovative new techniques and novel technology exploitation to retrieve data and extract information on boundary layer weather and atmospheric aerosols from traditional, non-traditional, and non-meteorological sensors and sources. Such methodologies might include, but are not limited to, assimilating volumetric data from multiple passive or active remote sensors simultaneously and integrating those data into traditional observation sets.
- d. Research on and models of atmospheric effects on sensor imagery under natural and battle-induced conditions.
- e. Development of and applications using advanced ultra-compact light detection and ranging (LIDAR) systems.
- f. Atmospheric aerosol properties and behavior, including the natural background, as well as man-made liquid/solid mineral, chemical and biological components.

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3.5.2 Atmospheric Modeling and Decision Aids. Improving the assimilation, analysis, forecasting, and dissemination of real and simulated digitized battle-space weather and atmospheric information.

The successful implementation of such modeling and DST systems will require the development of key technologies, including:

- a. Research on and development of models and DSTs for atmospheric effects on radar, LIDAR, acoustic and infrasonic acoustic, Electromagnetic (EM), especially electro-optical (EO), and unexplored energy/radiation propagation;
- b. Propagation in the battlefield atmospheric environment. This may include, but is not limited to sound detection and ranging techniques, and incorporation of the effects of weather, clutter, and battlefield obscurants into intelligence, surveillance, and reconnaissance.
- c. Microscale atmospheric boundary layer meteorology and numerical simulation, at horizontal grid resolutions from 100 to 1 m that address local effects of complex terrain including urban, mountainous and forested areas. .
- d. Technology and algorithms for Web enabling of numerical weather prediction (NWP) models, data assimilation methods, and related software including but not limited to web services, Java Spaces, widgets, cloud computing, and other emerging methods leading to the efficient distribution and handling of weather forecasting/nowcasting technology on future Army tactical computer platforms.

- e. Basic research to characterize and simulate atmospheric mechanical and optical turbulence throughout the boundary layer and over complex terrain including non-isotropy and intermittency, as well as atmospheric modeling and simulation techniques in support of accurate assessment of optical system performance in Army battlefield conditions.
- f. Physically accurate weather visualization tools.
- g. EM and acoustic propagation, especially for EO system performance, high energy laser effectiveness, emerging THz system design, infrasonic acoustic propagation analysis, and modeling of polarized EM propagation measurements through the atmosphere at UV through millimeter-wave lengths under natural and battlefield conditions for mitigating atmospheric effects;
- h. Environmental DSTs for transforming raw MET information and probabilistic weather forecast model output into mission planning and battle decision intelligence to include the decision aids for the effects of weather on Soldier performance, and for the use of smoke, camouflage, decoys, and multi-spectral and polarimetric technology;
- i. Data assimilation methods applicable to NWP models at meso-gamma to microscales running with horizontal grid resolution down to less than 10 m, and capable of running in near-real-time. Such data assimilation technologies could include weather observations from robotic platforms, Soldier-worn sensors, and social-media sources, to name only a few.
- j. Innovative technology and methods for detection of severe storms and other atmospheric phenomena such as through detection of impending and current lightning.
- k. Tailored applications of meteorology developed for modeling and simulation, transport and dispersion of airborne hazards, real time monitoring, and input data sets for decision aids.
- l. Methodologies to extract, quantify, and apply measures of risk to the output and products of NWP models;
- m. Novel new approaches in the area of “social meteorology;” meaning both methodologies of extracting useful MET data from social media and other sources, as well as predicting human behavioral patterns from prevailing or forecast weather conditions.
- n. Investigate the potential implementation of weather DSTs and ultimately even NWP models on emerging wearable computing technologies.

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3.5.3 Intelligent Atmospheric Optics Systems for Army Battlefield Applications. The objectives are to mitigate the effects of weather and battle-induced atmospheric processes and constituents on EO transmissions; to optimize the performance of Friendly forces under realistic battlefield conditions; and to enhance the exploitation of smoke, camouflage, concealment, deception, and multi-spectral and polarimetric technology. For example, atmospheric turbulence introduces random phase distortions and intensity scintillations into the transmitted and received EO waves. These distortions lead to intensity fading of the received signal in optical communication

systems, degradation of image quality in surveillance and automatic target recognition systems, and significant decline in energy density at the target in the high-energy laser based directed energy systems. Combined with an understanding of the impact of atmospheric turbulence effects on various military systems, develop techniques for mitigation of these effects using intelligent optics elements and systems.

The successful implementation of such intelligent optics systems will require the development of key technologies, including:

- a. Innovative atmospheric sensing, characterization and evaluation techniques including complex-field (phase and intensity) sensors capable of operation in deep turbulence conditions (long-range and slant propagation paths).
- b. Research on and models of atmospheric effects on sensor imagery under natural and battle-induced conditions. This area includes active and passive imaging techniques and on-the-fly image processing algorithms that result in dramatic enhancement of image quality in severe atmospheric conditions.
- c. Active/adaptive multi-gigabit rates free-space laser communications for high-resolution (high-definition) video information relay.
- d. New generation of intelligent (active/adaptive) laser tracking and high-precision beam pointing systems that are resilient to atmospheric effects.
- e. Conformal optical systems based on an array of adaptive laser beam transceiver elements for directed energy, remote sensing and laser communication applications.
- f. New generation of optical systems for efficient high-energy laser beam projection and relay. That is, develop new optical system architectures and systems that are small size, light weight, less expensive, and more robust in respect to both atmospheric turbulence and platform jitter induced effects.

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### **3.6 Electronic & Information Warfare Vulnerability**

ARL provides survivability, lethality and vulnerability (SLV) analysis and evaluation support over the entire life cycle of major Army systems; and helps acquire systems that will survive and be lethal in an electromagnetic environment. Measurement and emulation of the electromagnetic (EM) spectrum for use in analyzing systems during developmental and operational evaluation would provide insight into system performance and provide an opportunity for mitigating vulnerabilities. These emulators should be mobile thus allowing use in laboratory, anechoic chamber, and field experimentation on communication (including wireless networks), radar, navigation and information systems.

#### **d. CORE COMPETENCY 4: HUMAN SCIENCES**

ARL plans, manages, and conducts a comprehensive, multi-disciplinary program of scientific research directed toward defining human performance in sensory, perceptual, cognitive, and physical domains, utilizing experimental and modeling approaches from disciplines such as psychology, cognitive and computer science, neuroscience, human factors engineering, and systems engineering. ARL research provides the scientific foundations for application to militarily relevant domains such as human systems integration, task performance modeling, and anthropometric biomechanical modeling. The end goal is to guide optimal design of human-system interaction in operational environments. ARL also conducts research associated with training technologies, and advanced distributed simulation, including adaptive and intelligent training technologies, virtual human research, immersive learning, synthetic environments, and training application domains such as medical, dismounted Soldiers, and embedded/live training.

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#### **4.1 Soldier Performance**

4.1.1. Soldier Performance Research: Proposals are requested involving Soldier-oriented research and development (R&D) that advances and improves human factors design principles and guidance for enhancing Soldier and small team sensory (e.g., auditory, visual, and tactile), perceptual, cognitive, and physical performance while providing the materiel development community with the information necessary for effectively designing systems that are best suited to the operator, maintainer, or trainer. Proposals for technology for collecting sensory, cognitive and physical performance data (including biomechanics data) in field environments are also requested. Results of studies will be used to quantify trade-offs between the benefits of providing new technology and the cost to the dismounted Soldier of having and using that technology.

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4.1.2. Neuroscience: ARL is seeking proposals that provide fundamental research underlying the development of neurotechnologies to enhance human-system interactions, to include mission rehearsal and training environments. Specifically, ARL is seeking to understand the nature of the human-system interactions and use that information combined with technological advancements across computational and system design fields to create enhanced and total novel interaction technologies for tomorrow's Soldier. This effort requires the translation of laboratory-based neuroscience research and methods to militarily-relevant environments, to include training and virtual environments, in order to enable system designs that exploit the capabilities of both Soldier's brain function and systems to maximize Soldier-system performance. Research is focused on the capability to sense, process, and extract critical information about brain activity in dynamic, complex environments; characterizing and modeling neural processes in real-world contexts and those processes critical to Army-relevant operational tasks; and creating and extending novel brain-computer interaction technologies which have the potential to revolutionize the basic interactions Soldiers have with their systems and each other. This effort



addresses the rapid technological advances in areas such as sensing, computation, robotics, microelectronics, and computer and network information systems that are outstripping the capabilities of the human brain and limiting both Soldier-system effectiveness and the Army's ability to fully exploit investments in these new technologies. Also of interest are new approaches for understanding and predicting the behavior of individuals and groups, especially those that elucidate the neurobiological basis of behavior and decision making; new approaches for training individuals and teams, including embedded training and simulation; and understanding and improving team performance.

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4.1.3. Social/Cognitive Network Science: This research topic is aligned with the broader ARL efforts in Network Science that also include the domains of Information and Communication Networks and draws on cognitive science, computer science, and social network innovations. ARL's efforts focus on two areas: socio-technical network operations and network-enabled cognition with both areas sharing the goal of the improving cognitive performance for collaboration and decision making in complex network-enabled operations. The research contributes to the development of theory, measures, models, and understanding of social networks and the cognitive implications of those networks and ultimately will guide the design of human-team-system interaction aligned with future operational systems. Research is conducted via computational modeling, networked laboratory (human-in-the-loop) experimentation, virtual simulations, and field exercises, such as those conducted by the Mission Command Center of Excellence (CoE) and Communications-Electronics Research, Development and Engineering Center (CERDEC). An applied cognitive system engineering approach is used which employ cognitive work analysis and the newly developed dynamic social network tools. Key themes include social/cognitive network properties, domain modeling and workflow, networked information requirements, trust in automation, , measurement of team performance, cognitive workload, situation awareness, and methods to drive the information and communication networks with dynamic social network information for real time support for the Soldier/decision maker.

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## **4.2 Simulation and Training**

4.2.1. Adaptive and Intelligent Training Technologies: Proposals are requested to design, develop, apply, and evaluate artificially-intelligent agent technologies (e.g., computer-based tutors, virtual humans, process agents and authoring tools/methods) to enhance training effectiveness and reduce associated training support costs. The goal of this research is to enhance the realism, adaptability and decision-making skills of artificially-intelligent computer-based tutors and virtual humans to support one-to-one and one-to-many training experiences where human support is limited, impractical, or completely unavailable. Technical challenges include the development/application of intelligent agents that can adapt in complex, ill-defined domains; understanding natural language in multi-sided conversations with trainees; rapid authoring of effective computer-based tutors for individuals and teams, and realistic virtual humans. Anticipated capabilities include computer-based tutors on par or better than expert human tutors

and realistic virtual humans that are so visually and cognitively realistic that they are indistinguishable from humans. These capabilities will serve to provide enhanced “self-directed” learning while at the same time reducing associated training support costs.

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#### 4.2.2. Advanced Distributed Simulation

4.2.2.1. Advanced Training Technologies: Emerging training concepts established by the U.S. Army Training and Doctrine Command (TRADOC) prescribe the transformation of the Soldier education and training processes through the integration of advanced training technologies and methods (Ref: The Army Training Concept, The Army Leader Development Strategy, The Army Learning Concept for 2015, and The Army Learning Model). The Simulation and Training Technology Center of ARL's Human Research & Engineering Directorate is investigating innovative, license-free tools, and techniques to train and educate Soldiers and leaders in individual and team knowledge, skills, attributes, and abilities in order to execute full spectrum operations in an era of persistent conflict. Whitepapers are solicited for studies, demonstrations and development that combine elements from areas such as: Next-Generation Learning Management Systems; authoring tools that are user friendly with minimum train-up time and support the rapid development of learning principle-based content across several platforms (e.g. game-based, mobile, virtual worlds); Content Management Systems that are data-driven and capable of taking doctrine, training requirements, historical records, and other user inputs, creating a linkage between the set, and auto-generating content for courseware across multiple, varied platforms at once; Social Media and Social Networks for Learning in and out of the classroom; and other innovative learning technologies in support of the Army Learning Model. Any efforts focusing on a combination of these diverse areas will include proper experimental design techniques and metrics to evaluate the effectiveness of the capability researched and developed. Note: Efforts in this topic will focus on the integration of new capabilities that do not already exist vice researching only one particular area listed above.

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4.2.2.2. Simulation Interoperability Technologies and Future Architectures: In order to support future training, experimentation, and acquisition decisions there is a need to refine and demonstrate advances in computer science to develop next generation architectures for Modeling and Simulation (M&S), including considerations for Live, Virtual, Constructive, and Gaming environments. Moreover, gaps in simulation capabilities must be filled either through new development, interoperability of disparate systems or through some other innovation. Whitepapers are solicited for studies, demonstrations and development in areas, such as hardware and software technology solutions for current and future training, experimentation, test, and analysis challenges; formalizing training and analysis execution requirements for a cloud environment supporting software as a service across a distributed environment; leveraging continued growth in computing power and the increasing affordability of those capabilities, achieving efficiencies transcending current hardware, middleware, protocols and data structures; systems engineering information captured within a database-driven system to facilitate composable engineering

design decisions and automatically generated artifacts; novel encapsulation of military representations in support of disparate simulations; and, other innovative technologies or means in the areas of simulation architecture, interoperability, integration, ease of use, efficiency, etc. Efforts will demonstrate timely solutions to Army questions and training needs through increased availability, scalability and affordability of advanced hardware and software services for execution of distributed training, experimentation, test, and analysis. Additionally, efforts will support the capability to improve cost, schedule, and performance early on through the ease of use of M&S in the acquisition lifecycle by enabling the timely and effective use of M&S in support of the analyst.

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4.2.3. Immersive Learning: Immersive learning includes but is not limited to, games and virtual worlds for learning as well as immersive collaboration environments and traditional simulations (otherwise described as virtual environments). It also includes the means by which we interact with those environments. We seek advances in virtual environment research that improves the sense of presence and engagement in a virtual environment, improves the realism of a virtual environment and the ability to visualize information, improves the user's experience and within the environment, and provides the ability for multiple users to edit the environment on-the-fly (a user should be able to easily replicate a concept within their mind without platform limitations). The environment is only part of the equation. The user interface should not limit but rather should augment the virtual experience by providing realistic feedback from experiences within the virtual environment. The interface should also provide subtle environmental effects to the user and improve the user's ability to navigate through and within the environment through natural means.

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4.2.4. Synthetic Environments: Army simulation and battle command systems are transforming into highly integrated, distributed/collaborative tool suites that improve Warfighter readiness and responsiveness by enabling commanders and staffs to see, understand, act first and finish decisively. To function properly, these systems depend on accurate, timely geospatial data; this will be especially true for the Army's Current and Future Force. Accurate, timely geospatial data is also critical to the user defined operational picture, embedded training systems, mission rehearsal systems, course of action analysis/development/evaluation tools and other Command and Control (C2) planning, integrated intelligence, surveillance, and reconnaissance, situational awareness, and robotics. Providing representations of complex environments is a critical element of models and simulations. It includes those physical aspects of the real world that provide the context for application-specific simulations. Interoperability of heterogeneous simulation systems depends heavily on sharing complex environment data in a consistent and complete manner. The emphasis is to provide the capability to represent the synthetic environment as realistically as possible to support the Army mission, including the ability to update the synthetic environment and to provide access to derived services across many platforms. Areas of consideration focus on synthetic environments representation and include environment generation, environment representation, environment services and dynamic

environments. Others areas of interest are in research and technology that in research use of synthetic environments.

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4.2.5. Three-Dimensional (3D) Holography Modeling and Simulation: There continues to be a need for visualization tools that provide a bridge between complex imagery data and the ability to view this data. This visualization problem is particularly acute for complex terrain, subterranean bunkers, and urban environments where two dimensional maps and photographs cannot adequately represent a 3D area. The Simulation and Training Technology Center of ARL's Human Research & Engineering Directorate has an interest in research, development and demonstration of 3D holography to address this need for use in mission planning, mission rehearsal and mission execution. Areas for consideration include:

- a. Imaging systems (e.g., holographic technologies and laser-optical projection systems)
- b. 3D holographic technologies that do not require viewing aids
- c. 3D technologies to be viewed with existing military issued equipment (e.g., night vision goggles)
- d. Holographic displays incorporating dynamic movement
- e. Lightweight, portable, and rugged display systems
- f. Hologram output from multiple input sources, data agnostic
- g. Linking to existing Warfighter simulations
- h. Incorporation of medical content, such as medical imaging data and anatomical models, into novel imagery projection systems

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4.2.6. Training Application Environments: Ground

4.2.6.1. Embedded Simulation and Training for Combat Systems and Vehicles: Embedded Training (ET) is a capability designed into a Ground Combat System (GCS) and Dismounted Soldiers (DS) that enables the GCS and DS to provide necessary environmental and system feedback to train individuals, crews and units, and enhance operational readiness using the system's operational equipment. Having a training capability integrated within the system's operational equipment allows units to train anywhere and anytime, including while deployed. The goal is to enable more cost-effective training and mission rehearsal, on demand, whether at home station or deployed. ET must ensure maximum accessibility, as well as flexibility in execution of training for Soldiers and commanders. ET must have the capability to train without significant external support, and rapidly execute training with organic assets saving time for leaders to focus on execution and retraining. ET development may also aid in the areas of vehicle development and operational testing. The advent of emerging technologies such as enhanced visual systems, miniaturization, and computational processing power combine to support on-vehicle/on-location training that is realistic, low cost, and environmentally friendly. ET is a mandatory requirement for the Army's future systems and a requirement for other current force systems (e.g., Abrams, Stryker, and Bradley) as well as dismounted ground Soldier

systems. The primary focus of research in this area is to mitigate the technology risk for current and future GCS by providing a technology demonstration on current force systems, with the goal of accelerating ET into the current force by facilitating the integration of earlier spirals of ET into the current force. Pacing technologies include, but are not limited to: embedding training and mission rehearsal on current force vehicles innovative methods for image generation and stimulated weapon sensors, methods to modify analog-based systems (brake, steering, direct view optics), embedded visual and display systems and mounted/dismounted interoperable ET environments.

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4.2.6.2. Tactical Engagement Simulation Sensor Technology for Live Training: The Army has successfully fielded the Multiple Integrated Laser Engagement System (MILES) as a means of providing non-lethal, real-time casualty assessment for direct fire, force-on-force engagement exercises. Current research efforts will extend capabilities to include engagement training of Non Line-of-Sight (NLOS) and area effects weapons such as mortars and grenade launchers. Novel technical approaches are being sought to enhance or improve upon current MILES technology to include simulated tactical engagements of indirect fire weapons. Innovative approaches may include technology such as:

- a. Increasing optical link reliability between the MILES laser transmitter and detector that achieve probability of detection better than 95% under poor atmospheric conditions
- b. Methods that can compensate in real time for the effects of optical scintillation for improved link signal-to-noise
- c. Laser modulators that generate modulated bit output at 2.5Gb/sec (or better) and consume less 50mW of power
- d. Soldier mounted laser detectors that function in dual wavelengths (904.5nm and 1550nm) that have the potential for 4X reduction (or better) of the unit cost of current Avalanche Photo Detector (APD) technology
- e. Real time optical control to vary the laser transmitter output divergence angle
- f. Eye-safe laser range-finding that achieves a distance measurement accuracy of 10m (or less), at a unit cost under \$500, occupies a volume under 3cm<sup>3</sup>, and draws less than 200mW of power
- g. Computer or image processing algorithms that can take 60Hz input of video scenes and measure relative changes in angular rate with a minimum accuracy of 0.5 degrees such that it performs as an optical gyroscope during dynamic changes in the camera's field of view

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4.2.6.3. Indoor Position, Location and Tracking for Live Training: ARL is interested in technologies that improve live training of simulated tactical engagements, particularly in urban terrain, where GPS signals may become degraded or obscured due to multi-path phenomena as Soldiers maneuver inside of buildings. During simulated tactical engagement training exercises, Soldier movements inside of buildings require accurate position/location measurement data that can be used for post training After Action Review (AAR) assessments. The technology

approach to solve these challenges must be capable of determining the position/location of a dismounted Soldier with accuracy equal to or better than 30 cm (95%), have a unit cost less \$1,000, occupy a volume under 100cm<sup>3</sup>, and have a battery life of up 72 hours (minimum) without changing or charging batteries. The need for infrastructure to support the technology must be minimal in terms of cost or maintenance, or ideally, none at all.

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4.2.7. Training Application Environments: Medical: ARL has an interest in researching, developing, and demonstrating technologies, techniques, and strategies for immersing the military medical community into realistic, simulated military medical training environments for initial, transition, refresher, and sustainment training. Both individual and team training concepts shall be included in this area of interest. Areas for consideration include:

- a. Technologies to reduce or eliminate the use of live tissue and cadavers in military medical training
- b. Imaging systems (e.g., holographic technologies and laser-optical projection systems)
- c. Virtual patients and innovative interaction capabilities
- d. Total immersion and mixed reality across levels of care
- e. High-fidelity haptics
- f. Integration with existing Warfighter simulations
- g. Medical training technologies that realistically simulate human trauma
- h. High-fidelity patient simulation technologies
  - Movement. Lifelike movement of simulated patients, including realistic response to painful stimuli
  - Tissue. Simulated tissue with properties that approach those of live human tissue
  - Olfactory. Olfactory and malodor simulation technologies
  - Fluids. Simulated body fluids and hemostatic agent training technologies
- i. Portable, rugged training systems
- j. Personal computer, game-based and mobile application training technologies
- k. Total immersion across levels of care; from the point of injury to return-to-duty status
- l. Methodologies that improve cost effectiveness and increase test scores as well as skill levels

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4.2.8. Training Application Environments Dismounted Soldier: The Army needs advanced technology to provide dismounted Soldiers with fully immersive, simulation based training environments. These systems will provide the small unit leaders and individual Soldiers with a capability to conduct fully immersive, self contained, simulation based training. ARL has an interest in researching, developing and demonstrating technologies and advanced techniques for virtual immersion as well as next generation Mixed Augmented Reality (MAR) environments for dismounted Soldiers. A core requirement of the system(s) is the ability to execute scenarios within immersive, virtual and MAR environments that allows advanced mission planning, analysis, and rehearsal. This environment should replicate the full spectrum operations to

include non-kinetic social and cultural situations. We seek to explore methods of presenting 2D/3D virtual objects (representing various types of targets, fire and effects, friendly forces and opposition forces, civilians on the battlefield, vehicles, etc.) to the dismounted Soldier while operating both indoors and outdoors, on various types of live training environments. Additionally, the trainee would be capable of interacting with virtual targets, personnel, vehicles, etc. as though real. The objective is to create an interactive, multi-sensory, non-linear environment that provides the Warfighter with training that is unparalleled in flexibility and realism.

The technology applied to solve these challenges should have the following characteristics or capabilities:

- a. Low power man-portable CPU and Graphics processing hardware
- b. Exploits the use of commercial gaming technology to provide immersive capabilities that leverages the advanced rendering and scenario development capabilities to present Soldiers with increasing levels of complexity and realism
- c. Flexibility to incorporate the latest tactics, techniques, and procedures for constantly changing mission environments
- d. Increased capabilities in field of view and resolution of head mounted display systems. Exploration of multi-modality for the man-machine interface
- e. Augmented Reality (AR) for dismounted Soldier applications must provide a low cost, man-wearable system that uses minimal infrastructure, site preparation and set up time
- f. Support interfaces, instrumentation & infrastructure in various types of military training environments (military operations on urban terrain sites, maneuver ranges, firing ranges, test ranges) as part of implementing realistic AR

Technologies include, but are not limited to: visual and display systems to include head mounted displays, computer systems, wireless tracking devices to include markerless tracking technologies, natural locomotion, wireless video/audio transmission, MAR systems to include optically aided video odometry, accurate depth sensing and occlusion mapping, visual landmark detection technology; mission rehearsal, distributed AAR systems, and advanced synthetic natural environments.

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#### 4.2.9 Advanced Situational / Battlespace Awareness

4.2.9.1 Adversarial Reasoning: The terms “predictive analysis” and “predictive battlespace awareness” describe future techniques and technologies that will help the commander estimate enemy courses of action and adaptively plan friendly actions based on these estimates. There is a lack of critical technologies, techniques, and simulation and training tools to support such capabilities. Adaptation of these types of technologies to the training and M&S domains is needed. For example, tactical platform and unit behaviors can be driven within a simulation by using the estimating tools to produce a “low overhead” driver capability. This capability is needed to reduce the manpower overhead currently required for simulation, training, and test

environments. New training process techniques (for individuals and teams) are also needed to address this technology area.

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4.2.9.2. Emerging Modeling and Simulation Technologies Thrust: ARL is exploring several emerging information processing technologies to include: novel uses of modeling and simulation to create new battle command paradigms; computational social science; research that closes the gap between new technology development and transition to Soldiers; quantifiable metrics that illustrate improved performance; application in immersive training environments; improved execution support via immersive environments and tactical analysis facilities. Ideas that address any combination of technology and application that falls within the purview of ARL's Human Research & Engineering Directorate broad mission may be submitted under this topic area. Proposed research should investigate innovative approaches and simulation and modeling techniques in one or more of the above-mentioned areas.

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### **4.3 Human Systems Integration**

4.3.1 Human Systems Integration (HSI) Human Performance and Accommodation Modeling Tools and Techniques-Development: Proposals are sought to develop tools and techniques that assist in optimizing total system performance, minimizing total ownership costs, and ensuring that systems are built to accommodate the characteristics of the user population who will operate, maintain, and support them. The purpose of ARL's HSI program is to develop human performance and accommodation modeling tools and techniques to represent system level mental and physical human performance tradeoffs at the system-of-systems level as a function of factors such as task requirements, level of automation, interface modality, workload, type of training, varying measures of anthropometry, and workspace design. These tools and techniques will support the execution of analysis to understand the collective and systematic consideration of manpower requirements, workload, and skill demands to avoid information and physical task overload, mismatch in physical accommodation, and to take maximum advantage of aptitudes, training (individual and collective), and numbers of Soldiers for an affordable Future Force.

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4.3.2 Human Robotic Interaction (HRI): Proposals are requested to develop human factors technologies and design principles that enhance the Soldier interface with robots, and therefore, manage workload, engender trust, and improve overall Soldier-robot performance. As autonomous robotic systems increase in capability and functionality, the operator will require "matching" enhancements to the methods and interfaces used to task and control those robotic systems. This includes the investigation of supervisory control, levels of robotic autonomy and interface automation, multimodal inputs and scalable interface technologies, and human-robot and robot-robot teaming that invokes the concepts of trust, natural interaction, and social/cultural



interactions across a range of single/multiple autonomous systems sizes and capabilities. Concept validation employs modeling, laboratory and field experiments, and simulations, moving from highly controlled to militarily-relevant environments. HRI also includes research to leverage bio- and cognition-inspired designs for autonomous and intelligent systems to enhance the interaction with Soldiers.

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## **e. CORE COMPETENCY 5: SURVIVABILITY, LETHALITY, AND VULNERABILITY ANALYSIS AND ASSESSMENT**

### **5.1 Ballistic Vulnerability Analysis and Assessment**

5.1.1. Vulnerability Research and Analysis for Under-body Blast. Conduct applied research and advanced development to create enhanced capabilities for assessing the vulnerability of mounted Soldiers to the effects of under-body blast. Areas of interest include instrumentation, sensors, data acquisition systems, data management and data basing and medical informatics, high-speed video, digital image correlation and motion tracking, medical diagnostic imaging including x-ray and computer-aided-tomography, medical image analysis, anthropomorphic test devices, anthropometry, signal analysis and filtering, human response and injury criteria (including experimentation with biological tissue), studies and analyses to correlate human response and injuries observed in military events to phenomena observed in laboratory experiments, verification and validation testing of injury assessment devices and instrumentation, analysis of alternatives, manufacturing technology studies including affordability analyses, materials technology especially for the simulation of biologic tissue, systems integration and engineering, novel experimental techniques, behavior of biologic material and surrogates under high loading rates, structural response, vehicle seat technologies, shock mitigating materials and structures, occupant restraint technologies, personal protective equipment, biofidelity response corridors, human injury probability criteria and functions and curves, methods for assessing and rating biofidelity, statistical analysis, biometrics, rapid prototyping, design of experiments, error and uncertainty analysis, laboratory devices for simulation of under-body blast, load transfer through the human skeletal structure, scaling of medical research including effects of size and mass and bone quality, and modeling and simulation.

ARL is also interested in methodologies and models for assessing Soldier/platform occupant injury probabilities as well as data collection and analysis in support of the WIAMan program, which is developing a new military-specific anthropomorphic test device and associated injury assessment tools for use in live-fire test and evaluation and vehicle development efforts.

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### **5.2 Electronic & Information Warfare Vulnerability Analysis and Assessment**

5.2.1. Radio Frequency Directed Energy (RFDE)/ High Power Microwave (HPM)/Electromagnetic Effects/ Electromagnetic coupling phenomena/ Electromagnetic Energy/

Electronic Warfare (EW) Survivability. ARL provides survivability, lethality and vulnerability (SLV) analysis and evaluation support over the entire life cycle of major Army systems; and helps acquire systems that will survive and be lethal in all environments against the full spectrum of battlefield threats. This is done by conducting SLV investigations, experiments, simulations, and analyses. ARL develops tools, techniques, and methodologies to improve the SLV analyses. ARL has a continuing interest in a broad spectrum of research in these areas, including: electromagnetic (EM) coupling phenomenology and antenna measurements.

There is ongoing interest in EM coupling to analog and digital systems, subsystems, components, boards, integrated circuits (ICs), and components. Of interest are susceptibility levels and dependent parameters. Understanding coupling phenomena provides insight into the system effects and is useful for analyst projections. Additionally, a methodology (that can be validated in a laboratory or open air environment) is needed to analyze and understand the performance of communication/electronic/ADP equipment when deployed/operating in battlefield electromagnetic environments (EME). EME sources in the battlefield include radars dedicated to various warning functions (acquisition, track, etc.) covering broad frequency bands, communication transmitters, and accouterments of EM generating equipment used in the battle management/command, control, communications, computers, and intelligence (BM/C4I) functions during a battle. Some of the sources encountered in the battlefield come under the realm of high-power microwave (HPM) and EW, and the coupling phenomenon associated with the pulsed environment needs to be understood.

Ideally a HPM predictive tool would be developed and used for electronic equipment survivability assessments. The radio frequency (RF) coupling study can be approached by placing the equipment under test (EUT) and the ancillary equipment in an anechoic chamber:

- a. To understand the low level RF coupling phenomenon associated with narrow-pulsed and/or transient EM environment.
- b. To characterize its performance when exposed to out-of-band environment in the 100 MHz to 18 GHz and around 35 and 95 GHz range.
- c. To diagnose/instrument digital EUT systems; e.g., computers, network devices, receivers, circuits, for RF effects. These measurements are conducted in an anechoic chamber to insure clutter free environment and facilitate cause and affect relationships observed due to RF environment.
- d. To understand complex antennas and the interaction with the ground and other clutter.

The results from out-of-band radiated susceptibility measurements would be invaluable in characterizing EUT susceptibility profiles. This profile would define EUT system sensitive frequencies and the corresponding incident energy levels required to induce an electronic effect. System response against narrow-pulsed or EM transient pulsed environments would allow an analyst to project the performance behavior of the system in a tactical environment. If performed thoroughly, this effort may provide insight into predictive tools for the system performance in the presence of high-power microwave/directed energy weapons (HPM/DEW).

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5.2.2. RF Digital Models/Simulations. There is an on-going interest in theoretically based digital models and simulation tools for the analysis and performance of RF electronic countermeasures (ECM) against radar/sensor/communication functions. To verify functionality, these tools need to be mathematically defined and must be able to identify/quantify the information gained or lost by the radar/sensor/communication function.

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## ARMY RESEARCH OFFICE (ARO)

### a. RESEARCH AREA 1: MECHANICAL SCIENCES

1.0 Mechanical Sciences. Research supported in the Mechanical Sciences Division of the ARO is concerned with a broad spectrum of fundamental investigations in the disciplines of fluid dynamics, solid mechanics, complex dynamics and systems, and propulsion and energetics. Though many creative and imaginative studies concentrate on a particular sub-discipline, increasingly, new contributions arise from interdisciplinary approaches such as the coupling between aerodynamics and structures, complex dynamics and systems, combustion and fluid dynamics, or solid mechanics and structures as in the structural reliability areas. Additionally, several common themes run through much of these four sub-disciplines, for example, active controls and computational mechanics. Research in such areas is addressed within the context of the application rather than as a separate subject of study. Fluid dynamics research is primarily concerned with investigations in the areas of rotorcraft wakes, unsteady aerodynamics of dynamic stall and unsteady separation, and fundamental studies of micro adaptive flow control. Solid mechanics include a wide array of research areas such as high strain rate phenomena, penetration mechanics, heterogeneous material behavior, and reliability of structures. The complex dynamics and systems area is focused on investigations in vehicle structural dynamics, and simulation and air vehicle dynamics including rotor aeromechanics. Research in the propulsion and energetics area is concentrated on processes characteristic of reciprocating (diesel) and gas turbine engines and the combustion dynamics of propellants used for gun and missile propulsion. The following narratives describe the details of the scope and emphasis in each of these sub disciplinary areas.

1.1 Fluid Dynamics. Research in fluid dynamics supports the development of improved or new technology for advanced helicopters, small gas turbine engines, improved airdrop (parachute) systems, maneuverable high-speed missiles, high performance gun-launched projectiles, and miniature unmanned air vehicles. While basic research studies that address the fundamental flow physics underlying these devices are solicited, innovative research in the specific topical thrust areas listed below is especially encouraged.

1.1.1 Vortex-Dominated Flows. In contrast to fixed-wing aircraft, rotorcrafts always operate under the influence of their own wakes. The prediction of rotor performance, vibratory loads, and the associated noise due to blade-vortex interaction depend strongly on the accurate prediction of the rotor wake. However, the prediction methodology of this wake remains one of the major challenges in fluid mechanics. Current computational fluid dynamics (CFD) approaches are computationally intensive, especially for Eulerian methodologies where the vorticity diffuses numerically through the grid points and makes prediction inaccurate. The process by which vorticity is shed by the blade, and its eventual roll-up to form vortex filaments are not now adequately simulated. In fact, under certain flight conditions and due to negative lift, multiple vortices are observed to form over the blade tip. The application of non-intrusive optical diagnostic techniques should yield new phenomenological understanding for the study of multiple vortices, the wake structure, and its development. New numerical algorithms or different techniques to increase accuracy and reduce the computational requirements are required.

1.1.2 Unsteady Aerodynamics. The flow fields around many modern Army weapons systems are characterized by a high level of unsteady flow, which can neither be predicted adequately by steady nor quasi-steady approaches. One classical example of unsteady aerodynamics of very high Army relevance occurs on the retreating blade of a helicopter rotor blade. At high angles of attack the retreating blade of the helicopter experiences boundary-layer separation that leads to load and pitching-moment overshoots. While mild separation causes increased vibration and reduces system performance, severe dynamic stall leads to unacceptably large vibratory loads, severe limitation to forward flight speed, and diminished maneuver capabilities. The physics of this unsteady flow phenomenon are known to depend on the Mach and Reynolds numbers of the flow, and hence future research in this area needs to be performed under realistic flight conditions. In addition, improved theoretical and numerical simulation is needed for the understanding of the unsteady separation process, and for the evaluation of concepts that may lead to greater flow separation control. Flow field simulations must be capable of accounting for boundary layer transition, and under some circumstances, the transition of the separating free shear layer. To achieve a fundamental understanding of the separation process, detailed experimental measurements of velocity and pressure in the separating region and the development of new turbulence models that are valid during dynamic stall are needed. In this regard, the validation of numerical simulations must focus on quantitative flow field measurements rather than the mere quantitative measurements on the airfoil surface. In addition, the flow field measurements require the use of new non-intrusive optical methods. Combined experimental and numerical efforts towards the control of unsteady separation using passive and active flow control, including the emerging field of Micro-adaptive Flow Control, are also sought.

A second example of the importance of unsteady aerodynamics to the Army occurs during the maneuvering of missiles and projectiles. As future emphasis in flight vehicle control and "smart" systems pervades munitions design, greater understandings of unsteady aerodynamic phenomena, such as; high alpha dynamic separation, vortex shedding, control surface/vortex interaction, divert thruster/vehicle interaction, roll control stability and propulsion system integration, will be required. It is anticipated that new composite material vehicles will have stringent thermodynamic limits and enhanced nonlinear aero elastic response to maneuver forces. Smart structures and MEMS technology will redefine control strategies, control surface shape and control surface dynamics, consequently driving fluid dynamics into new areas of research. All of these developments will require the prediction and experimental verification of complex nonlinear transient flow fields. In turn, these developments will require improved CFD for turbulent flow separation prediction, large eddy simulation, vehicle vortex interactions, and the accurate computations of gross flow field response to MEMS boundary layer flow perturbations. Parallel developments in experimental techniques will also be required to measure these complex flow fields in efforts to verify and guide the predictive technology.

1.1.3 Micro Adaptive Flow Control. Micro Adaptive Flow Control (MAFC) technologies enable the control of large-scale aerodynamic flows using small-scale actuators. MAFC technologies combine adaptive control strategies with advanced actuator concepts; such as, micro-scale synthetic jets, microelectromechanical systems (MEMS)-based microactuators, pulsed-blowing, plasma actuators, and combustion actuators. MAFC techniques are used to cause the delay, or

prevention, of fluid flow separation; to induce flow separation in previously unseparated flow; to alter supersonic flow shock structure; or to otherwise alter the large-scale flow field and provide overall system benefit. Army systems for which MAFC is currently being investigated include on-blade controls, dynamic stall control on helicopter rotor blades, separation control for drag and buffet reduction on helicopters, surge and stall control within Army gas turbines, and dispersion reduction and terminal guidance of subsonic, transonic, supersonic and future hypersonic Army projectiles.

Even though many successful demonstrations of the efficacy of MAFC technology have taken place, much of the supporting research has tended to be somewhat Edisonian in nature. To enhance and focus the adoption of MAFC technology into Army weapon systems, basic research is needed. MAFC research is needed but not limited to the following areas: the development of fundamental understandings of the methods by which MAFC actuation alters the overall flow field; the development of phenomenological models for flows and surface forces in micro and nano channels; the development of robust and efficient MAFC actuators leading to greater control authority and higher bandwidth; the development of computational analysis methodologies capable of accurately and efficiently predicting the effect of unsteady MAFC actuation on the entire flow field; and the development of methods to integrate all these technologies into Army systems.

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1.2 Solid Mechanics. Solid mechanics research plays a crucial role in the prediction of strength, damage initiation and failure progression of Army material systems under extreme loading conditions, such as blast, shock, impact, penetration, and thermal cycling. This research topic addresses the need to understand the response of Army assets to high rate impact and explosive detonation. It integrates approaches based on finite deformation, high pressure and high strain-rate, damage, and failure mechanics. Innovative use of material combinations for specific applications necessitates understanding the behavior of military systems under complex and severe constraints. The program seeks to develop an understanding of the underlying physics of solids that form the foundation of optimization tools to enhance performance, and minimize weight and volume for the future design of Army and DoD systems. Research approaches should consider the topological effects (both micro- and macro-scale), specific material geometry, layering, and interface properties on response to high rate loading. In addition, solid mechanics approaches may address non-traditional concepts including biologically inspired hierarchical structures, soft materials, human tissue and functional degradation of electronic components. Research should be conducted through a combination of physically based experiments, analysis, and computations to address these difficult multi-physics problems. Predictive models, validated by well-characterized experiments, are needed to identify dominant failure mechanisms at relevant scales. An important aspect of this research area is the deformation and fracture of materials under high strain rates ( $>10^7$  s<sup>-1</sup>), strains (ranging from 2% up to 100%), high temperatures (up to the melting point), and high pressures (up to 5 GPa). An important aspect of solid mechanics research is the development of novel techniques to expand the design space of new hierarchical design principles for the purpose of creating microstructures that eliminate

traditional inverse material property relationships to enable a combination of disparate properties (i.e. strength and toughness, strength and density, hardness and ductility, etc...).

1.2.1 Mechanics of Heterogeneous Systems. The mechanics of structures involves the development of integrated analytical, computational, and experimental approaches to investigate rate dependent behavior of heterogeneous materials that may include combinations of high strength and lightweight functionally graded material systems. Experimental and computational techniques are needed to optimize material microstructure as well as the topology of systems to provide the desired structural response for specific boundary and loading conditions. Of special interest is the thermo-mechanical response at strain rates encountered in high-speed impact or explosive loading. Phenomena of interest are wave propagation, scattering, dispersion, and progressive failure behavior.

Quantitative prediction and measurement of parameters related to dominant heterogeneities and mechanisms are needed at appropriate length and time scales for specific material systems in order to relate atomistic and micro effects to the macro scale. Deterministic and statistical scaling methodologies are needed for toughness, strength, and geometrical effects which account for heterogeneities such as interfaces, interphases, reinforcement distribution and their combined effects on failure. Constitutive relations for multi-scale mechanisms should include mechanism-based and experimentally verifiable failure and damage criteria to investigate hierarchical structures for blast- and ballistic-impact mitigation. The integration of sensor technology and the concept of adaptive microstructures may be explored for enhanced control of energy dissipation and load transfer under multiple loading conditions.

1.2.2 Mechanics of Soft Materials & Biologic Systems. The mechanics of biologic structures involves the development and validation of a hierarchical approach to accurately predict stresses, strains, and cavitation in biologic tissue resulting from blast shock waves and high rate blunt trauma. The development of improved protection and injury prevention for military specific injuries requires experimental techniques capable of characterizing the response of soft materials in compression, tension, or shear for strain rates that range from  $10^2$  to  $10^5$  s<sup>-1</sup>. High rate loading of different durations and amplitudes may lead to cascading events that cause functional loss and impairment of human tissues. Identification of resultant fundamental processes ranging from molecular changes to physical injury is in their infancy for high rate loading conditions. Such identification will lead to the quantification of high fidelity injury thresholds and novel protective solutions. Several aspects of tissue damage are of interest: (a) high strain rate characterization of constitutive behavior of damaged tissues, (b) damage initiation and evolution at the cellular level, (c) force transduction through temporal and spatial scales from organs to cellular substructures, and (d) effect of blast load (pressure and electromagnetic loads, toxicity, etc.) on short and long term functionality of lower extremities. The aforementioned issues must be placed in perspective of high rate loads and their transmission through protective equipment, human tissue and bone. Advances require interdisciplinary teams combining solid mechanics and biological sciences.

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1.3 Complex Dynamics and Systems. The Complex Dynamics and Systems Program emphasizes fundamental understanding of the dynamics, both physical and information theoretic, of nonlinear and nonconservative systems as well as innovative scientific approaches for engineering and exploiting nonlinear and nonequilibrium physical and information theoretic dynamics for a broad range of future capabilities (e.g. novel energetic and entropic transduction, agile motion, and force generation). A common theme amongst all programmatic thrust areas is that systems of interest are “open” in the thermodynamic sense (or, similarly, dissipative dynamical systems). The program seeks to understand how information, momentum, energy, and entropy is directed, flows, and transforms in nonlinear systems due to interactions with the system’s surroundings or within the system itself. Research efforts are not solely limited to descriptive understanding, however. Central to the mission of the program is the additional emphasis on pushing beyond descriptive understanding toward engineering and exploiting time-varying interactions, fluctuations, inertial dynamics, phase space structures, modal interplay and other nonlinearity in novel ways to enable the generation of useful work, agile motion, and engineered energetic and entropic transformations. Further information on the current scientific thrust areas are detailed in the paragraphs that follow.

1.3.1 Dynamics of Nonlinear and Nonconservative Systems – Classical dynamics has produced limited fundamental insight and theoretical methods concerning strongly nonlinear, high-dimensional, dissipative, and time-varying systems. For over a century, qualitative geometric approaches in low-dimensions have dominated research in dynamics, dissipative processes are mostly relegated to phenomenological models, and reduced-order-modeling of high-dimensional dynamics are often premised on empirical and statistical model fitting and are incapable of capturing the effects of slowly growing instabilities and memory. Experimental efforts have similarly faded. There is prescient need for a return to fundamental investigations and new theoretical and experimental frameworks for high-dimensional nonlinear and nonconservative systems. At the same time, however, a number of exciting and new research problems are emerging. Research in this thrust concentrates on (but is not limited to):

- Spatially Extended and High-Dimensional Dynamics Far-from-Equilibrium – Develop novel theoretical and experimental methods for understanding the physical and information dynamics of driven dissipative continuous systems and novel reduced-order-modeling methodologies capable of retaining time-dependent and global nonlinearities. Novel research pertaining to the analysis and fundamental physics of time-varying nonlinear systems and transient dynamics is a high-priority. Programmatic interests also include unifying advances in nonequilibrium statistical mechanics with Statistical Energy Analysis (SEA), developing new methods for vibratory regimes outside the scope of overly-simplistic SEA assumptions (e.g. non-trivial modal overlap, mid-frequency range problems, and non-Gaussian stochastic processes), and novel research in experimental structural dynamics. This thrust also has special interest in pioneering research on creating and controlling nontraditional nonequilibrium critical phenomena and critical dynamics.
- Nonsmooth Dynamics and Interactions – Nonsmooth dynamics, for even a single degree-of-freedom, are extremely counter-intuitive and poorly understood yet they arise in many Army-relevant contexts spanning wave propagation in interconnected structures, autonomous system dynamics (e.g. locomotion and jumping), suddenly applied loads, etc. Novel and



fundamental investigations concerning the experimental and theoretical physics for a variety of nonsmooth dynamical systems are of interest. Programmatic interests herein extend to the emerging field of experimental and theoretical terradynamics, especially in the domain of low-inertia systems and novel, non-wheeled and biomechanical propulsion mechanisms where Bekker's theories and assumptions are invalid.

- Formalisms for Engineering Complexity and Resilience – Developing an engineering science of complexity and resilience to understand complex engineered systems as well as enabling the next generation of engineering systems capable of exhibiting hallmark features of complex systems (e.g. engineering robustness, fragility, propensity for self-organization) requires new mathematical methods, uncertainty propagation techniques, and clever leveraging of many recent advances and insight from complex systems science. Proposals taking a fundamental and rigorous scientific approach are encouraged.

1.3.2 Morphologically Modulated Motion and Underactuation – This scientific thrust seeks to develop deeper understanding through supporting theory and experiment of the role of embodiment and dynamics on a physical system's capability to process information and transform energy and entropy. Generally, this thrust strongly leverages advances in, and approaches from, sensory biomechanics, neuromechanics, underactuated systems theory, and mechanical locomotion dynamics to understand the motion of both articulated and continuum dynamical systems operating in highly-dynamic environments. The scientific principles sought, however, are not limited to biological movement and manipulation. Proposals are strongly encouraged that view morphology in an abstract sense. For example, understanding morphology as a system's symmetry, its confinement (e.g. chemical reactions), or its coupling topology.

1.3.3 Force Generation, Work and Power in Nonequilibrium Dynamical Systems – This thrust pioneers novel and innovative approaches, grounded in nonequilibrium and dissipative dynamical systems theory, for novel thermodynamic “engines” and new ways of generating forces, producing useful work and power, and transforming information to energy (e.g. Szilard engines) in both artificial and biological systems. Recently, advances in physics have suggested that nontraditional work cycles featuring non-ergodic intermediate steps (where processes cannot relax or are prohibited from reaching equilibrium) can potentially exceed Carnot efficiency bounds. However, more research is needed to explore this novel regime, connect ideas with modern concepts in information dynamics, as well as to perform experiments. Other major interests include enabling novel synthetic emulation capabilities by exploring universal features in biological “prime movers” (e.g. molecular motors, actin, dynein) as well as principles underlying biological force generation, dissipation, and load transfer via the nonlinear dynamics of muscles.

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1.4 Propulsion and Energetics. Propulsion and Energetics Research supports the Army's need for higher performance propulsion systems. Future systems must provide reduced logistics burden (lower fuel/propellant usage) and longer life than today's systems. Fundamental to this area are the extraction of stored chemical energy and the conversion of that energy into useful work for

vehicle and projectile propulsion. In view of the high temperature and pressure environments encountered in these combustion systems, it is important to advance current understanding of fundamental processes as well as to advance the ability to make accurate, detailed measurements for the understanding of the dominant physical processes and the validation of predictive models. Thus, research in this area is characterized by a focus on high pressure, high temperature combustion processes and on the peculiarities of combustion behavior in systems of Army interest.

1.4.1 Engines. Research on combustion phenomena relevant to engines is focused on intermittent reacting flows encountered in diesel combustion chambers and on continuous combustion characteristics of small, gas turbine combustors. Optimizing engine performance, through understanding and control of in-cylinder combustion dynamics, while retaining high power density, is a major objective. This focus leads to a strong emphasis on fuel injection processes, jet break-up, atomization and spray dynamics, ignition, and subsequent heterogeneous flame propagation. Research on heterogeneous flames requires supporting study into kinetic and fluid dynamic models, turbulent flame structure, soot formation and destruction, flame extinction, surface reactions, multiphase heat transfer, and other factors that are critical to an understanding of engine performance and efficiency. An additional consideration is the high pressure/temperature environment encountered in advanced engines, which influences liquid behavior and combustion processes at near-critical and super-critical conditions. Of particular interest are investigations of fundamental characteristics related to highly stressed engines, such as elevated temperature and pressure combustion, accelerated mixing, and transient heat transfer. Engine performance degradation under low temperature conditions due to reduced fuel volatility, high oil viscosity, poor atomization and vaporization, etc., is a major concern. Fundamental research is needed in many areas, including low temperature physical and chemical rate processes, instantaneous friction and wear mechanisms, and combustion instability effects at low temperatures. New characterization methods to investigate kinetics and flame phenomena at high pressure are needed. New computational methods to be able to model complex reacting systems are also needed. With advances in sensing, modeling, and control architectures, it is becoming possible to further optimize the performance of combustion systems. Providing the foundations for such active control is also a major goal of the program.

1.4.2 Propellant Combustion Processes. Research on propellant combustion processes is focused on understanding the dynamics of the planned and inadvertent ignition and subsequent combustion of energetic materials used for propulsion in gun and missile systems and in ordinance. The program is also addressing the characterization of advanced energetic materials, e.g., those based on nanoscale structures and/or ingredients. Basic research is needed in several areas, including: thermal pyrolysis of basic ingredients and solid propellants; flame spreading over unburned surfaces (particularly in narrow channels); surface reaction zone structure of burning propellants; chemical kinetics and burning mechanisms; propellant flame structures; characterization of physical and chemical properties of propellants and their pyrolysis and coupling effects among the ignition, combustion, and mechanical deformation/fracture processes. The use of advanced combustion diagnostic techniques for reaction front measurements, flame structure characterization, and determination of reaction mechanisms is highly encouraged. Especially of interest are novel methods which can well characterize the ignition and burning behavior of a material utilizing only minute quantities of that material. Complementary model

development and numerical solution of these same ignition and combustion processes are also essential. There is also need to understand the unplanned or accidental ignition of energetic materials due to stimuli such as electrostatic discharge, impact, friction, etc. This requires, for example, research on the processes of energy absorption and energy partitioning in the materials, the effect of mechanical damage on the ignition events, and other topics relating to the safety of energetic materials.

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## **b. RESEARCH AREA 2: EARTH SCIENCES**

**2.0 Earth Sciences.** The Earth Sciences Division of the ARO seeks to advance understanding of the terrestrial environment by embracing long-term, high risk, high-payoff opportunities for the US Army with special emphasis on Earth Materials and Processes and Environmental Chemistry. Research supported by the Division seeks to explore the properties of Earth surface materials and environments to discover how they respond to external forces and their interactions with the atmosphere, hydrosphere, and biosphere, especially in the context of chemical species affecting human health and the environment. The work, although basic in nature, is focused on processes occurring at spatial and temporal scales relevant to Army operations and land management. Fundamental research lays the foundation to support a range of Army needs, including the remote characterization of land surfaces, the trafficability of ground vehicles, and environmental needs such as waste management and remediation. Furthermore, there is lasting interest in new ideas and cross-disciplinary concepts in Earth science that may have future applications for the Army.

**2.1 Earth Materials and Processes.** The Earth Materials and Processes program seeks to elucidate the properties of natural and man-made Earth surfaces, with the goals of revealing their histories and governing dynamics and developing theory that describes physical processes responsible for shaping their features.

(i) Earth Surface Materials aims to utilize experiments, models, and theory development to describe the physical and mechanical properties and behaviors of rocks, minerals, and soil, and to exploit the properties of these materials to provide quantitative information on recent and ongoing surface processes and perturbations.

(ii) Surface Energy Balance aims to determine, at Army-relevant spatial and temporal scales, how natural and artificial surfaces (e.g., soil, sand, or concrete) store and conduct energy depending on their spatial relationships, inherent material properties, and imparted features such as moisture storage and evapotranspiration.

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**2.2 Environmental Chemistry.** The Environmental Chemistry program seeks to support the U.S. Army's need to understand chemistry in the environment through high-risk, high-impact basic

research. In particular, the program seeks to broaden and deepen our understanding of anthropogenic chemical transformations, transport, and fates in the troposphere, in soils, and in aqueous media, including single particle and particle-particle interactions with the environment, and to better understand uptake and transformations of anthropogenics by living organisms. Such research will form the foundation to address Army technical needs in chemical warfare agent and toxic industrial compound assessments, remediation of hazardous areas, and access to clean water resources in deployment areas.

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### **c. RESEARCH AREA 3: MATHEMATICAL SCIENCES**

3.0 Mathematics. Mathematical language, theory, and methods pervade research, development, testing, and evaluation encountered by the Army and the academic disciplines in science, engineering, and technology. Furthermore, increased demands are being placed on the mathematical sciences because of its role in building a foundation for emerging sciences and technologies in the information, network, life, decision, and social sciences. Although these problems are often naturally stated in terms of their disciplinary context, their solutions are often dependent on new mathematical results and theories. For example, promising approaches to computer vision for automatic target recognition (ATR) require research in a wide range of mathematics including constructive geometry, numerical methods for stochastic differential equations, Bayesian statistics, probabilistic algorithms, and distributed parallel computation. In the area of modeling and simulation of large-scale systems (systems of systems approach), improvements in model fidelity and capacity depend on the mathematics of optimization, stochastic methods, large scale scientific computing and real time computing for embedded systems. Similarly, advances in robotic and sensor systems depend on mathematics of dynamics, control, communication, logic, cooperation, and complexity. In order to respond to these increasing demands on the mathematical sciences, the ARO supports and advances fundamental research and knowledge that focuses on the needs of the Army. To accomplish this objective, the Division supports extramural basic research in the four areas that follow. The research supported by the Division does not cover all the topics in these areas, but only those areas that are of strategic importance for the Army. The sub disciplinary boundaries within the Division and the disciplinary boundaries in the ARO are not rigidly drawn and there is strong interest in and appreciation for multidisciplinary research in which the mathematical sciences play a major role.

3.1 Modeling of Complex Systems. The Modeling of Complex Systems Program is a program of fundamental mathematics-oriented research, the objectives of which are to develop quantitative models of complex phenomena in two areas in which current models are not fully based on first/basic principles and in which metrics based on first/basic principles are not yet well known. The two areas of interest to the Modeling of Complex Systems Program are 1) geometric and topological modeling and 2) small-group social and sociolinguistic modeling. Complete and consistent mathematical analytical frameworks for the modeling effort are the preferred context for the research, but research that does not take place in such frameworks can be considered if the phenomena are so complex that such frameworks are not feasible. Metrics

are part of the mathematical framework and are of great interest. Traditional metrics, when they exist, often do not measure the characteristics in which observers in general and the Army in particular are interested. For many complex phenomena, new metrics need to be developed at the same time as new models. Just as is the case for the modeling effort, these metrics should preferably be in a complete mathematical analytical framework. The research in modeling of and metrics for complex phenomena supported by the Modeling of Complex Systems Program is mainly mathematical analysis (not computational mathematics).

The two major areas of research of the Modeling of Complex Systems Program are:

3.1.1 Geometric and Topological Modeling. Representation of complex, irregular geometric objects and of complicated, often high-dimensional abstract phenomena and functions is fundamental for Army, DoD and civilian needs in modeling of urban and natural terrain, geophysical features, biological objects (including humans and their clothing), information flow and many other objects and functions. Real-time representation and visualization of 3D terrain (not just as a height field but with multivalent height functions and non-genus-0 topology) directly from real-time or stored point-cloud data cannot be achieved with current techniques. A key to achieving this goal is data compression at ratios and with accuracy that strongly exceed what is currently available. A multitude of variants of piecewise planar surfaces (including those on triangulated irregular networks or “TINs” and triangular mesh surfaces or “TMSs”), splines, multiquadrics, kriging, wavelets, neural nets and many other techniques developed in the past perform well on many types of data. However, none of these procedures are able to provide, without human intervention, representation of irregular objects and functions with the accuracy and compression that is needed. New approximation theory that does not require the assumptions (primarily smoothness) of classical approximation theory and that provides structure for the many new non-smooth approximation techniques currently under investigation is required. Research on the metrics in which approximation should take place is needed. Approximation theory for information flow and other abstract phenomena in large wireless communication, sensor and social networks is of interest. The approximation theory developed under support of this program is expected to provide building blocks for computational geometry, pattern recognition, automatic target recognition, visualization systems, information processing and network information flow.

3.1.2 Small-group Social and Sociolinguistic Modeling. Quantitative, analytical models of small social groups and of sociolinguistic phenomena are required for operations, training, simulation (computer generated forces) and mission planning. Current models have limited accuracy. Research focused on mathematically justified, practically useful, computationally tractable and data-tractable models is needed. (“Data-tractable” means “does not require more data or more detailed data than is realistically likely to be available.”). Research on the metrics in which the accuracy of the models should be measured is needed. The existence of links, the frequency of message exchanges, the format of communication, etc. are all valuable but limited sources of information about social structure and phenomena. These sources need to be complemented by sociolinguistic analysis of the content of messages. However, real sociolinguistic content (as distinguished from the purely linguistic content) cannot yet be sensed automatically. Figurative speech, irony, copying (including paraphrasing), fabrication, manipulation and deception are

widespread and need to be taken into account. This area of investigation is distinct from language translation and computational linguistics.

“Metrics” (distance functions in generalized sense, not in the classical mathematical sense) derived from human-based goals are a cross-cutting theme in this research. New metrics should be derived from the fundamental principles that are at the core of the human activities being investigated and should not simply be chosen or imposed on the model.

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3.2 Probability and Statistics. The Probability and Statistics program supports extramural basic research in stochastic analysis and control, and statistical analysis and methods in response to the Army's need for real-time decision making under uncertainty and for the test and evaluation of systems in development. Special emphasis is placed on methods for analyzing data obtained from phenomena modeled by such processes. The two major areas of research are described below.

3.2.1 Stochastic Analysis and Control. Many Army research and development programs place emphases on modeling, analysis, and control of stochastic dynamical systems. Such problems generate a need for research in stochastic processes, random fields, and/or stochastic differential equations in finite or infinite dimensions. The research concentration areas in stochastic analysis and control thrust include but are not limited to the following:

- a. Stochastic Partial Differential Equations. Research on analytical and approximation methods for solving stochastic delay and stochastic partial differential equations and their related nonlinear filtering and control problems is one of the program objectives. The Hamilton-Jacobi-Bellman theory via dynamical programming principle and/or necessary optimality conditions in terms of maximum principles have yet to be developed for optimal control of these infinite dimensional equations. Modeling of rare event analysis of spatial-temporal random phenomenon requires a fundamental mathematical understanding of the theory of large deviations for infinite-dimensional stochastic dynamical systems, in particular stochastic partial differential equations driven by Brownian and/or Poisson space time noises.
- b. Measure-Valued Stochastic Processes. An emerging and mathematically challenging area is the study of measure-valued process models of stochastic networks. One of the goals of this program is to develop general tools for the study of these processes, and their application to gain insight into the performance analysis, stability, control and design of this class of network models.
- c. Weakly Interacting Stochastic Systems and Mean-Fields Control and Game Theory: Many physical and engineering systems can be modeled as a large collection of stochastically evolving agents or particles, whose dynamics are weakly coupled by an interaction that depends only on the empirical measure or distribution of the particles. The design and control of these systems give rise to many mathematically challenging

questions. Among the many areas where progress is needed, the most important include the development of a general methodology to understand the long-time behavior of the solution to the limit measure-valued stochastic equation, and a related analysis into the implications of the long-time behavior of the limit for the stability or metastability of the stochastic N- particle system. Also of interest are issues of mean-field stochastic control, and game theory, and in particular the design of stochastic controls via Lyapunov function techniques and the interplay between ergodicity and controllability in the stabilization of the stochastic system

- d. Quantum Stochastics and Quantum Control. With technological advances now allowing the possibility of continuous monitoring and rapid manipulations of system at quantum level, there is an increasing awareness of the applications and importance of quantum filtering and quantum control in engineering of quantum states, quantum error correction, quantum information, and quantum computation. To further understand the back action effects of measurements on quantum states and control of the system based on these measurements, mathematical development of non-commutative quantum stochastic calculus, quantum filtering and quantum control theory is necessary. Proposed mathematical research of this nature that has potential applications in quantum information and quantum computation is hereby solicited.
- e. Other Areas that Require Stochastic Analytical Tools. Other research areas of importance to the Army in stochastic analysis and applied probability include stochastic fluid dynamics and turbulence.

3.2.2 Statistical Analysis and Methods. The following research areas are of interest to the Army and are important in providing solutions to Army problems:

- a. Statistical Testing and Validation of Network Models. The structure (network design), data sets and human element have a major impact on soldier performance. The need exists to develop new statistical techniques and theories to support the selection of optimal designs, validate predictive network models and modify data mining and inferential statistical techniques to use on ill-defined data and improve measurement. The research concentration areas include dynamical inference of structure in underlying models. In particular, ability to measure reaction of particular features buried in the network and not directly observable, and sequential analysis (changepoint detection) in networks.
- b. Reliability and Survivability. To support future network-centric operations, the Army needs novel and efficient statistical tools for improving network reliability and survivability, and for analyzing data collected from sensor networks.
- c. Statistical Theory and Techniques for Real Time Analysis of Data Stream. The Army has pressing research needs in the area of streaming data. Especially, sampling theory methodology or the consideration of data epochs with meta-analysis relating findings across epochs may reduce the need to retain the entire stream of information. However, Army analysts frequently have very large or very small data sets sampled

from nonstandard, poorly understood distributions. The two situations lead to very different statistical problems. Large data sets may occur in a stream, that is, they may be produced quickly and continually, so that new data compression methods are required to extract and update the relevant information for the decision-maker. On the other hand, in many testing situations, only small amounts of data are available due to cost, time, and safety constraints. The problems to be studied are sometimes vaguely formulated and appropriate models are not developed before acquiring the data. Close collaboration with scientists who work in the field of applications is required to develop new methodologies for addressing the problem of extracting information from meager samples. To extract more information from less data, improved methods for combining information from disparate tests may be needed.

- d. Bayesian and Non-parametric Statistics. Future emphasis in statistics on "predictive" models vice explanatory models is important. Military operations call for predictive models based on a growing base of sensor-fueled data stores. Increased computational capability is also leading statistics in a new direction, away from using "classical" results which are really approximations to avoid computational issues. This suggests a need for increased emphasis on research in areas such as robust statistics, non-parametric statistics, non-linear models etc.
- e. Statistical Analysis of Very Large and Very Small Data Sets. The state-of-the-art in statistical methods is well adapted to elicit information from medium-size data sets collected under reasonable conditions from moderately well-understood statistical distributions. However, Army analysts frequently have very large or very small data sets sampled from nonstandard, poorly understood distributions. Very often the data available does not measure the variable of interest and gives only indirect information. Thus the variable of interest is sampled in some ill-defined fashion. One needs to look at this problem in some generality and develop new theory to handle such problems with ill-defined data.
- f. Geometric Methods for Statistical Inference. ARO seeks unifying mathematical frameworks to capture the space of statistical models for inference and learning purposes. Models using differential geometric insights (such as Information Geometry) to characterize the manifold of probability density functions, to conceptualize measure-valued stochastic processes as paths on such manifold, and to understand the metric of model comparison and selection are welcome.

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3.3 Biomathematics. Biomathematics is an exciting and important new area of activity for ARO. The introduction of biomathematics as a separate area of basic research recognizes the importance and specialized nature of quantitative methods, specifically mechanistic modeling, in the biological sciences. Biology involves a large number of entities that interact with each other and their environment in complex ways and at multiple scales. This complexity makes biomathematics a highly interdisciplinary field that requires unique and highly specialized



mathematical competencies to quantify structure in these relationships. In fact, progress in mathematical models of biological systems has traditionally been achieved by making convenient simplifications; major advances in biomathematics research continue to require removing these assumptions (for example, stationarity, ergodicity and deterministic nature) and finding ways to effectively model the real complexity.

Modeling techniques currently utilized in the field range from agent-based approaches for determining the results of individual behavior, whether those individuals be molecules, zooplankton, or humans, to multi-compartmental modeling in physiology, epidemiology and neurobiology, to network models involved in understanding ecosystem and human social dynamics. Research in control techniques is also valuable for its potential application in militarily important areas such as biowarfare and disease spread. Exciting new opportunities to advance the field are found in high risk attempts to develop modeling techniques in areas of mathematics not traditionally brought to bear on biological problems, advances in Bayesian statistics, a growing recognition that the diffusion approximation is not necessarily adequate for many systems, and the availability of large amounts of complex biological data.

The ultimate goal of the Biomathematics Program focuses on adapting existing mathematics and creating new mathematical techniques to uncover fundamental relationships in biology, spanning different biological systems as well as multiple spatial and temporal scales. One area of special interest to the Program is neuromathematics, the mechanistic mathematical modeling of neural processes. Recent advances in neuroscience provide important foundations to begin understanding how the brain works. Combined with experimental data, innovative mathematical modeling provides an unparalleled opportunity to gain a revolutionary new understanding of brain physiology, cognition (including sensory processing, attention, decision-making, etc.), and neurological disease. With this new understanding, improved soldier performance, as well as treatments for Post-Traumatic Stress Disorder, Traumatic Brain Injury, and other brain-related disorders suffered by the warfighter will be able to be achieved more effectively and efficiently.

Thrust areas of the Biomathematics Program are as follows:

3.3.1 Fundamental Laws of Biology. The field of physics has long been “mathematized” so that fundamental principles such as Newton’s Laws are not considered the application of mathematics to physics but physics itself. The field of biology is far behind physics in this respect; a similar process of mathematization is a basic and high-risk goal of the ARO Biomathematics Program. The identification and mathematical formulation of the fundamental principles of biological structure, function, and development applying across systems and scales will not only revolutionize the field of biology but will motivate the creation of new mathematics that will contribute in as-yet-unforeseen ways to biology and the field of mathematics itself.

3.3.2 Multiscale Modeling/Inverse Problems. Biological systems function through diversity, with large scale function emerging from the collective behavior of smaller scale heterogeneous elements. This “forward” problem includes creating mechanistic mathematical models at different biological scales and synchronizing their connections from one level of organization to another, as well as an important subproblem, how to represent the heterogeneity of individual elements and how much heterogeneity to include in the model. For example, the currently

increasing ability to generate large volumes of molecular data provides a significant opportunity for biomathematical modelers to develop advanced analytical procedures to elucidate the fundamental principles by which genes, proteins, cells, etc. are integrated and function as systems through the use of innovative mathematical and statistical techniques. The task is complicated by the fact that data collection methods are noisy, many biological mechanisms are not well understood, and, somewhat ironically, large volumes of data tend to obscure meaningful relationships. However, traditionally “pure” mathematical methods such as differential geometry, algebra and topology, integration of Bayesian statistical methods with mathematical methods, and the new field of topological data analysis, among others, show promise in approaching these problems. Solutions to these types of multiscale problems will elucidate the connection, for example, of stem cells to tissue and organ development or of disease processes within the human body to the behavior of epidemics.

The “inverse” problem is just as important as the forward problem. From an understanding of the overall behavior of a system, is it possible to determine something of the nature of the individual elements? For example, from knowledge of cell signaling, can we go back and retrieve information about the cell? Although inverse problems have been studied for a long time, significant progress has been elusive. This thrust area involves innovations in spatial and/or temporal modeling of multi-level biological elements with the goal of achieving a deeper understanding of biological systems and eventually connecting top-down (data-driven) and bottom-up (model-based) approaches.

3.3.3 Modeling at Intermediate Timescales. Biological processes operate at a variety of timescales; understanding the dynamics of a system at intermediate timescales, as opposed to its long term, asymptotic behavior, is critically important in biology, more so than in many other fields. For example, an epidemic is a necessarily transient phenomenon. In addition, deterministic models are an approximation that often is not good enough to be informative about the system. Yet, intermediate timescales of nonlinear dynamics with stochasticity, both internal and external, are not well understood. This thrust area attempts to fill the gap in the basic understanding of modeling of systems, as well as their control, at intermediate timescales.

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3.4 Computational Mathematics. Scientific computation is an essential component of scientific inquiry, complementing theory and experiment, and is also an essential element of engineering in both design and in failure autopsy. Simulations in support of inquiry, design, or autopsy often require expert knowledge in order to select methods that are appropriate to the assumptions of the scenario at hand, require considerable effort to set up, require considerable computer time and memory on large scale parallel/distributed/heterogeneous systems to compute, and require considerable skill and effort to distill useful information from the massive data sets which result. Expert knowledge is also required to quantitatively estimate solution accuracy and to estimate the effort required to achieve a desired accuracy. Data has become ubiquitous and is potentially very valuable in increasing solution accuracy and/or decreasing effort required to solve, but mathematically sound methods for incorporating data into accurate simulations are incomplete. Simulations are not always timely, with results often not being available until after they are

needed, for example in calculating failure of New Orleans levees during Katrina and in revising those estimates based on real time surge data. The emphasis in the Computational Mathematics program is on mathematical research directed towards overcoming these and related shortcomings.

3.4.1 For problems that are not time-limited, research areas of interest include but are not limited to the following:

1. Advances in Numerical Analysis. Novel methodologies are sought for solving currently intractable problems. New ways of taking advantage of symmetry, conservation, and recurrence are of interest, as are new ways of creating sparsity and new computational structures which can adapt to both the evolving solution and to the evolving run-time resource allocation of modern computer architectures. Rigorous analysis sought for each in order to enable error bounds, error distribution, and error control.
2. Multi-scale methods. Problems of interest to the Army are increasingly characterized by the fact that behavior at microscopic scales has a large influence on performance of systems. To analyze these situations, algorithms are needed to deal with different mathematical models at different scales, interacting subsystems, and coupling between models and scales. The emphasis of this program is on mathematical methods which have some promise of universal application rather than methods applicable only to specific application areas.
3. Fractional order methods. As an alternative to high order methods and other less-local operators, fractional operators are another nonlocal operator that have proven to work well in modeling and have the advantage of not enforcing dubious assumptions of smoothness, especially at discontinuities and interfaces. However, the nonlocality of fractional operators also typically introduces a potentially significant increase in computational load. Advances in novel efficient computational methods for these operators are of interest.

3.4.2 Army systems often operate under rapidly-changing unpredictable and adverse conditions. It is desirable for models to be computationally simulated and fast enough to drive decision making, exercise control, and to help avoid disaster. Such simulations need to be created, run, and interpreted in better than real time. Research directed towards making this goal achievable is of interest, such as:

1. Reduced Order Models. Full scale simulations are often not realized in real time. In order to investigate the behavior of systems under a variety of possible scenarios, many runs are required. Reduced order models are one major way to enable this. Possible methods to create these models include adaptive simplification methods based on singular value decompositions and reduced order numerics. To be useful, all such models should be equipped with reliable estimates of accuracy.

2. Problem Solving Environments. New approaches which enable rapid decision making is to be driven by simulation, it is necessary to set up simulations very quickly and obtain results in an understandable format. Matlab is one current tool for such a problem solving environment. Are there other approaches?

3. Embedded Simulation. As algorithms become more efficient and computational devices shrink, it will become increasingly possible to use real-time simulation to drive control systems. New methods which address this goal are welcome, especially those which permit user-controlled and/or adaptively-controlled tradeoffs between speed and accuracy.

4. Decision Making. One valid criticism of numerical simulation is that it takes so long to set up, run, and post-process the results that they cannot be used in a timely manner to guide decision making. Mathematical ideas that can help address this problem are of interest.

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#### **d. RESEARCH AREA 4: ELECTRONICS**

4.0 Electronics. Electronic components are recognized as key force multipliers in today's Army and will remain so for the foreseeable future. The Electronics Division seeks to support scientific and engineering endeavors in research areas that possess the potential to define new electronic capabilities or to enhance future electronic performance. The Division is more concerned with generating basic knowledge about processes and mechanisms than creating actual devices, although prototype devices may be useful for demonstration of principle. The Electronic research sub-areas are (1) Nano and Bio- Electronics, (2) Optoelectronics, (3) Electronic Sensing, and (4) Electromagnetics and Circuit Integration. Proposals are sought that advance fundamental understanding of electronic and photonic processes leading to new or improved materials and devices with a strong prospect for use in future Army technology.

4.1 Nano- and Bio-Electronics. This research area emphasizes efforts to discover and create unique phenomena at the nanoscale by use of nanoscience, bioscience, and the combination thereof in an effort to provide novel electronic technological capabilities for defense-related applications such as sensing, data acquisition, information processing, communications, target recognition, and surveillance.

To establish the needed science base for future Army battle-space capabilities, innovative research is sought in areas involving mesoscopic quantum phenomena, internally and externally induced stimulus, and novel transport and electromagnetic interaction effects in nano-scale electronic structures. This fundamental research will address issues related to design, modeling, fabrication, testing and characterization to include the ability to individually address, control, and modify structures, materials and devices, and the assembly of such structures into systems of nano- and microscopic dimensions. This research will seek to discover and develop novel electronic materials, advance processing and fabrication science, and identify advanced device concepts with revolutionary capabilities. Scientific opportunities in this research include, but are

not limited to, quantum-confined structures (nano-tubes/-wires/-dots) and large-scale precise alignment and integration of these structures to create collective interactions; mesoscopic transport phenomena in 2-dimensional atomic crystals and their heterostructures; spintronic, valleytronic, and mixed domain (charge/spin/quantum) device concepts based on topological insulator and other emerging nanomaterials; heterogeneous integration of different nanostructures into complex functional nanosystems; novel nanostructures/systems for efficient generation, transmission, and detection of electromagnetic radiation, especially those covering the THz spectral range.

The bio-electronics sub-area is concerned with investigation of nanoscale electronic phenomena and processes in biological environment. The goals of this sub-area are to: 1) Develop new mechanisms to interface with and manipulate molecular and biological systems; 2) Explore biomimetic approaches to new electronic circuit functionality based on the detailed understanding of biological electrical and magnetic phenomena. Multi-disciplinary approaches linking nanoelectronics and neurology, synthetic biology, genetics, biomimetics, etc., are highly desirable and encouraged. Scientific opportunities in this research include, but are not limited to, bio-compatible nanomaterials for biotic-abiotic interface such as that between neurons and electronics materials; imaging, interrogation, and control of biomacromolecules, biological cells, neurons, and other bio-nanostructures utilizing electromagnetic wave spanning DC to THz, and optical frequencies; nanomaterial/structure platforms for artificial synthetic neuronal growth and bio-hybrid neural circuits incorporating both networks of synthetic neurons and non-biological nanoelectronic structures/components; neuromorphic and biomimetic nanodevices/systems which exploit intrinsic material or structure physical limitations such as variability and stochasticity to create unprecedented capabilities; synthesis and fabrication of hybrid bio-nanostructures utilizing DNA origami self-assembly or other xenobiotic functional nano-scaffolds. Bio-inspired sensors and transducers based on semiconductor, hybrid molecular-semiconductor, and other hybrid organic-inorganic nanomaterial combinations are also included in this sub-area.

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4.2 Optoelectronics. Research in this subarea includes novel semiconductor structures, processing techniques, and integrated optical components. The generation, guidance and control of UV through infrared signals in semiconductor, dielectric, and metallic materials are of interest. The Army has semiconductor laser research opportunities based on low dimensional semiconductor structures (quantum dots, wells, wires, etc.) operating in the eye-safe ( $>1.55$ ), 3-5, 8-12, and 18-24 microns regions for various applications, such as ladar, IR countermeasures, and free space/integrated data links. Components and sources in the UV/visible spectral ranges (particularly  $< 300$  nm) may be of interest as well. Research is necessary in semiconductor materials growth and device processing to improve the efficiency and reliability of the output of devices at these wavelengths.

High performance devices and components will be optimized for applications including high data-rate optical networks. Interfacing of optoelectronic devices with electronic processors will be investigated for full utilization of available bandwidth. Electro-optic components will be

studied for use in guided wave data links for interconnections and optoelectronic integration, all requirements for high speed full situational awareness. Optical interconnect components are needed in guided-wave data links for computer interconnection and in free-space links for optical switching and processing. For high-speed optical signal processing as well as potential for power scaling, research on individual and 1 or 2-D arrays of surface or edge-emitting lasers is necessary. Research addressing efficient, novel optical components for high speed switching based on plasmonics, quantum dots, metamaterials or other regimes may be of interest. Emitters and architectures for novel display and processing of battlefield imagery are important.

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4.3 Electronic Sensing. The ultimate goal of Army sensing is 100% situational awareness to include day/night, all weather, non-line-of-sight and through natural and man-made obstructions for sensing of vehicles, personnel, weapons, chemical and biological threats, projectiles, explosives, landmines, IEDs, and motion. Sensing technologies of interest to this research sub-area currently include acoustic; seismic; passive electromagnetic; magnetic, hyperspectral, and infrared. Novel techniques that enhance the stimulus-response characteristics of nano-structures and semiconductor devices are of interest. Other innovative sensors that meet an Army need are also welcome, however chemical, biological, and radar sensing techniques are generally funded through other sub-areas as is image processing.

Novel infrared or multispectral detectors and structures are of particular interest. Efforts are sought that raise the operating temperature and reduce the cost of “cooled” high performance infrared detectors, as well as, efforts that increase performance of “uncooled” infrared detectors. Research opportunities include components based on quantum confined devices and semiconductor materials operating in the infrared 1-24 microns regions. Also of interest is the ultra-violet spectral region. In both regions, fundamental studies involving growth, defects, interfaces, substrates, doping, and other electronic characteristics will be considered.

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4.4 Electromagnetics and Circuit Integration. This area concerns the exploration of new concepts for circuit integration for greater functionality, smaller size/weight, lower power consumption, enhanced performance, with focus in the frequency regime from low to terahertz frequencies. It also involves investigation of electromagnetic (EM) and acoustic phenomena for integrated antenna arrays, multifunctional antennas, EM power distribution, and new sensing modalities.

This area will address the basic science behind new approaches to the generation, transmission, and reception of EM power and signals. Emphasis will be placed on the HF through terahertz spectrum, however, novel ideas at lower frequencies down to direct current may be addressed. RF circuit integration offers orders of magnitude improvements in systems performance, cost, weight, reliability, size characteristics, and functionality. Issues include the coupling of EM radiation into and out of complex structures, antennas, both active and passive, transmission lines

and feed networks, power combining techniques, EM wave analyses of electrical components, and EM modeling techniques. The solution to thermal problems stemming from the concentration of higher and higher power into smaller and smaller volumes will be addressed. Antenna research must break away from the methodologies that were developed for continuous-wave, narrowband, steady-state operation to invent new design techniques, architectures, and materials that can dramatically increase the radiation efficiency and bandwidth of tactical antennas while simultaneously reducing their size and signature. The EM and acoustic detection and analysis of underground targets, landmines, and IED's is of interest. Unusual propagation effects in the atmosphere and gaseous plasmas offer new opportunities for sensing and detection. Army applications of this technology include communications (both tactical and strategic), command and control, reconnaissance, surveillance, target acquisition, and weapons guidance and control.

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#### **e. RESEARCH AREA 5: COMPUTING SCIENCE**

5.0 Computing Science. The principal objective of the ARO Computing Science Division is to provide increased performance and capability for processing signals and data, and to extract critical information and actionable intelligence to enhance the warfighters' situation awareness, decision making, command and control, and weapons systems performance. The division supports research efforts to advance the Army and nation's knowledge and understanding of the fundamental knowledge, principles, and techniques governing intelligent and trusted computing. More specifically, the division aims to promote basic research studies to establish new computing architectures and models for intelligent computing, to create novel data fusion and extraction techniques for efficient information processing, and to build resilient computing systems for mission assurance. The results of these research efforts will stimulate future studies and help to keep the U.S. at the forefront of research in the computing sciences. The research topics described in this section of the BAA are those needed to provide the warfighters with the latest information science technology needed to achieve the vision of future Army operations.

5.1 Computational Architectures and Visualization. The Computational Architectures and Visualization program is concerned with modeling, analysis, design, and validation of computational infrastructure (hardware and software) with special emphasis on the effect emerging and future computational architectures will have on managing, processing, analyzing, and visualizing massive data sets. This is due to the fact that the Army's ability to generate data of all types from the battlefield to the laboratory far outpaces the Army's ability to efficiently manage, process, analyze, and visualize such massive amounts of information. Emerging architectures only exacerbate the problem because the present and traditional models of computation no longer apply. Specific areas of interest can be found in the following two paragraphs.

5.1.1 Computational Architectures. Future computer systems will be both massively heterogeneous and parallel implying the present and traditional models of computation will no longer be applicable. As a result, this thrust supports the development of new computational

theories, mathematical abstractions, and models of computation needed to address the difficulties associated with heterogeneous, parallel and distributed processing. Of special interest is determining how these new abstractions, algorithms, and computational processes map onto emerging computational resources of different types (e.g., multi-core, quantum, cloud, and chaotic computing, and determining which platforms are most suitable for Army applications). Other important issues to be considered for these emerging and future architectures are programmability, language and compiler support, real-time scheduling, resource-allocation and the development of a flexible software environment.

5.1.2 Visualization. The visualization thrust of this program is concerned with all aspects of visualization and computer simulation of interest to the Army and is not limited to any one type of data or computer model. Specific research areas of interest are, but not limited to, discrete mathematics, computational geometry, robust geometric computing, graph theory, geometric and solid modeling, interactive graphics, 3D visualization tools, verification & validation, and synthetic environments. Special emphasis is placed on making very large simulations and the visualization of massive data sets faster, more computationally efficient, and more interactive for the user while maintaining an appropriate level of fidelity and physical realism.

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5.2 Information Processing & Fusion. With ubiquitous data acquisition capabilities, effective data and information processing is of increasingly critical importance to defense missions. The Information Processing and Fusion program is concerned with the creation of innovative theories and algorithms for data modeling, data processing, information extraction, and information integration to support the development of real-time decision-making and advanced targeting capabilities for military operations. Emphasis is placed on mathematical theories, methodologies and algorithms for image processing, image understanding, video-based tracking, and data/information fusion. The program consists of four thrust areas as described below.

5.2.1 Foundations of Image and Multimodal Data Analysis. Remote sensing, whether in the visible, infrared or other spectra, presents unique challenges due to a number of operation factors such as clutter, illumination, and occlusion. Innovative research is sought concerning (1) task-oriented representations of multimodal data to enable the understanding of multimodal sensor data and contextual information; (2) detection, localization, and recognition of objects and locations from imaging data with particular emphasis on provable performance guarantees; (3) detection of events, actions, and activities to extract activity-based intelligence, especially when the events are rare and no extensive training data is available; and (4) integrated approaches that enable semantic descriptions of objects and events including relations. Learning and adaptation should be enabled in the representation at both low and high-levels, where inputs from actual users of the systems are used to improve the performance of the algorithms and the fidelity of models at all levels of the modeling hierarchy. Also of interest are methods to exploit the structure of the data and capture its intrinsic dimensionality. The development of an “information/complexity theory” and a “learning theory” specific for remote sensing, imaging data and decision tasks is highly desirable.



5.2.2 Data and Information Fusion. Multimodal data acquisition systems are increasingly prevalent with disparate sensors and other information sources. This thrust seeks advanced mathematical theories and approaches for integrating multimodal data and contextual information to provide actionable intelligence. Of particular interest are systematic and unifying approaches for data and information fusion from diverse sources. Scalable methods are needed for efficiently handling vast amounts of data. Fusion in networked environments addressing issues such as adaptive, distributed and cooperative fusion is emphasized. Theories and principles for performance analysis and guarantees at all fusion levels to support robust data and information fusion are important to ensuring successful military operations.

5.2.3 Active and Collaborative Sensing. Modern sensing systems typically include multiple networked sensors with communication capabilities where the whole network can be thought of as a sensor that can be controlled, in addition to each individual node having some controllable degrees of freedom such as mobility for unmanned aerial/ground systems, pan-tilt-zoom for infrastructure sensors, or waveform for agile radar. Depending on the task or query, it is desirable for the system to control the data acquisition process so as to acquire the “most informative data” for the specific task or query. Consequently, research is solicited to address the integration of mobility, sensor-selection, modality selection, and active observation for real-time assessment and improvements of sensing performance. Another research area of interest is performance-driven active data collection. A query is given to the system together with a desired performance bound. Where the confidence in answering the query is insufficient, the system should actively interrogate or control sensors so as to achieve the desired confidence. Such an active learning and information-driven sensor control must include the soldier in the feedback loop.

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5.3 Information and Software Assurance. From the Army perspective, Information Assurance must provide authentic, accurate, secure, reliable, timely information to warfighters in order to achieve information dominance, regardless of threat conditions. Computing and information processes may be carried out over distributed and heterogeneous systems, which may include mobile computing and communications systems, and high performance information process systems that are inter-connected through both tactical and strategic communication systems.

5.3.1 Supporting Army Tactical Mission. Research is needed in the areas of protocols and techniques that would assure delivery of trustworthy data to support battlefield missions. Reconfigurable, survivable, and self-healing systems allow a combat unit to dynamically establish and maintain its command and communication capability under diversified and extreme battlefield situations. The Army requires a fully mobile, fully-communicating, agile, and situation-aware force that operates in a highly dynamic, network centric environment. This force consists of a heterogeneous mixture of individual soldiers, ground vehicles, airborne platforms, unmanned aerial vehicles, robotics, and unattended sensor networks that operate in a complex wireless environment. Information theory has played a founding role in the study of security. Across a wide range of application domains and security objectives, information theory leads to insight to the underlying tradeoffs between security and performance. The Army seeks novel

ideas in fundamental research areas such as information-theoretic security and the science of security that will provide direct guidance in the design of secure tactical wireless systems. In particular, topics of interest include new paradigms for physical layer security (ranging from confidentiality to authentication to trustworthiness in physical layer communications), the fundamental bounds in key management in distributed systems, and the exploitation of key establishment and distribution protocols. The corresponding constructions that would arise from such an investigation represent a significant avenue for improving future wireless systems as well as the corresponding secrecy capacity limits that could be obtained from such an investigation serve as valuable guidelines in developing future wireless systems with confidential and authenticated communications. New computing and communication protocols and techniques are needed to assure critical information processing and delivery even when such systems are under severe resource constraints.

5.3.2 Foundations for next generation survivable systems. The field of information assurance needs a foundational science to guide the design of systems and to quantitatively measure safety and the level of assurance of complex systems that we depend upon today. Assurance principles and metrics are needed to help define, develop, and evaluate future robust and resilient systems and network architectures that would survive sophisticated attacks and intrusions with measurable confidence. We seek the capability to measure a complex system and to produce a scalar value that can determine the trustworthiness of that system. In addition, human users need to be in the loop for system assurance analysis. Developing human centric security-usability metrics, computational models for usable security in stressful situations, and adaptive security protocols according to perceived threats are some of the research areas of interest in improving warfighter performance while maintaining sufficient security requirements. One new challenging area of research that offers great promise in stronger system robustness is the modeling of adversaries, since ultimately systems need to defend effectively against their attacks. A deeper understanding and more accurate modeling of adversarial behaviors lead to better future system development.

5.3.3 Trusted social computing. Cheaper but more powerful computing devices and ubiquitous wireless communication have profoundly changed our way of life, and transformed computing from being data processing centric in the past to being human centric now. Though social computing applications have grown rapidly, understandings on trust and assurance principles for social computing remain very limited, with no quantitative models for reliable trust determination and validation. A need exists to gain an understanding on the impact of social dynamics on trust, to explore and analyze the representation of human interaction via social protocols and collaboration patterns in social networks via parameters informed by social sciences and economics, to establish trust theories and a framework for human centric computing, to build metrics and quantitative models for determining levels of trust and implications of such trust values, and to develop new techniques for trust management and automated trust determination for multi-dimensional social computing. Social networking and social media have created an enormous amount of data (text, image and video) that contains a tremendous amount of information that can be exploited for various applications such as situational awareness and intelligence gathering. A need exists for reliable, trustworthy models and analytical tools that can be used to guide the development of new methodologies for social-

media-based data sensing and processing, given that social media data can easily be forged, manipulated or fabricated.

5.3.4 Principles of Moving Target Defense. Current cyber defenses are often static and governed by lengthy processes, while adversaries can plan their attacks carefully over time and launch the attacks at cyber speeds at times of their choosing. We seek a new class of defensive strategies to present adversaries with a moving target where the attack surface of a system keeps changing. Although such an idea of a “moving target” is a powerful paradigm for building systems robust to security threats, many fundamental aspects associated with such a strategy need to be further investigated and understood. For example, such a “moving target” system may operate under many different contexts, ranging from the use of frequency hopping in spread spectrum to software diversification. It is critical to establish new theories and models that can provide trade-off analysis between system robustness against attacks vs. performance/usability, and quantify the risks associated with system adaptation under an adversarial setting. Ultimately the understandings and analytical models obtained will establish an important foundation for creating robust tactical systems capable of maximizing the difficulties for the adversaries to attack while minimizing the impact to system performance and usability.

5.3.5 Hardware Assurance. Assuming the trustworthiness of underlying hardware, current information systems typically implement security services in software that provide authenticity, integrity and confidentiality of information; however this assumption is increasingly being challenged, given the current globalized, horizontal semiconductor business model. Malicious insertion of Trojan circuits designed (e.g., to act as ‘kill switches’), extraction of sensitive IP from an IC using hardware-based side channels, and malicious system disruption and diversion using backdoors in hardware are all real and serious threats to information and cyber-physical infra-structure. In contrast to software assurance, where security risks and vulnerabilities are better studied and understood, understandings on hardware assurance are limited. New hardware analysis models and methodologies are needed to carry out correctness verification and to detect malicious logic insertion that could happen either in hardware design specification or during chip fabrication. Emergent properties of silicon chips such as Physically Unclonable Functions (PUFs) provide a promising mechanism for IC identification, authentication and potential on-chip key generation. Novel techniques are also sought that can minimize side channel information leakage from the IC and help establish tamper proof to eliminate physical access to the chip/system from an unauthorized user.

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5.4 Social Informatics. Technologically enabled social interaction has had explosive growth over the past several years. Social media in general and the Internet in particular facilitate social interaction and information exchange at high levels that were previously not available. They have created and continue to create an enormous amount of data (text, image and video) and information that can be exploited for various applications, such as situational awareness and intelligence gathering. Traditional models and analytical tools for physical phenomena often do not work for social phenomena. One salient difference is in trust. It is normally assumed that information about physical phenomena can be trusted (perhaps with limitations). However, one can never fully trust the information from technologically based social media since they can

easily be and are commonly known to be widely forged, manipulated or fabricated. There is a lack of fundamental understanding of how to collect, model and analyze information obtained from social media in a robust and trustworthy way.

The Social Informatics Program is a program of fundamental research the objectives of which are to quantify technology-based social interaction phenomena, to develop metrics for the quantified phenomena and to develop forensic and predictive analytical and computational models based on these quantifications and metrics. The objects of interest will generally be social phenomena (social groups/structure) and socio-cognitive phenomena (human intentions in a social context). The quantification and metrics of interest to this program are those based on domain-scientific principles of social and socio-cognitive science that are at the same time mathematically consistent and computationally feasible.

The research of interest to the Social Informatics Program includes quantified, analysis-based research about technology-based social interaction phenomena in the following two areas:

5.4.1 Quantification and Metrics. Extraction of information from social media requires research in quantification of and metrics for these phenomena. The metrics by which one measures distance between phenomena will likely be nontraditional. Here, the word “metric” means simply a general distance measure, not a “metric” in the classical mathematical meaning of the word. In particular, a metric need not fulfill the triangle inequality, an inequality that does not seem to correspond to many social or socio-cognitive phenomena, and need not be symmetric, that is, the distance from y to x may be different from the distance from x to y. Traditional metrics, when they exist, often do not meaningfully measure the social or socio-cognitive phenomena in which observers in general and the Army in particular are interested. All metrics should be computationally feasible, mathematically justified and based on known or hypothesized sociological or socio-cognitive principles. Ad hoc or purely heuristic metrics are insufficient. The metrics need to be derived, not assumed or assigned. Quantification and metrics need to extend to reliability and accuracy, since falsification and deception are often present at the level of the input into the social medium by a human being. Processing of soft information such as text and voice has been extensively investigated, but insufficiently in the social context which often determines meaning and which can resolve ambiguities.

5.4.2 Analytical and Computational Models. Of interest are analytical and computational models for both forensic and predictive purposes. These models complement the qualitative models of much of sociological research, especially those in the less-investigated area of weak-tie sociology that is important for technology-based social interaction. The models are dependent on the quantification and metrics discussed in the item above as well as on quantitatively expressed social and socio-cognitive principles. Since such principles are often not yet well understood, they may have to be developed along with the models. Falsification and deception may not be identifiable at the level of input information and may have to be identified by the model. By looking at patterns of information across a variety of sources in an appropriate analytical framework, one may be able to select “true information”, avoid “false information” and produce accurate results. The analytical framework will virtually certainly be deeper and more complicated than weighting (for example, weighting information sources according to ratings or presumed trust), averaging and correlation. The models should be embedded in applicable

sociological and socio-cognitive theory and should not simply be computationally descriptive of social-media phenomena and/or be based only on analogies to physical phenomena.

All of the research will need to take place in an open-world context that is significantly different from the closed-world context that has been commonly assumed in the past. Among other questions, there arises the question of what representation of uncertainty is applicable for the poorly understood open-world situations that occur in social-media phenomena. To what extent is classical probability and statistics, which is often an excellent model for well understood closed-world situations, applicable? If it is not applicable, is there evidence that some alternative theory (possibility theory, plausibility theory, various evidence theories, etc.) is applicable? The representation of uncertainty needs to be derived from applicable sociological and socio-cognitive principles, not simply assumed or assigned.

Understanding and being able to predict technology-based social networking and social media phenomena will enhance defense in current and future asymmetric conflict, especially in the technology-based component of that defense.

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## **f. RESEARCH AREA 6: PHYSICS**

6.0 Physics. The objective of the ARO Physics Division is to develop forefront concepts and approaches, particularly exploiting atomic-scale and quantum phenomena, that will in the long-term have revolutionary consequences for Army capabilities, while in the nearer-term providing for existing Army needs. In support of this goal, the interests of the Physics Division are primarily in the following areas: condensed matter physics, quantum information science, atomic and molecular physics, and optics and fields. There is little direct interest in relativity and gravitation, cosmology, elementary particles and fields, nuclear physics, astronomy, or astrophysics, since they generally have little impact on the areas of Army needs. Nevertheless, the possible relevance of topics within these other physics disciplines is not absolutely discounted, and discussions of potential exceptions are welcome.

The disciplinary boundaries of ARO are not sharply drawn, as shown by the joint support of a number of efforts by the Physics Division and other ARO Divisions. In addition, it is not necessary that a potential investigator be associated with a physics department to receive support from the ARO Physics Division.

6.1 Condensed Matter Physics. Condensed matter physics (CMP) is a foundational science enabling fundamental Army technologies in areas such as information processing, communications, sensors, optical components, electronics, optoelectronics, night vision, seekers, countermeasures, and many others. Technologies such as these would not exist today, at least not as we know them, without visionary research in the field of CMP. The ARO CMP Program strives to continue this level of impact by looking beyond the current understanding of natural and designed condensed matter, to lay a foundation for revolutionary technology development for next generation and future generations of warfighters.

*Strong Correlations and Novel Quantum Phases of Matter.* Understanding, predicting, and experimentally demonstrating novel phases of matter in strongly correlated systems will lay a foundation for new technology paradigms for applications ranging from information processing to sensing to novel functional materials. Interest primarily involves strong correlations of electrons, but those of other particles or excitations are not excluded. This thrust has predominantly emphasized complex oxide heterostructures as a material system in which the discovery, design and control of electronic correlations may be possible, but other material systems are of interest as well. The thrust also has interest in quantum criticality, dynamically-stabilized electronic states and metastable phases that are not adiabatically accessible from known ground states. The Program seeks to foster novel experimental and theoretical research targeting the discovery and rational design of new quantum phases of matter, along with exploring how excitations within these phases can be probed and controlled.

*Topological Electronic Phases in Condensed Matter.* Novel quantum phases of electronic matter can also exist apart from strong correlations as recent developments in topological insulators has demonstrated. This thrust seeks to expand the physics embodied in the topology of the electronic structure, including the role of strong correlations and other influences, theoretically predicted or not. Interest emphasizes experimental studies but not to the exclusion of theoretical efforts. Studies in physics and physics-enabling chemistry, such as bulk crystal growth, heteroepitaxial growth modes, and surface chemistry are also of interest.

Unique Instrumentation Development. Advanced studies of CMP phenomena often require unique experimental techniques with tools that are not readily available. The construction and demonstration of new methods for probing and controlling unique phenomena, especially in the studies of novel quantum phases of matter, is of particular interest. Further, structures and assemblies exhibiting unique CMP phenomena may require unique synthetic techniques, which might range from biological assembly to optical lattices. Establishing such techniques for the fabrication or simulation of condensed-matter systems are of interest when they provide access to novel quantum phenomena that are not otherwise readily obtainable.

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6.2 Quantum Information Science. Quantum mechanics provides the opportunity to perform highly non-classical operations that can result in beyond-classical capabilities in imaging, sensing and precision measurements, exponential speed-ups in computation, or ultra-secure transmittal of information. This Program seeks to understand, control, and exploit such non-classical phenomena for revolutionary advances beyond those possible with classical systems. An overarching interest is the exploration of small systems involving small numbers of entangled particles. There are three major areas of interest within this Program.

*Foundational Quantum Physics.* Experimental investigations of a fundamental nature of quantum phenomena, potentially useful for quantum information science, are of interest. Examples include coherence properties, decoherence mechanisms, decoherence mitigation, entanglement creation and measurement, nondestructive measurement, complex quantum state

manipulation, and quantum feedback. An important objective is to ascertain the limits of our ability to create, control, and utilize quantum information in multiple quantum entities in the presence of noise. Of particular interest is the demonstration of the ability to manipulate quantum coherent states on time scales much faster than the decoherence time. Theoretical analyses of non-classical phenomena may also be of interest if the work is strongly coupled to a specific experimental investigation, such as proof-of-concept demonstrations in atomic, molecular, and optical as well as other systems.

*Quantum Sensing, Imaging, and Metrology.* This research area seeks to explore, develop, and demonstrate multi-particle coherent systems to enable beyond classical capabilities in imaging, sensing, and metrology. Central to this research area is the exploration of small systems involving a few entangled particles. Topics of interest in this research area include the discovery and exploration of (a) multi-particle quantum states advantageous for imaging, sensing, and metrology, (b) quantum circuits that operate on multi-particle quantum states to enable beyond-classical capabilities, and (c) methods for the readout of quantum states. Other research topics of interest are: theory to explore multi-particle quantum states useful for beyond classical capabilities, quantitative assessment of capabilities and comparison to classical systems, efficient state preparation, quantum circuits for processing these states as quantum bits, readout techniques, decoherence mitigation and error-correction for improved performance, supporting algorithms as a basis for processing circuits, connections between the solution of hard computational problems and overcoming classical limitations in imaging, sensing, and metrology, entanglement as a resource, and suitable physical systems and key demonstration experiments.

*Quantum Computation and Communication.* Quantum computing and communication will entail the control and manipulation of quantum bits with high fidelity. The objective is the experimental demonstration of quantum logic performed on several quantum bits operating simultaneously, which would represent a significant advance toward that ultimate goal of tremendous speed up of computations. Demonstrations of quantum feedback and error correction for multiple quantum bit systems are also of interest. There is particular interest in developing quantum computation algorithms that efficiently solve classically hard problems, and are useful for applications involving resource optimization, imaging, and the simulation of complex physical systems. Input/output interfaces for quantum computation to handle large amounts of classical data efficiently are of interest. The ability to transmit information through quantum entanglements distributed between spatially-separated quantum entities has opened the possibility for an ultra-secure means of communication. Exploration of quantum communication of information based on distributed entanglements such as in quantum teleportation is of interest. In addition, the exploration of long-range quantum entanglements, entanglement transfer among different quantum systems, and long-term quantum memory are also of interest.

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6.3 Atomic and Molecular Physics. Research efforts in the Atomic and Molecular Physics (AMP) Program will create fundamentally new capabilities for the Army, as well as provide the

scientific underpinnings to enhance existing technologies. Topics of interest include (i) quantum degenerate atomic gases, both Bose and Fermi, their excitations and properties, including mixed species, mixed state, and molecular, (ii) quantum limited precision metrology, (iii) nonlinear atomic and molecular processes, (iv) quantum topological matter, (v) novel forms and effects of coherence, and (vi) emerging areas. Cooling schemes for molecules are of importance for extending the range of systems that may be exploited. In addition, there is an interest in emerging areas of atomic, molecular, and optical (AMO) physics such as states of protected matter including but not limited to topological phases, emergent lattices in quantum gases, opto-mechanical interfaces, non-equilibrium many body dynamics, and weak measurements. Research efforts within the AMP Program fall within two thrust areas: *Advanced Quantum Capabilities and Novel Quantum Methods*. It is anticipated that research efforts within these areas will lead to applications including novel materials, robust quantum devices, and novel fieldable quantum sensors.

*Advanced Quantum Capabilities.* The two focus areas of this thrust are the development of quantum simulators and foundational research in quantum entanglement. The quantum simulator portion of the thrust seeks research on novel cooling, trapping, and the expansion of atomic and molecular species. The effort seeks the validation of many-body quantum theories through the development of experimental tools including quantum gas microscopes, synthetic gauge fields, mixed species, and novel interactions. Complimenting this effort will be the inclusion of foundational investigations into quantum mechanics, such as entanglement, topologically protected states, and entropy. To take advantage of the precision inherent in future quantum devices, these systems will need to connect to the classical world in such a manner that allows them to sample the signal of interest while remaining robust to noisy environments. Investigating how to maximize both the quality and quantity of entanglement within these systems will be a priority. General issues of quantum coherence, quantum interference, entanglement growth, entanglement purity, and non-equilibrium phenomena, as well as discovering new scientific opportunities are also of interest.

*Novel Quantum Methods.* The AMP Program has a general interest in exploring fundamental atomic and molecular physics that may impact future Army capabilities. This thrust is divided into two main areas: quantum limited precision metrology and quantum state determined chemical reactions. The quantum limited precision metrology effort will expand the foundations of quantum measurement into new areas including opto-mechanics, weak-value measurement, and other areas that increase fundamental precision through interactions, including cavities and Rydberg atoms. Quantum state determined chemical reactions will explore molecular and ion chemistry, controlled at the level of quantum state. Methods will be developed that exploit Feshbach resonances and other methods to tune interactions, both as a mechanism for ultracold molecule production and as a way to cross over from weak coupling to strong coupling regimes (e.g., in superfluidity). It is expected that research in this thrust will complement efforts in the *Advanced Quantum Capabilities* thrust. For example, molecules could be studied in mixed dimensions in optical lattices or quantum gas microscopes. The *Novel Quantum Methods* thrust is distinguished from programs in the materials and chemical sciences. One distinguishing feature is its focus not on synthesis, but on the underlying mechanisms, such as electronic transport, magnetic response, coherence properties (or their use in molecule formation/selection),



control, and/or linear and nonlinear optical properties. The systems of interest are well-defined molecules, generally small or of high symmetry, and their functionalized variants.

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6.4 Optical Physics and Fields. The Army seeks fundamental physics related to optics and electromagnetism. The objective of this Program is to investigate physical phenomena that will lead to a deeper understanding of the underlying physics or the discovery of new physical effects that can improve capabilities of the Army. In particular, this program emphasizes physics that will significantly improve areas such as remote sensing, information processing, light and energy transmission, interactions between light and matter, and new or emerging phenomena relating to optical physics and fields. Much of the Army's capability in sensing and information and/or energy exchange depends on light. This Program also seeks research for other long-range physical fields that can complement electromagnetic radiation

*Extreme Light.* This thrust focuses on research on extreme light, meaning the examination of light in the extreme limits, such as the shortest pulses attainable and the highest intensity fields attainable. Advances in these areas require theoretical and experimental research. For example, ultrashort pulsed lasers have now achieved intensities of  $10^{22}$  W/cm<sup>2</sup>. Future applications of these pulses may include high-harmonic generation, nanolithography, particle beam acceleration and control, and light filaments. In addition, effects such as THz formation and control and broadband localized radiation from filaments are of interest. In the near future, even higher intensities are expected. Theoretical and experimental research efforts are needed to describe and understand how matter behaves under these conditions—from single particle motion and radiation reaction to the effects in materials—and how to generate these pulses and use them effectively. Pulses as short as 80 attoseconds have been produced, and the Program seeks ways to make them shorter and to understand both the physics and applications of this form of radiation. Another example of extreme light is light filaments, where light and plasmas interact to form a new kind of energy propagation. The physics of the interactions as well as many yet-to-be discovered issues need to be understood, such as how far can light filaments propagate and how much energy can they contain. Proposals for new areas of extreme light such as relativistic optics are welcome.

*Meta-Optics.* This thrust pursues a fresh start in optics due to the new kinds of effects allowed by negative index materials and more generally, optical metamaterials. In this area, many conventional limits of optics can be broken in ways such as sub-wavelength imaging and superlensing related phenomena. It is timely to look at the quantum optics of such processes. This program has interest in new methods to overcome loss in metamaterials, hyperbolic materials, and new phenomena made possible by flat photonics. Proposals for new areas of meta-optics such as parity-time (PT) symmetries and non-Hermitian Hamiltonians are of interest. New forms of imaging using transformation optics or other novel imaging, including quantum optics, are also of interest. In general, any optical phenomena that can ultimately improve Army capabilities are sought.

*Non-Electromagnetic Fields* . Other forms of propagating energy have been predicted and will theoretically have properties that differ dramatically from electromagnetism. Modern theories of gravity as well as string theory predict, in addition to gravity, the existence of two other long-range fields. If these theories are correct in their predictions, this suggests applications in which these new fields may be useful for detection or communication, especially in situations where electromagnetism and optics are not useful, such as propagating through conducting media. This program seeks proposals that may lead to the detection and/or measurement of these fields.

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## **g. RESEARCH AREA 7: CHEMICAL SCIENCES**

7.0 Chemical Sciences. The ARO Chemical Sciences Division supports research efforts to advance the Army and Nation's knowledge and understanding of the fundamental properties and processes governing molecules and their interactions in materials and chemical systems. The Division encourages proposals that promote basic research to develop methods for accurately predicting the pathways, intermediates, and energy transfer of specific reactions, to understand the fundamental processes governing electrochemical reactions and transport of species, and to discover the relationships between macromolecular microstructure, architecture, functionality, and macroscopic properties. In addition, these efforts will likely lead to new methods for synthesizing and analyzing molecules and materials that will open the door to future studies not feasible with current approaches.

7.1 Molecular Structure and Dynamics. The goal of this Program is to determine the pathways and intermediates for fast reactions of molecules in gas and condensed phases at high temperatures and pressures, and to develop theories that are capable of accurately describing and predicting these phenomena. In the long term, these studies may serve as the basis for the design of future propellants, explosives, and sensors. This Program is divided into two research thrusts: (i) *Reaction Dynamics* and (ii) *Computational Modeling*.

Research in the *Reaction Dynamics* thrust explores energy transfer mechanisms in molecular systems. In particular, research is focused on understanding dynamic processes such as roaming radicals, chemical reactions in solid state crystals and heterogeneous mixtures, phase transformations at extreme conditions, and control of processes using both shaped laser pulses and continuous wave laser beams. Studies that yield new insights on the decomposition pathways of energetic molecules, both in the gas and condensed phases, are also of interest.

Research in the *Computational Modeling* thrust is focused on the development and validation of theories for describing and predicting the properties of chemical reactions and molecular phenomena in gas and condensed phases. In particular, research targeted at the development and implementation of novel theoretical computational chemistry methods is of interest. Ideally, such methods will go beyond current theories to allow for efficient, accurate, and *a priori* prediction of thermochemical properties. Such methods may take advantage of near-ideal parallel processing on massive computer clusters, or they may seek to solve current scaling problems through novel implementation of unprecedented computer algorithms. The accurate prediction of

intermolecular forces for problems in solid-state chemistry, such as the prediction of x-ray crystal structures, is also of current interest.

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7.2 Electrochemistry. This Program supports fundamental electrochemical studies to understand and control the physics and chemistry that govern electrochemical redox reactions and transport of species, and how these are coupled with electrode, catalysis, electrolyte, and interface. Research includes ionic conduction in electrolytes, electrocatalysis, interfacial electron transfer, transport through coatings, surface films and polymer electrolytes, activation of carbon-hydrogen and carbon-carbon bonds, and spectroscopic techniques that selectively probe electrode surfaces and electrode-electrolyte interfaces. Novel electrochemical synthesis, investigations into the effect of microenvironment on chemical reactivity, quantitative models of electrochemical systems, and electrochemistry using excited electrons are also of interest.

This Program is divided into two research thrusts, although other areas of electrochemical research may be considered: (i) Reduction-oxidation (Redox) Chemistry and Electrocatalysis, and (ii) Transport of Electroactive Species. The *Redox Chemistry and Electrocatalysis* thrust supports research to understand how material and morphology affect electron transfer and electrocatalysis, to tailor electrodes and electrocatalysts at a molecular level, and to discover new spectroscopic and electrochemical techniques for probing surfaces and selected species on those surfaces. The *Transport of Electroactive Species* thrust identifies and supports research to uncover the mechanisms of transport through heterogeneous, charged environments such as polymers and electrolytes, to design tailorable electrolytes based on new polymers and ionic liquids, and to explore new methodologies and computational approaches to study the selective transport of species in charged environments.

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7.3 Polymer Chemistry. The goal of this Program is to understand the molecular-level link between polymer microstructure, architecture, functionality, and the ensuing macroscopic properties. Research in this Program may ultimately enable the design and synthesis of functional polymeric materials that give the Soldier new and improved protective and sensing capabilities as well as capabilities not yet imagined. This Program is divided into two research thrusts: (i) *Precision Polymeric Materials* and (ii) *Complex Polymer Systems*. Within these thrusts, high-risk, high-payoff research is identified and supported to pursue the Program's long-term goal.

The *Precision Polymeric Materials* thrust supports research aimed at developing new approaches for synthesizing polymers with precisely-defined molecular weight, microstructure (monomer sequence and tacticity), architecture, and functional group location, exploring how changes in molecular structure and composition impact macroscopic properties; and on developing polymers that exhibit programmed molecular responses to external stimuli. Of particular interest is research related to sequence-defined polymers, self-immolative polymers, and polymer

mechanochemistry. The *Complex Polymer Systems* thrust focuses on controlling polymer assembly to enable complex structures with diverse functions and new properties. Of interest to this thrust are research efforts that explore how molecular structure influences polymer assembly into more complex, hierarchical structures as well as influence interactions with other materials (e.g., inorganic or biological materials) to render functional hybrid assemblies. Research efforts that explore assembly/incorporation of multiple responsive groups into a single polymeric materials system to engender complex responsive behavior are also of interest.

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7.4 Reactive Chemical Systems. The goal of this Program is to achieve a molecular level understanding of interfacial activity and dynamic nanostructured and self-assembled chemical systems to provide unprecedented hazardous materials management capabilities and soldier survivability. This Program supports high-risk, high-payoff basic research with Army relevance in surfaces, catalysis, organized assemblies, and stimuli-responsive chemical systems. This program is divided into two thrusts: (i) *Interfacial Activity* and (ii) *Synthetic Molecular Systems*. The *Interfacial Activity* thrust supports research on understanding the kinetics and mechanisms of reactions occurring at surfaces and interfaces and the development of new methods to achieve precise control over the structure and function of chemical and biological molecules on surfaces. Specific areas of interest include adsorption, desorption, and the catalytic processes occurring at surfaces and interfaces and the interface between nanostructures and biomolecules to generate advanced materials. The *Synthetic Molecular Synthesis* thrust supports research that imparts multi-functionality, stimuli-responsive and dynamic behavior to completely synthetic molecular and chemical systems. Research of interest includes design and development of nanostructured scaffolds and sequential catalytic systems. This thrust also supports research aimed at exploring the properties and capabilities of self-assembled and supramolecular structures, including their functionality, and how to control assembly in different environments.

In addition, the emerging field of dynamic, responsive, multi-functional materials has great potential to provide revolutionary new capabilities. A specific technical area in this field is "targeting and triggering" in which a specific chemical (or event) is targeted (recognized) and that recognition triggers a response. Particular technical challenges of interest include selective and reversible recognition, amplification, and multi-responsive systems. Alternative approaches to selective, yet reversible, recognition are needed. Amplification includes an understanding of how to amplify the response from a single molecular recognition event to a multi-molecular response with approaches that promote chain reactions, self-amplification or cascade-type reactions within a single system. Multi-responsive systems in which specific stimuli trigger distinct responses are also of interest.

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## **h. RESEARCH AREA 8: LIFE SCIENCES**

8.0 Life Sciences. The ARO Life Sciences Division supports research efforts to advance the Army and Nation's knowledge and understanding of the fundamental properties, principles, and processes governing DNA, RNA, proteins, organelles, prokaryotes, and eukaryotes, as well as multi-species communities, biofilms, individual humans, and groups of humans. The interests of the Life Sciences Division are primarily in the following areas: biochemistry, neuroscience, microbiology, molecular biology, genetics, genomics, proteomics, epigenetics, systems biology, bioinformatics, and social science. The results of fundamental research supported by this division are expected to enable the creation of new technologies for optimizing warfighters' physical and cognitive performance capabilities, for protecting warfighters, and for creating new Army capabilities in the areas of biomaterials, energy, logistics, and intelligence.

The Division's research programs are currently focused on five research areas. The titles, scopes and points of contact for these programs, each of which address general aspects of basic research in life sciences, are listed below. A small number of symposia, conferences and workshops are also supported in part or in whole to provide an exchange of ideas in areas of Army interest.

8.1 Biochemistry. This Program emphasizes innovative high-risk basic research focused on understanding and controlling the activity and assembly of biomolecules. Scientific advances supported by this Program are anticipated to enable the development of novel systems, materials and processes that enhance Soldier protection and performance. An overarching goal of the Program is to provide the scientific foundations to support biological activity outside of the natural biological context, including integration of biological systems with synthetic systems. The *Biomolecular Specificity and Regulation* thrust is focused on elucidating the mechanisms by which biomolecules recognize and interact with their targets, as well as the regulatory mechanisms utilized to activate or inhibit biomolecular activity. This research thrust also includes novel engineered approaches to modulate and control biomolecular activity. The *Biomolecular Assembly and Organization* thrust is focused on understanding the molecular interactions and design rules that govern self-assembly of biomolecules into both naturally occurring biomolecular structures and designed architectures. This research thrust also includes novel approaches to control biomolecular assembly and approaches to utilize biomolecular architectures to organize biomolecular activity and/or achieve specialized properties.

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8.2 Genetics. This Program supports basic research in genetics, molecular biology, genomics, epigenetics, and systems biology in areas that may enable the optimization of the Soldier's cognitive and physical performance capabilities, increase Soldier survivability, and improve Army capabilities in areas such as biomaterials, sensing, energy, and intelligence. This Program emphasizes innovative high-risk fundamental research in areas such as identification and characterization of gene function, gene regulation, genetic interactions, gene pathways, gene expression patterns, epigenetics, mitochondrial regulation and biogenesis, and nuclear and mitochondrial DNA replication, mutagenesis, oxidative stress, and DNA repair. This Program is

interested in identifying and understanding the molecular factors that affect human performance capabilities as well as human survival and protection under normal conditions and when affected by a variety of stressors likely to be encountered in battlefield situations, such as dehydration, heat, cold, sleep deprivation, fatigue, caloric insufficiency, pathogens, and physical and psychological stress. Also of interest are mechanisms of prokaryotic adaptation, biological components of social instability, and biological systems for sensing and detection.

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8.3 Microbial Physiology and Engineering. This Program supports research in fundamental microbiology and the bioengineering of microbial systems that can help advance needs in Soldier protection and performance. There are two primary research thrusts within this program: (i) *Microbial Survival Mechanisms* and (ii) *Synthetic Bioengineering of Microbes*. The *Microbial Survival Mechanisms* thrust focuses on the study of the cellular and genetic mechanisms and responses that underlie microbial survival in the face of environmental stress. These stressors include extremes in temperature, pH, or salinity; the presence of antibiotics/antimicrobials and toxins including metals and toxic organic molecules; oxidative stress; and the depletion of specific nutrients. Research approaches can include fundamental studies of microbial physiology and metabolism, cell biology, molecular genetics that examine key cellular networks linked to survival, microbial cell membrane structure and the dissection of relevant critical signal transduction pathways and other sense-and-respond mechanisms; the dynamics of microbial-host interactions; and systems level, ecological and evolutionary approaches that examine the relationship and molecular communication within bacterial communities. The *Synthetic Bioengineering of Microbes* thrust supports the engineering of microorganisms toward biotechnological outputs and applications of interest to the Army. Engineered synthetic microbiological approaches are encouraged toward studies in protein engineering, electromicrobiology, the production of biofuels and commodity chemicals and the bioremediation of toxins. Additionally, of joint interest with the Biomathematics Program, are research efforts that advance our ability to work with complex biological data sets to increase understanding of microbiological systems, ranging from single-cell processes to multi-cellular interactions.

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8.4 Neurophysiology of Cognition. Research in the neurophysiological bases of perception, cognition and behavior, covering areas such as neuronal cellular/molecular physiology and biophysics, neuropsychology and integrative neurobiology is of interest. Specific examples can include physiological, neuro-psychological and/or cortical/cognitive mechanisms underlying successful completion of complex task behaviors; including amelioration of induced losses as well as enhancement in defined perceptual, cognitive and/or motor abilities in healthy humans. Investigations can span the gamut from single-neuron electrophysiology and multi-unit recordings through neuro-imaging technologies and computational neurobiology to define the relationship between structural and functional neural connectivity and humoral or psychological correlates of both central and peripheral nervous system function. Non-medically oriented

research in both human volunteers and animal models designed to elucidate the fundamental physiology underlying cognition during normal activity that is applicable to non-laboratory environments under non-ideal conditions is appropriate. Perceptual and/or psychophysiological implications of brain-machine interfaces ranging from optimizing auditory, visual and/or somatosensory display, and control systems based on physiological or psychological states through modeling of individual cognitive dynamics is also relevant to this research area.

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8.5 Social and Behavioral Science. The goal of this Program is to promote basic research on human and social behavior to discover the theoretical foundations of behavior at all levels, from individual actors to global societies. The goals of this Program include (i) developing reliable and valid measures of social and behavioral concepts, and (ii) discovering and testing causal theories that describe, explain, and predict behavioral responses to physical, environmental, psychological, or social stimuli. Research in this program can include a broad range of methodological and theoretical approaches including empirical studies that require primary data collection, such as random control trials, quasi-experiments, laboratory and field experiments, surveys, comparative and observational studies, or the use of secondary data sources, such as media archives or area reports. Formal computational approaches are encouraged to aid in the development of testable dynamic models of individual, group, and population-level phenomena. Of particular interest is research that examines (1) the interrelationships among human, social, natural, and physical systems and (2) multi-level system dynamics. Examples might include, but are not limited to (a) understanding how change in man-made and natural environments affects migration, urbanization, change in governance systems, collective action, deviance; (b) investigating the interrelationships between individual values, group identity, and interpersonal and intergroup cooperation and conflict; (c) studying how emerging technologies impact intra- and intergroup interaction and decision-making under risk and uncertainty; and (d) modeling the diffusion of values, beliefs, and influence across individuals, groups, and societies along with the physical and natural contexts that impact pathways of diffusion

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## **i. RESEARCH AREA 9: MATERIALS SCIENCE**

9.0 Materials Science. The Materials Science Division of the ARO seeks to realize unprecedented material properties by embracing long-term, high risk, high-payoff opportunities for the US Army with special emphasis on: Materials by Design, Mechanical Behavior of Materials, Physical Properties of Materials, Synthesis and Processing, and Earth Materials and Processes. Research supported by the division seeks to discover the fundamental relationships that link chemical composition, microstructure, and processing history with the resultant material properties and behavior. The work, although basic in nature, is focused on developing new materials, material processes, and properties that promise to significantly improve the performance, increase the reliability, or reduce the cost of future Army systems. It also

endeavors to advance the understanding of geological materials and processes, to establish opportunities from which to optimize the performance of future Army systems functioning within them. Fundamental research that lays the foundation for the design and manufacture of multi-component and complex materials is of particular interest. Foundational research that integrates novel experimental work with the development of new predictive materials theory is also of significant interest. Furthermore, there is lasting interest in new ideas and cross-disciplinary concepts in materials science that may have future applications for the Army.

9.1 Materials by Design. The Materials by Design program seeks to establish the experimental techniques and theoretical foundations needed to facilitate the hierarchical design and bottom-up assembly of multifunctional materials that will enable the implementation of advanced materials concepts including transformational optics, biomimetics and smart materials.

(i) Directed 3D Self-Assembly of Materials is aimed at enabling the directed 3D assembly of reconfigurable materials, and developing viable approaches to the design and synthesis of multi-component materials incorporating hierarchical constructs.

(ii) Functional Integration of Materials focuses on demonstrating the predictive design and integration of functional properties into complex multi-component systems, and developing analytical techniques for interrogating the evolution of the 3D structure and properties of material assemblies at the nanoscale

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9.2 Mechanical Behavior of Materials. The Mechanical Behavior of Materials program seeks to reveal underlying design principles and exploit emerging force-activated phenomena in a wide range of advanced materials to demonstrate unprecedented mechanical properties and complementary behaviors.

(i) Force-Activated Materials involves demonstration and characterization of robust mechanochemically adaptive materials based on force-activated molecules and force-activated reactions, tailoring the deformation and failure mechanisms in materials to mitigate the propagation of intense stress-waves and control energy dissipation, and the creation of a new class of adaptive structural materials that demonstrate “mechanical homeostasis.”

(ii) Mechanical Complements in Materials discovers superior ionic transport materials and transparent materials through a complementary, interdependent, optimization of mechanical properties, catalyzes a self-sustaining investigation of fiber precursors, tailored for lateral and axial interactions, to generate new paradigms for revolutionary structural fibers, and discovers and validates new atomic-scale strengthening mechanisms governing bulk mechanical behavior.

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9.3 Physical Properties of Materials. The Physical Properties of Materials program seeks to elucidate fundamental mechanisms responsible for achieving extraordinary electronic, photonic, magnetic and thermal properties in advanced materials to enable future Army relevant innovations.



(i) Free-standing 2D Materials focuses on the creation of novel free-standing 2D materials, heterostructures and hybrids with physical properties complementary or superior to graphene, and the invention of novel characterization techniques specific to 2D materials to determine unprecedented properties.

(ii) Defect Science & Engineering explores the specific influence of defects (positive or negative) on the physical properties of novel functional materials, and elucidates defect control mechanisms during thin film growth and bulk processing of novel functional materials.

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9.4 Synthesis and Processing of Materials. The Synthesis and Processing of Materials program seeks to discover and illuminate the governing processing-microstructure-property relationships for optimal creation of superior structural and bulk nanostructured materials.

(i) Stability of Nanostructured Materials focuses on the creation of thermally-stable, ultrahigh strength nanocrystalline materials through interfacial grain boundary engineering, and the realization of high strength, stable nanostructured alloys via pinning nano-precipitates and internal coherent boundaries.

(ii) Manufacturing Process Science supports discovery of the fundamental physical laws and phenomena of materials processes, and the exploitation of unique phenomena that occur under metastable and complex processing conditions for the creation of revolutionary materials.

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## **j. RESEARCH AREA 10: NETWORK SCIENCE**

10.0 Network Science. Work over the past ten years by researchers in various fields including Statistical Mechanics, Anthropology, Structural Biology, Distributed Systems, Theoretical Computer Science, Robotics and Control theory has shown that there is a lot of commonality in the structure of different networks – be it communication among a school of fish, pack of wolves, a group of jihadis, or an ad-hoc wireless network. The goal of the Network Sciences Division is to make use of this commonality, in a synergistic way, to address issues of importance to the Army. Networks of sensors, communication and computation nodes, and robots are pervasive throughout the Army and especially in Command, Control, Communications, Computing, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems. The Network Science Division identifies and addresses the Army's critical basic research problems in C4ISR where progress has been inhibited by a lack of novel concepts or fundamental knowledge. Research in this program has applications to a wide variety of developmental efforts and contributes to the solution of technology-related problems throughout the Army's Future Force operational goals.

The ARO supports and advances fundamental research and knowledge that focuses on the needs of the Army's effort to be net-centric. To accomplish this objective, the Division supports extramural basic research in the four areas of Communication and Human Networks, Intelligent Networks, Multi-Agent Network Control and Socio-Cognitive Networks. The boundary between these programs is fluid and, thus, a research topic might fall in more than one area. In fact, research that will elucidate and define the common underpinning science that cuts across different types of networks is of particular interest. In many cases, there will be a close relationship to the Mathematical and Computer Sciences programs in the directorate.

10.1 Communication and Human Networks. This program is concerned with the application of the emerging network science to wireless communication networks and human social networks. In both of these areas, DoD and particularly Army unique problems will be investigated. For communications networks, tactical multi-hop wireless communications which lack fixed infrastructure will be investigated. For social networks, problems such as understanding adversarial networks with limited data and the effects of the human network on military decision making are example topics of interest. Also of interest is the interaction of the communications network with primarily the social network but also the information network.

New and existing methods in the areas of information theory, game theory, and graph theory need to be applied to these problems in order to find unique solutions.

10.1.1 Wireless Network Theory. Research is required in the broad area of wireless network science including fundamental limits, performance characterization, novel architectures, and high fidelity simulation. Metrics, fundamental limits, and performance need to be characterized for multi-hop wireless networks with mobility, node loss, and bursty traffic. New simulation techniques are necessary to allow for very large simulations without losing the fidelity at the physical layer that is necessary for realistic results.

10.1.2 Mobile Ad Hoc and Sensor Networks. Networks serving Army needs must operate in highly dynamic environments with limited infrastructure support. Nodes in such networks often have only noisy local information and must operate in a decentralized fashion. New research approaches are needed to explicitly account for the lack of full network state information and the cost of coordination.

Adaptive networking techniques are needed for the dynamic allocation of resources based on operation needs, traffic characteristics, dynamic topologies, interference conditions, and security considerations. Networks need to be able to adapt to varied quality of information (QoI) requirements of various applications. Dynamic optimization and learning methods are needed to discover and capture communication and networking opportunities. Networking and sensing architectures for cognitive mobile ad hoc networks need to be developed with qualitative and quantitative performance measures. The impacts of mobility, fading, and multi-user interference need to be investigated.

Networking in combat operations needs to cope with the presence of passive or active adversaries of various types. New signal processing, information theory, and networking theory methodologies are needed to provide reliable and efficient communications in the presence of

various adversarial actions. There is a need to characterize fundamental tradeoffs among various conflicting objectives: between secrecy/anonymity vs. rate of communications vs. resource consumption, the need for rapid response and the requirement of authentication and security.

Providing energy efficient sensor networking under different operating conditions presents difficult technical challenges. New techniques are needed for sensor fusion using Shannon and non-Shannon information theoretic metrics for bandwidth and energy efficiency. Distributed synchronization methods with limited information exchange for varying network topology and heterogeneous delay requirements are needed. Research should investigate fundamental performance bounds and characterize the tradeoffs between conflicting metrics.

10.1.3 Interactions Between Social and Communications Networks. The synergy among social networking and communication networking, particularly in a tactical mobile ad-hoc scenario, is a fertile research area that can provide significant advances for the design of new communication. Important questions include: How do human networks behave in the presence of constraints imposed by the communication network? How do we design communication networks to achieve a global mission among the human actors which may be evolving in time as more information gets revealed and circumstances change? Interaction between human and communications networks need to be analyzed, such as the interaction of QoS communications goals with the requirements of the human network in a tactical scenario. There are many social networking aspects that are common to mobile ad-hoc networking needs such as distributed decision making, robustness, cooperation, self-organization, cluster formation, search and exploration to name a few. Social Networking Analysis concepts have been recently used in routing and storing of information for Disruption (or Delay) Tolerant Networks (DTN), with some encouraging results.

10.1.4 Human Networks. Topology, dynamics, and information flow within human networks is of interest as well as interaction of communications and human networks. In particular, this program will leverage mathematical techniques utilized in network science to analyze other types of networks, such as network information theory, graph theory, game theory, data mining, and Markov chains, to analyze human networks.

Determining social network structure from heterogeneous data is of prime interest to this program. Data can be derived based on multiple forms of electronic contacts, such as email, phone calls, social networking sites, as well as face to face contacts. Complicating factors include very large networks, limited data per potential link, and distinguishing between important links and coincidental links.

An important question is to characterize how social networks facilitate such functions as aggregating information, propagating beliefs, imposing constraints, developing incentives, and conducting transactions. How do groups aggregate information over networks? How do information shocks get absorbed in the network or explode through the network? How can misinformation be contained? How does the network structure affect the efficiency of information propagation? Which networks are robust in aggregating information efficiently?

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10.2 The goal of the Social and Cognitive Networks program is to understand human cognition processes and behaviors leading to group level phenomena particularly relevant in military settings. Social networks are the underlying structure of interaction and exchanges between humans within both strategically designed and emergent or self-organized systems. Social networks allow for collective actions in which groups of people can communicate, collaborate, organize, mobilize, attack, and defend. The changing nature of DoD's missions greatly increase the need for models that capture the cognitive, organizational, and cultural factors that drive activities of co-present, virtual, or distributed groups, teams, and populations. Better understanding the human dimension of complexity will provide critical insights about emerging phenomena, social diffusion and propagation, thresholds, and tipping points.

The Social and Cognitive Networks program supports projects that contribute substantive knowledge to theories about human behavior and interaction and make methodological advancements in modeling and analyzing social network structures. The US Army is particularly interested in research that uses defense-relevant empirical data to feed into computational and mathematical models of human interaction. As such, this program funds projects successful in blending theories and methods from the social sciences with rigorous computational methods from computer science and mathematical modeling.

10.2.1 Human Behavior and Interaction. This program supports research from disciplines such as communication, health and behavioral science, I/O and social psychology, library and information science, management science, and sociology that use a social networks lens to focus on the ways people think and interact whereby creating higher-order systems. Topics of interest include social influence, leadership, trust, team science, cooperation and competition, and crisis management. Social influence processes determine how ideological groups form and dissolve, information and beliefs spread and interact, and how populations reach consensus or contested states. Additionally, health topics related to education, healthcare behaviors, disease propagation, and wellness from a social networks perspective are of particular interest.

10.2.2 Information and Knowledge Management. This program supports social network centric research to study the ways people learn individually and collectively and how they utilize that information for decision making and goal attainment. Examples of relevant topics include transactive memories, public goods, collective action, information sharing, information fidelity, diffusion and propagation dynamics, and collective decision-making. Diffusion dynamics research will develop mechanistic understanding of opinion and behavior change associated with influence, contagion, and other social propagation processes. Collective decision-making research will contribute fundamental theories and models to predict, evaluate and simulate how teams organize, exchange information, build knowledge, influence, adapt, learn, and build consensus using cooperative strategies and emergent capabilities.

10.2.3 Social Network Analysis. In addition to the topical areas identified above, this program supports methodological advancements for social network analysis. Methodological research in this program will focus on important advances in exponential random graph models (ERGMs or  $p^*$ ), object oriented agent-based models, computational models, and dynamic simulations that resolve network modeling issues. Such research will focus on scalability of networks, hierarchical or multilevel (nested) systems, longitudinal networks, social influence models, network resilience, techniques to deal with missing, incomplete, or inaccurate network data, and techniques to deal with visualizing multilevel multimodal networks. Scalability and dimensionality research will identify overarching mechanisms that span scales and dimensions of human systems that will parameterize, model, and predict both small group and big data network models. Data accuracy research focuses on investigating effects of measurement error on metrics and inferences due to incomplete (missing or inaccurate) network data. These projects could include research examining small group dynamics within big data sets; multi-level models that account for nested cognitive, social, cultural, physical dimensions of systems; or link and subgroup estimation algorithms to deal with incomplete data and clandestine activities.

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10.3 Intelligent Networks. The overall objective of the Intelligent Networks program is to augment human decision makers (both commanders and soldiers) with enhanced-embedded battlefield intelligence that will provide them with the necessary situational awareness, reconnaissance, and decision making tools to decisively defeat any future adversarial threats which is in line with the DoD's adoption of net-centric warfare, variously defined as flattening the information space to interconnect soldiers and commanders to provide instantaneous access to information, knowledge, and situational awareness. Given this goal, it becomes necessary to understand (a) fundamentals of what intelligence means in the context of autonomous systems, (b) how to build intelligent systems, and (c) what role intelligence plays in man-machine teams. The following thrusts, among others, are intended to address the goals of the Intelligent Networks program.

10.3.1 Integrated Intelligence and Theory of Mind. Intelligence emanates from several components acting in synergistic ways, be it human cognition that embodies cumulative effects of various separate components of the human brain or the collective intelligence of a network of agents (humans, birds, insects, etc.). Fundamental questions that need to be answered include: What is the least amount of knowledge necessary to boot-strap learning in autonomous systems (or in a network)? How can joint reasoning over various components be carried out (vision, knowledge representation, reasoning, planning, for instance) to obtain a sum that is more than its parts? Are there viable, computable theories of mind that can realistically implement reflection and meta-cognition?

10.3.2 Robust Reasoning Under Uncertainty. The ability to adapt or compensate, in reasoning, for the uncertainty inherent in real systems related to modeling error, sensing errors and noise, system failures, and changing dynamic environments, are important. Two further aspects of reasoning are reflection and transparency – the ability of autonomous systems and intelligent tools to explain the current state of the world, as they see it, and to be able to explain their internal state and their actions. The latter is especially important in systems that can learn and, thus, its behavior can change with time.

10.3.3 Adversarial Reasoning. Development of appropriate mathematical tools to model and reason about societies and cultures, that brings together tools from Game Theory, Social Sciences and Knowledge Representation. Research of interest include, but is not limited to, Game Theory for security applications while accounting for bounded rationality, development of Game Theory based on data regarding cultural and adversarial groups, and Behavioral Game Theory that can explain intelligence in groups and societies.

10.3.4 Collective Intelligence. Can wisdom of crowds be harnessed to solve problems of importance to societies and problems that are deemed computationally hard? In particular, can a man in the middle of a man-machine ensemble, or, more appropriately, can a crowd and machine ensemble solve inherently hard problems? Approaches to mechanism design that teases out intelligence inherent in a crowd (or society) are of interest in this thrust.

10.3.5 Distributed Graph Algorithms. Large graphs and voluminous data characterize problems in Network Science. Questions of interest include: are there scalable, distributed graph algorithms that can be used to represent and reason about graphs as large as the Internet? Is it possible to design approximate algorithms that have tight performance bounds and tight guarantees on efficacy of results? New approaches that would advance algorithmic approaches to generalization of computational problems involving graphs, hyper-graphs, matroids, etc. are necessary to advance computational aspects of Network Science.

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10.4 Multi-Agent Network Control. The objective of the Multi-Agent Network Control program is to establish the physical, mathematical, and information processing foundations for the control of complex networks. The research program is concerned with developing novel mathematical abstractions and methods for the modeling and control of both individual agents as well as the collective behavior of large scale networks of heterogeneous multi-agent systems. In this regard, the term “agent” can span the biological, physical, and information and communication domain. Autonomy is central to program efforts as anticipated dynamics of the future battle space will require a greatly increased level of autonomy to enable the necessary mobility, sensor coverage, information flow, and responsiveness to support the military goals of information superiority, dominant maneuver, and precision engagement.

10.4.1 Control and Dynamical Systems Theory for Complex, Co-Evolving Networks. The high-dimensionality and complex, evolving topologies in complex networks requires new dynamical systems and control theory tools. There is a need for mathematically rigorous methods and

physics of continuous and discrete high-dimensional dynamical systems, uncertainty propagation methods in spatiotemporally heterogeneous dynamical systems, models for rare cascading events and failures, and integration of realistic factors in the development of multi-agent control such as high-order, possibly non-minimum phase, un-modeled dynamics, noise, and delays. In large-scale networks of interdependent dynamical systems, temporal anisotropy, spatial non-locality, and multiscale processes precipitate local dynamics to global responses in a non-straightforward manner such that ergodicity may only apply at certain spatiotemporal scales and hierarchies. Of particular interest are methods and techniques from complexity science, dynamical systems theory, computational homology, topology, graph theory, and percolation theory to develop stability and control principles. Multiscale projection-operator methods and renormalization groups for novel reduced order modeling strategies for controlling complex dynamical systems is of major interest.

10.4.2 Information Structure, Causality, and Dynamics for Control. Understanding information processing within and for controlling complex and co-evolving networks requires new tools for causality and topological inference as well as unification with the mathematical foundations in the first programmatic thrust. Major programmatic interests center on formulating abstractions of cognitive processes and perception for fundamentally changing the way information is exploited to enable control and re-shaping the actions of multiple agents and complex networks. Further questions include: How does control as an objective effect communication and information processing in complex networks? What are the fundamental limits of causality? How do we infer causality and perform estimation in co-evolving complex networks?

10.4.3 Fundamental Physics of Co-Evolving, Complex Networks. Presently, there is a significant need to bring together statistical physics, nonlinear dynamics, and nonlinear control to establish a physics of large-scale far-from-equilibrium systems that does not exist today. Determining, understanding, and manipulating the mathematical structures, bifurcations phenomena, self-similarity, chaotic and fractional dynamics, etc., will lead to unprecedented capabilities for controlling complex networks. New scientific understanding of feedback architectures are needed within hierarchically organized multi-agent systems and complex networks. Such systems may be either synthetic, naturally occurring, or some combination thereof. Further topics include, but are not limited to: mathematical abstractions related to distributed system theory; metrics for system complexity, information content, flow, structure, swarming phenomena, design of emergent behavior for heterogeneous multi-agent systems, and information processing and data fusion for decision-making and distributed multi-agent theory.

Technical Point of Contact: Dr. Samuel Stanton  
e-mail: [samuel.c.stanton2.civ@mail.mil](mailto:samuel.c.stanton2.civ@mail.mil), (919) 549-4225

## **k. RESEARCH AREA 11: ARO SPECIAL PROGRAMS**

### **11.1. SHORT-TERM INNOVATIVE RESEARCH (STIR) PROGRAM.**

The objectives of the STIR program are to provide rapid, short-term investigations to assess the merit of innovative new concepts in basic research.

11.1.1. Eligibility. Research proposals are sought from educational institutions, nonprofit organizations, and commercial organizations. Prospective offerors of a STIR proposal are encouraged to contact the appropriate ARO Technical Point of Contact (TPOC/ Program Manager) identified earlier in the ARO Research Areas of this BAA, to ascertain the extent of interest in the specific research project.

11.1.2. Research Sought. Proposals in the amount of \$50,000 or less are sought for research in the areas identified earlier in the ARO Research Areas of this BAA.

11.1.3. Proposal Preparation.

11.1.3.1. Organizations or institutions should submit proposals that are no more than twenty (20) pages in length, inclusive of the budget, transmittal letter, and attachments. No brochures or explanatory material should be submitted with the proposal.

11.1.3.2. Proposed research efforts must be "stand alone" and not predicated on the use of any facilities other than those under the direct control of the offeror. Research must be completed within nine (9) months of award of the agreement. **Extensions of the nine-month performance period will not be granted.**

11.1.3.3. The research proposal should follow the format set forth in Section II.D (Application and Submission Information) of this BAA. Limited rights in technical data and restricted rights in computer software should be identified as an attachment to the proposal. Otherwise, it will be assumed that the proposal does not contain any such limitations or restrictions.

11.1.3.4. No capital equipment may be purchased. Travel costs must not exceed \$500. Report preparation costs must not exceed \$100. Fee is not permitted under STIR Program awards. Indirect costs will not be reimbursed under STIR Program awards. Any applicable indirect costs must be borne by the offeror.

11.1.3.5. The principal investigator(s) should disclose and explain the relevance of the proposal to the research interests identified earlier in the ARO Research Areas of this BAA.

11.1.3.6. A brief, final technical report is required. Please note that your award document will reference Form 18, "Reporting Instructions," as found at <http://www.arl.army.mil/www/default.cfm?page=29>. You shall use these reporting instructions for format instructions only; the due date for receipt of a final technical report is thirty (30) days from completion of the award.

## **11.2. YOUNG INVESTIGATOR PROGRAM (YIP).**

YIP awards are one of the most prestigious honors bestowed by the Army to outstanding scientists beginning their independent careers. The objective of the YIP is to attract outstanding young university faculty Members to pursue fundamental research in areas relevant to the Army, to support their research in these areas, and to encourage their teaching and research careers. Young investigators meeting eligibility requirements may submit a YIP proposal. Outstanding



YIP projects may be considered for a Presidential Early Career Award for Scientists and Engineers (PECASE).

11.2.1. Eligibility. This program is open to U.S. citizens, U.S. Nationals, and Permanent Resident Aliens holding tenure-track positions at U.S. universities and colleges, who have held their graduate degrees (Ph.D. or equivalent) for fewer than five years at the time of application. Faculty at an institution of higher education which does not designate any faculty appointments as "tenure track" are eligible if that is so indicated in the proposal, and the supporting letter from the university states that the faculty member submitting the proposal will be considered for a permanent appointment.

11.2.2. Research Sought. Proposals are encouraged for research in areas described earlier in the ARO Research Areas. Proposals may be submitted at any time. As is the case for all other research programs, discussions with the cognizant ARO Technical Point of Contact (TPOC/ Program Manager) identified earlier in the ARO Research Areas of this BAA is strongly recommended before submission of a formal proposal. An award in each topic area is not guaranteed. YIP awards, not to exceed \$120,000 per year for three years, will be made based on evaluation factors discussed below.

11.2.3. Proposal Preparation.

11.2.3.1. An individual applying for a YIP award must submit a research proposal and a supporting letter, both through official university channels. Any resulting agreement will be made to the institution, not to the investigator. The research proposal should follow the format set forth in Section II.D (Application and Submission Information) of this BAA.

Technical Point of Contact: Contact the relevant Program Manager

11.2.3.2. The supporting letter must be from the applicant's Department Chairperson, Dean, or other official who speaks for the university, and should address support for and commitment to the applicant. Strong university support for the applicant is essential. This support can include the applicant's nine-month academic salary, release time from administrative responsibilities, the purchase of equipment, support for the applicant's graduate students, waiver of indirect costs, departmental cost sharing, start-up funding, and so on. It must be clear that the university views the applicant as a truly outstanding, faculty member, and is making a long-term commitment to the application and the research.

11.2.4. Evaluation Factors. The evaluation factors to be used in determining which proposals are selected for funding are described in Section II.E (Application review information) of this BAA. In addition, proposals submitted for YIP funding will be evaluated based on a long-term commitment by the university to the applicant and the research. YIP proposals will be selected for award on a competitive basis after a peer scientific review.

11.2.5. Continued Support. Support under the YIP is limited to three years. Upon completion of the YIP, young investigators may apply and be considered for continued support in the areas identified earlier in the ARO Research Areas of this BAA. Decisions about continued funding

outside the context of the YIP will be made following a peer scientific review, a review of ARO's research priorities, and the creativity and productivity demonstrated during the previous research program.

### **11.3. Presidential Early Career Award for Scientists and Engineers (PECASE).**

11.3.1. An applicant may not directly apply for a PECASE award. Instead, once a year, ARO technical program managers will nominate PECASE candidates from among all ARO YIP and other proposals and whitepapers (if any) received. The technical program manager will make the PECASE nomination based on strong endorsement of the YIP proposal by the external scientific reviewers and on the great potential shown by the applicant to contribute to science and to the mission of the Army.

11.3.2. Following nomination of a PECASE candidate, a supplemental PECASE proposal will be requested in which the candidate will indicate how PECASE funding would augment the YIP project. PECASE awards are not to exceed \$200,000 per year for five years. Supporting information including letters of recommendation, detailed scientific biographical information, and a summary of past research accomplishments will be required in the PECASE proposal.

11.3.3. Complete PECASE proposal packages will be evaluated by external scientific reviewers. The proposals which demonstrate the greatest potential to contribute to science and to the mission of the Army will be rank ordered by an Army PECASE Evaluation Committee. The PECASE packages are evaluated based on (1) Publications, (2) Presentations, (3) Scientific Leadership, (4) Mission Relevance of the research, (5) Community Outreach, (6) Department Commitment & Recommendation Letters, and (7) Scientific Quality of the research.

11.3.4 Continued Support. Support under PECASE is limited to five years. Upon completion of the PECASE project, young investigators may apply and be considered for continued support in the areas identified earlier in the ARO Research Areas of this BAA. Decisions about continued funding outside the context of PECASE will be made following a peer scientific review, a review of ARO's research priorities, and the creativity and productivity demonstrated during the previous research program.

Technical Point of Contact: Dr. Tom Doligalski, [thomas.l.doligalski.civ@mail.mil](mailto:thomas.l.doligalski.civ@mail.mil), (919) 549-4251.

### **11.4. RESEARCH INSTRUMENTATION (RI) PROGRAM.**

Research instrumentation is designed to improve the capabilities of U.S. universities to conduct research and educate scientists and engineers in areas important to national defense. Of the funds available to support ARO mission research described in this BAA, funds may be provided to purchase instrumentation in support of this research or in the development of new research capabilities.

11.4.1. Eligibility and Areas of Interest. It is highly recommended that potential offerors contact the appropriate ARO Technical Point of Contact (TPOC/ Program Manager) identified earlier in the ARO Research Areas of this BAA for advice and assistance before preparation of an instrumentation proposal.

11.4.2. Content of Request for Instrumentation. The request for instrumentation shall include:

11.4.2.1. A concise abstract (approximately 300 words) that describes the instrumentation requested and the research to be supported by that instrumentation.

11.4.2.2. A budget that addresses equipment to be purchased, cost per item, and total cost. Indicate the proposed source of the equipment and the name and telephone number of a contact at that source. The budget should indicate the amount of funds to be contributed by other sources toward the purchase of the instrumentation.

11.4.2.3. A description of how the proposed instrumentation will: (i) establish new research capabilities, (ii) contribute to research currently proposed to DOD, or (iii) enhance the quality of research currently being funded by ARO.

11.4.2.4. A description of how the proposed instrumentation will interface with or upgrade other research facilities and instrumentation now available.

11.4.2.5. A description of the amounts and sources of ongoing or proposed support for the research to be supported by the instrumentation.

**Note: Costs associated with equipment/facility modifications are generally considered unallowable and require the review and approval of the Grants Officer.**

## **11.5. DOD PROGRAMS.**

11.5.1. Each year the Army Research Office, along with the Office of Naval Research (ONR) and the Air Force Office of Scientific Research (AFOSR), participates in two programs sponsored by the Office of the Assistant Secretary of Defense for Research and Engineering. These two programs, titled the Defense University Research Instrumentation Program (DURIP) and the Research and Educational Program (REP) for Historically Black Colleges and Universities/Minority-Serving Institutions (HBCU/MI) are conducted under separate BAAs that are posted yearly on the ARO web site. For the purpose of these two programs, the areas of interest for submitting proposals are limited to Research Areas as identified earlier in the ARO Research Areas of this BAA. Offerors are reminded that these two BAAs have definitive closing dates for receipt of proposals (see each specific BAA for details). In addition, offerors must review the specific BAAs for eligibility considerations.

Solicitations are available on the ARO website under “Funding Opportunities” as well as the Grants.gov website. These solicitations will have a definite closing date for proposal submission, and offerors are advised to review the solicitations for eligibility considerations.

11.5.2. DEFENSE UNIVERSITY RESEARCH INSTRUMENTATION PROGRAM (DURIP). Research instrumentation is designed to improve the capabilities of U.S. universities to conduct research and educate scientists and engineers in areas important to national defense. Of the funds available to acquire research described earlier in the ARO Research Areas of this BAA, funds may be used only to purchase instrumentation in support of this research or in the development of new instrumentation in support of these research areas.

11.5.2.1. Eligibility and Areas of Interest. To be eligible for an instrumentation award, it is highly recommended that potential offerors contact the appropriate ARO Technical Point of Contact (TPOC/ Program Manager) identified earlier in the ARO Research Areas of this BAA for advice and assistance before preparation of an instrumentation proposal.

11.5.2.2 Content of Request for Instrumentation. The request for instrumentation shall include:

11.5.2.2.1. A concise abstract (approximately 300 words) that describes the instrumentation requested and the research to be supported by that instrumentation.

11.5.2.2.2 A budget that addresses equipment to be purchased, cost per item, and total cost. Indicate the proposed source of the equipment and the name and telephone number of a contact at that source. The budget should indicate the amount of funds to be contributed by other sources toward the purchase of the instrumentation.

11.5.2.2.3. A description of how the proposed instrumentation will: (i) establish new research capabilities, (ii) contribute to research currently proposed to DOD, or (iii) enhance the quality of research currently being funded by ARO.

11.5.2.2.4. A description of how the proposed instrumentation will interface with or upgrade other research facilities and instrumentation now available.

11.5.2.2.5. A description of the amounts and sources of ongoing or proposed support for the research to be supported by the instrumentation.

Technical Point of Contact: Dr. Tom Doligalski, [thomas.l.doligalski.civ@mail.mil](mailto:thomas.l.doligalski.civ@mail.mil), (919) 549-4251.

11.5.3. Research and Educational Program (REP) for Historically Black Colleges and Universities and Minority-Serving Institutions (HBCU/MI).

The Army Research Office periodically issues solicitations for proposals from HBCUs and MIs under the policy and guidance of the Office of the Assistant Secretary of Defense for Research and Engineering (OASD(R&E)). The program aims to (a) enhance HBCU/MI programs and capabilities in scientific and engineering disciplines critical to the national security functions of the DoD, (b) encourage greater HBCU/MI participation in DoD programs and activities, (c) increase the number of graduates, including underrepresented minorities, in the fields of science,

technology, engineering and/or mathematics (STEM), and (d) encourage research and educational collaborations.

Technical Point of Contact: Ms. Patricia Huff  
Email: [patricia.a.huff26.civ@mail.mil](mailto:patricia.a.huff26.civ@mail.mil), (919) 549-4283

### **3. OTHER PROGRAMS**

#### **a. CONFERENCE AND SYMPOSIA GRANTS**

1. Introduction. The Army supports conferences and symposia (as defined in the DOD Travel Regulations) in special areas of science that bring experts together to discuss recent research or educational findings or to expose other researchers or advanced graduate students to new research and educational techniques. The Army encourages the convening in the United States of major international conferences, symposia, and assemblies of international alliances.
2. Eligibility. Notwithstanding the Army's authority to provide grant support for such events, only non-commercial scientific, technical, or professional organization which qualify for tax exemption under the provision of 26 U.S.C. Sec. 501(c) (3) may receive a conference grant/symposia grant. Those who meet this requirement should also be aware that the Department of Defense (DOD) does not permit "co-sponsorship" (as defined in DoD 5500.07-R) absent additional high level staffing and approval. In other words, the conference grant support identified in this BAA is NOT DoD sponsorship or co-sponsorship since ARL//ARO is neither an organizer nor provider of any substantial logistical support for the conferences addressed in this section.
3. Conference Support. Conference support proposals should be submitted a minimum of six (6) months prior to the date of the conference
4. Technical Proposal Preparation. The technical portion of a proposal for support of a conference or symposium should include:
  - a. A one page or less summary indicating the objectives of the project.
  - b. The topics to be covered.
  - c. The location and probable date(s) and why the conference is considered appropriate at the time specified.
  - d. An explanation of how the conference will relate to the research interests of the Army and how it will contribute to the enhancement and improvement of scientific, engineering, and/or educational in general and activities as outlined earlier in the ARO Research Areas.
  - e. The name of chairperson(s)/principal investigator(s) and his/her biographical information.
  - f. A list of proposed participants and the methods of announcement or invitation.
  - g. A summary of how the results of the meeting will be disseminated.
  - h. A signed cover page.
5. Cost Proposal Preparation. The cost portion of the proposal should show:

- a. Total project conference costs by major cost elements.
  - b. Anticipated sources of conference income and amount from each.
  - c. Anticipated use of funds requested.
  - d. A signed budget.
6. Participant Support. Funds provided cannot be used for payment to any federal government employee for support, subsistence, or services in connection with the proposed conference or symposium.
7. Cognizant ARO Technical Point of Contact (TPOC/ Program Manager). It is highly recommended that potential offerors contact the appropriate ARO TPOC/ Program Manager identified earlier in the ARO Research Areas of this BAA for advice and assistance before preparation of a conference/symposia proposal.

**b. HISTORICALLY BLACK COLLEGES AND UNIVERSITIES AND MINORITY-SERVING INSTITUTIONS (HBCU/MIs)**

The Army has a long history of advocating and supporting research at HBCU/MIs. Through this solicitation, the Army Research Laboratory (ARL) and the Army Research Office (ARO) actively seek proposals from the HBCU/MI community in full and open competition with all offerors. Proposals may relate to any research topic described herein. In addition to single investigator research proposals, collaborative research proposals are also encouraged. Collaborations may be between HBCU/MIs and other institutions of higher education (not limited to HBCU/MIs) and/or industry partners.

The ARO encourages basic research proposals from HBCU/MIs in response to the ARO Research Areas of this BAA in full and open competition with all offerors. Included are special emphasis programs such as Short-Term Innovative Research (STIR) and the Young Investigator Program (YIP), described in detail elsewhere in this announcement.

Through this solicitation, the ARO encourages basic research proposals from the HBCU/MI community in full and open competition with all offerors. Proposals may relate to any research topic described herein. In addition to single investigator basic research, collaborative research proposals are also of interest. Collaborations may be between HBCU/MIs and other institutions of higher education (not limited to HBCU/MIs) and/or industry partners.

In addition to the ARO basic research program, there are other special funding opportunities available to HBCUs/MIs through ARO. Research and educational programs and activities for HBCUs/MIs are established in accordance with Section 252 of the National Defense Authorization Act for Fiscal Year 2010 (enacted in 10 U.S.C. 2362) and the Department of Defense Appropriations Act, 2010. As noted above, the program is executed under policy and guidance of the Office of the Assistant Secretary of Defense for Research and Engineering (OASD(R&E)). Solicitations are issued annually and are available on the ARO website as well as through Grants.gov.

The program aims to (a) enhance HBCU/MI programs and capabilities in scientific and engineering disciplines critical to the national security functions of the DoD, (b) encourage greater participation by HBCU/MI in DoD programs and activities, (c) increase the number of graduates, including underrepresented minorities, in the fields of science, technology, engineering and/or mathematics (STEM), and (d) encourage research and educational collaborations.

In addition, ARO may periodically release special DoD solicitations that target specific groups such as Tribal Colleges and Universities (TCUs). The DoD solicitations may offer one or more of the following components: research; instrumentation enhancement (for research and/or educational purposes); scholarships; fellowships; collaborative research; and centers of excellence.

Point of Contact for the ARO and DoD HBCU/MI programs is Ms. Patricia Huff  
Email: [patricia.a.huff26.civ@mail.mil](mailto:patricia.a.huff26.civ@mail.mil), (919) 549-4283

Eligibility. Eligible institutions include:

- a. institutions of higher education eligible for assistance under Title III or V of the Higher Education Act of 1965 (20 U.S.C. 1051 et seq.); or
- b. an accredited postsecondary minority serving institutions.

These definitions encompass a large and diverse group of institutions. Enrollments, accreditation, and other factors may affect an institution's eligibility in any given year. Therefore, each institution must determine its eligibility based on these criteria. A current copy of minority certification or Title III or V certificate and accreditation documents must be included with each proposal.

### **c. Science, Technology, Engineering, and Mathematics (STEM) Army Educational Outreach Program (AEOP)**

AEOP is comprised of Army-sponsored research, education, competitions, internships and practical experiences designed to engage and guide students and teachers in science, technology, engineering, and mathematics (STEM). More information about AEOP is available at [www.usaeop.com](http://www.usaeop.com). With available funding, the Army seeks to expand the reach and scope of the AEOP by considering ideas from the field for innovative STEM education programs that will fit into the AEOP portfolio and strengthen its mission of impacting the Nation's STEM literacy. Program emphasis may include, but is not limited to, reaching underrepresented or disadvantaged populations, reaching areas of the country not currently served by AEOP, supporting teachers' efforts to engage students, engage K-6 grade students in STEM activities.

Programs can apply a wide range of approaches including virtual education/resources, hands-on activities, development of classroom resources, novel partnerships with industry or academia, to name a few. Proposals should have a defined program evaluation plan to measure efficacy and collect/report participation data. The program also supports the development of methodologies (e.g., data collection, statistical methods, and research designs) that have the potential to help advance the DoD impact in STEM education outreach and/or the development of initiatives that aim to increase human capital in the management of STEM.

Technical Point of Contact: Mr. Michael Caccuitto, (919) 549-4369, e-mail: [michael.j.caccuitto.civ@mail.mil](mailto:michael.j.caccuitto.civ@mail.mil) .

#### **d. High School Apprenticeship Program (HSAP)/Undergraduate Research Apprenticeship Program (URAP)**

The HSAP funds the STEM apprenticeship of promising high school juniors and seniors to work in a university structured research environment under the direction of ARO sponsored principal investigators (PIs) serving as mentors. The URAP provides similar opportunities for Undergraduate students. Awards will be made as add-ons to research grants, MURIs, UARCs, and cooperative agreements that have at least 12 months' period of performance remaining from the date of HSAP/URAP proposal submission.

HSAP/URAP program goals are to:

- Provide authentic science and engineering research experience to high school and undergraduate students
- Educate students about the Army's interest and investment in science and engineering research and the associated educational opportunities available to students through the Army Educational Outreach Program (AEOP) and Department of Defense Graduate Fellowships
- Provide participants with experience in developing and presenting scientific research
- Benefit from the expertise of a scientist or engineer as a mentor for professional and academic development purposes
- Develop students' skills and background to prepare them for competitive entry to science and engineering education programs and careers

Limited funding is available annually for Principal Investigators interested in participating in HSAP/URAP. PIs should submit a short proposal that clearly articulates the meaningful research that the apprentice will conduct along with the strategy for mentorship and facilitation of follow-on opportunities (e.g., university attendance, other research experiences, etc). Proposal should include provisions to pay HSAP/URAP students a stipend equivalent to approximately \$10 per hour; not to exceed 300 hours total. Proposal should generally be limited to two students per PI, except for UARC or MURI awards on which up to 6 students are allowed. If more than one student is proposed, there must be a near equal mix of HSAP and URAP (i.e. proposals should not be for multiple URAP students only).

*Evaluation Criteria:* Proposals will be evaluated for both the scientific and educational merit of the proposed student research experience. PIs should communicate with the Technical Point of Contact below regarding expectations of educational merit.

Educational merit will be evaluated in the four areas:

- Student project definition –PI must determine what aspect(s) of the current program the student will be working on, desired deliverables, and anticipated research outcomes
- Mentor Identification – PIs should describe who within the lab will be responsible for



day to day mentoring of the students (e.g. PI, research associate, graduate student etc.) If direct supervision of students will be someone other than the PI, the mentor's CV must be provided.

- Anticipated outcomes – Identify the gains for the student and the lab for HSAP and URAP participation in terms of technical skills, scientific reasoning in specific domains, or publication opportunities. Follow-on opportunities and relationships for students within the lab are encouraged.
- Specific qualifications/Areas of Interest – PIs should explain any specific skills, coursework, educational level (high school or undergraduate) and particular areas of interest that would be required of a student candidate to work on the proposed project. If the lab or PI will recruit students without Army assistance the recruitment source, process and selection criteria must be identified. If the lab or PI will not facilitate the participant recruitment process ARO Youth Science will cooperate with the PI to recruit students.

*Describing an Outreach Strategy:* A primary objective of the HSAP and URAP programs is to expose new students to research opportunities in a research laboratory. Thus, PIs must describe a plan to attract and engage students not already affiliated with the PI, laboratory, or research project. The proposal should include a short description of the local outreach and student recruitment strategy to be used to make schools/students aware of the opportunity and identify/select student candidates. All student applications for the HSAP and URAP programs must be collected through the Army's Educational Outreach Program (AEOP) Application portal ([www.usaeop.com](http://www.usaeop.com)). PIs must plan to conduct local outreach to promote awareness of the opportunity among students/schools, and then direct them to the AEOP website to apply. The PI will receive all of the applications and make the final decision about which students are invited to participate in the lab. Student participants are responsible to develop a brief (one-page) abstract of their work to be included in an AEOP program booklet. PIs shall review and approve these abstracts before submission to ARO.

*Timeline:* Consistent with the BAA, proposals are accepted on a rolling basis. However, PIs interested in receiving HSAP/URAP funding for the summer of 2015 should submit proposals by December 10, 2014 to provide sufficient time for proposal review, award processing, and student outreach/recruitment. For the summers of 2016 and beyond, proposals should be submitted by November 10 of the prior year (For example, to receive funding for use in summer 2016, proposals should be submitted by November 10, 2015) to improve the timing of student outreach and recruitment. Proposals should not exceed three pages in length and must be submitted through grants.gov utilizing solicitation no. W911NF-12-R-0011-03. Please include the title of the research project, the proposal number of the core grant, and the specific number of HSAP and/or URAP opportunities.

Technical Point of Contact: Mr. Michael Caccuitto, (919) 549-4369, e-mail: [michael.j.caccuitto.civ@mail.mil](mailto:michael.j.caccuitto.civ@mail.mil) or Ms. ReShockie Smith, (919) 549-4339, e-mail: [reshockie.r.smith.ctr@mail.mil](mailto:reshockie.r.smith.ctr@mail.mil).

## **B. Award Information**

The ARL, to include ARO, have the authority to award a variety of instruments. The ARL/ARO reserves the right to use the type of instrument most appropriate for the effort proposed. Offerors should familiarize themselves with these instrument types and the applicable regulations before submitting a proposal. Following are brief descriptions of the possible award instruments.

1. Procurement Contract. A legal instrument, which, consistent with 31 U.S.C. 6303, reflects a relationship between the Federal Government and a State, a local government, or other recipient when the principal purpose of the instrument is to acquire property or services for the direct benefit or use of the Federal Government.
2. Grant - A legal instrument that, consistent with 31 U.S.C. 6304, is used to enter into a relationship:
  - a. The principal purpose of which is to transfer a thing of value to the recipient to carry out a public purpose of support or stimulation authorized by a law or the United States, rather than to acquire property or services for the DOD's direct benefit or use.
  - b. In which substantial involvement is not expected between the DOD and the recipient when carrying out the activity contemplated by the grant.
  - c. No fee or profit is allowed.
3. Cooperative Agreement - A legal instrument which, consistent with 31 U.S.C. 6305, is used to enter into the same kind of relationship as a grant (see definition "grant"), except that substantial involvement is expected between the DOD and the recipient when carrying out the activity contemplated by the cooperative agreement. The term does not include "cooperative research and development agreements" as defined in 15 U.S.C. 3710a. No fee or profit is allowed.

Grants and cooperative agreements are governed by the following regulation:

- a.2 Code of Federal Regulations (CFR) part 200, "Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards," as modified and supplemented by the Department of Defense's (DoD) interim implementation found at 2 CFR part 1103, "Interim Grants and Cooperative Agreements Implementation of Guidance in 2 CFR part 200" (79 FR 76047, December 19, 2014).

**Note: Any inconsistencies in the requirements of an assistance award shall be resolved in the following order:**

- Federal statutes
- Federal regulations
- 2 CFR part 200, as modified and supplemented by DoD's interim Implementation found in 2 CFR part 1103
- Award-specific terms and conditions

Copies of OMB regulations may be obtained from:

Executive Office of the President  
Publications Service  
New Executive Office Building  
725 17th Street, N.W., Room 2200  
Washington, DC 20503

Telephone: (202) 395-7332  
FAX Requests: (202) 395-9068  
<http://www.whitehouse.gov/OMB/grants>

An electronic copy of the DODGARs may be found at:

<http://www.ecfr.gov/cgi-bin/text-idx?rgn=div5;node=32%3A1.1.1.3.16>

4. Technology Investment Agreement (TIA) Assistance Transaction other than a Grant or Cooperative Agreement (see 32 CFR, Part 37). A legal instrument, consistent with 10 U.S.C. 2371, which may be used when the use of a contract, grant, or cooperative agreement is not feasible or appropriate for basic, applied, and advanced research projects. The research covered under a TIA shall not be duplicative of research being conducted under an existing DOD program. To the maximum extent practicable, TIA's shall provide for a 50/50 cost share between the government and the offeror. An offeror's cost share may take the form of cash, independent research and development (IR&D), foregone intellectual property rights, equipment, or access to unique facilities, as well as others. Due to the extent of cost share, and the fact that an other transaction does not qualify as a "funding agreement" as defined at 37 CFR 401.2(a), the intellectual property provisions of a TIA can be negotiated to provide expanded protection to an offeror's intellectual property. No fee or profit is allowed on other transactions. Cost sharing & matching is not an evaluation factor used under this BAA . Exceptions to this may exist if the offeror is proposing the use of a TIA or an OTA as an award instrument.
  
5. Other Transaction for Prototype (OTA). A legal instrument, consistent with 10 U.S.C. 2371 (as supplemented by Section 845 of Public Law 104-201 and Section 804 of Public Law 104-201), which may be used when the use of a contract, grant, or cooperative agreement is not feasible or appropriate for prototype projects directly relevant to weapons or weapon systems proposed to be acquired or developed by the DOD. The effort covered under an other transaction for prototype shall not be duplicative of effort being conducted under an existing DOD program (please refer to the "Other Transactions" OT Guide for Prototype Projects at [www.acq.osd.mil/dpap/Docs/otguide.doc](http://www.acq.osd.mil/dpap/Docs/otguide.doc)). For Cost-Sharing requirements for these types of awards please see "C2.16. COST SHARING" found on page 30 at the web-link directly above.

Unsuccessful Proposal Disposition. Unless noted in an offeror's proposal to the contrary, unsuccessful proposals will be retained for six (6) months from declination and then properly destroyed.

## **C. Eligibility Information**

### **1. Eligible Applicants:**

Eligible applicants under this BAA include degree-granting universities, nonprofit organizations, or industrial concerns. There is no restriction on the place of performance included in the BAA. Proposals are encouraged from Historically Black Colleges and Universities (as determined by the Secretary of Education to meet requirements of Title III of the Higher Education Act of 1965, as amended (20 U.S.C. § 1061)) and from Minority Serving Institutions defined as institutions “whose enrollment of a single minority or a combination of minorities...exceeds 50 percent of the total enrollment.” [20 U.S.C. § 1067q and 10 U.S.C. § 2362].

### **2. Cost Sharing or Matching:**

There is no required cost sharing, matching, or cost participation to be eligible under this BAA and cost sharing & matching is not an evaluation factor used under this BAA . Exceptions to this may exist if the offeror is proposing the use of a TIA or an OTA as an award instrument.

### **3. Duns and Bradstreet Universal Numbering System (DUNS) Number and System for Award Management (SAM):**

Each applicant (unless the applicant is an individual or Federal agency that is exempt from those requirements under 2 CFR 25.110(b) or (c), or has an exception approved by the agency under 2 CFR 25.110(d)) is required to: (i) Be registered in the SAM prior to submitting its application; (ii) provide a valid DUNS number in its application; and (iii) continue to maintain an active SAM registration with current information at all times during which it has an active Federal award or an application or plan under consideration by an agency. An award will not be made to an applicant until the applicant has complied with all applicable DUNS and SAM requirements.

### **4. Other:**

Foreign owned, controlled, or influenced firms are advised that security restrictions may apply that could preclude their participation in these efforts. Before preparing a proposal, such firms are requested to contact the ARL Security and Counterintelligence Branch (301) 394-2441 concerning their eligibility. Pursuant to the policy of FAR 35.017 and supplements, selected Federally Funded Research and Development Centers may propose under this BAA.

## **D. Application and Submission Information**

### **1. Address to View Broad Agency Announcement**

This BAA may be accessed from [www.grants.gov](http://www.grants.gov), [www.fbo.gov](http://www.fbo.gov), and the ARL website <http://www.arl.army.mil/www/default.cfm?page=8>.

### **2. Content and Form of Application Submission**

#### **Section 1 - General Information:**

**Preliminary Inquires:** The ARL and ARO receive several hundred research proposals annually. Because of financial constraints, we are able to provide support for only a limited number of the proposals received. We realize that the preparation of a research proposal often represents a substantial investment of time and effort by the offeror. Therefore, in an attempt to minimize this burden, we strongly encourage organizations and individuals interested in submitting research proposals to make preliminary inquiries as to the general need for the type of research effort contemplated, before expending extensive effort in preparing a whitepaper, detailed research proposal or submitting proprietary information. The TPOCs' names, telephone numbers, and e-mail addresses are listed immediately after each research area of interest and they should be contacted as appropriate prior to the submission of whitepapers or formal proposals.

**Classified Submissions:** Classified proposals are not expected. However, in an unusual circumstance where an offeror believes a proposal has the potential to be classified, contact the corresponding security office. For ARL Core Competencies contact (301) 394-1978 and for the ARO Research Areas contact (919) 549-4356, prior to the proposal's submission.

**Use of Color in Proposals:** All proposals received shall be stored as electronic images. Electronic color images require a significantly larger amount of storage space than black-and-white images. As a result, offerors' use of color in proposals should be minimal and used only when necessary for details. Do not use color if it is not necessary.

**Post Employment Conflict of Interest:** There are certain post employment restrictions on former federal officers and employees, including special government employees (Section 207 of Title 18, U.S.C.). If a prospective offeror believes a conflict of interest may exist, the situation should be discussed with Technical Point of Contact (TPOC) listed in the BAA for their area of scientific research who will then coordinate with appropriate ARO/ARL legal personnel prior to expending time and effort in preparing a proposal.

**Statement of Disclosure Preference:** Please complete Form 52 or 52A stating your preference for release of information contained in your proposal. Copies of these forms are available at <http://www.arl.army.mil/www/default.cfm?Action=29&Page=218#baaforms>.

**NOTE:** Proposals may be handled for administrative purposes by support

contractors. These support contractors are prohibited from competition on BAA proposals and are bound by appropriate non-disclosure requirements.

Equipment: Normally, title to equipment or other tangible property purchased with Government funds vests with nonprofit institutions of higher education or with nonprofit research organizations if vesting will facilitate scientific research performed for the Government. Commercial organizations are expected to possess the necessary plant and equipment to conduct the proposed research. Deviations may be made on a case-by-case basis to allow commercial organizations to purchase equipment but disposition instructions must be followed.

## **Section 2 – The Application Process**

The application process is in three stages as follows:

Stage 1- Verify the accuracy of your Dun & Bradstreet (D&B) registration at the D&B website <http://fedgov.dnb.com/webform> before registering with the System for Award Management System (SAM) at <https://sam.gov>. Prospective offerors must be registered in SAM prior to award. The SAM obtains Legal Business Name, Doing Business Name (DBA), Physical Address, and Postal Code/ Zip+4 data fields from D&B: If corrections are required, registrants will not be able to enter/modify these fields in SAM; they will be pre-populated using D&B Data Universal Numbering System (DUNS) record data. When D&B confirms the correction has been made, the registrant must then re-visit sam.gov and click a “yes” D&B's changes. Only at this point will the D&B data be accepted into the SAM record. Allow two (2) business days for D&B to send the modified data to SAM.

Stage 2 - Prospective proposers are requested to submit whitepapers prior to the submission of a complete, more detailed proposal. The purpose of whitepapers is to minimize the labor and cost associated with the production of detailed proposals that have very little chance of being selected for funding. Based on assessment of the whitepapers, feedback will be provided to the proposers to encourage or discourage them from submitting full proposals. Whitepapers should present the effort in sufficient detail to allow evaluation of the concept's technical merit and its potential contributions of the effort to the Army mission. Due to Government budget uncertainties, no specific dollars have been reserved for awards under this BAA.

Stage 3 - Interested offerors are required to submit full proposals. All proposals submitted under the terms and conditions cited in this BAA will be reviewed regardless of the feedback on, or lack of, a whitepaper.

All proposals for Assistance Instruments must be submitted electronically through Grants.gov in a Portable Document Format (.PDF). Proposals for Contracts may be submitted via either Grants.gov or email to: [usarmy.rtp.aro.mbx.baa@mail.mil](mailto:usarmy.rtp.aro.mbx.baa@mail.mil). Requests for waiver of electronic submission may be submitted via e-mail to: [usarmy.rtp.aro.mbx.baa@mail.mil](mailto:usarmy.rtp.aro.mbx.baa@mail.mil) or regular mail:

Army Research Office  
ATTN: RDRL-RO (Proposal Processing)  
P.O. Box 12211  
RTP, NC 27709-2211

All required forms for proposals may be downloaded from the ARO web site at <http://www.arl.army.mil/www/default.cfm?page=29> under "For the Researcher" (Forms, ARO BAA Forms).

### **Section 3: WhitePaper Preparation**

1. Whitepapers should focus on describing details of the proposed research, including how it is innovative and how it could substantially increase the scientific state of the art, Army relevance, and potential impact should also be described.
2. Whitepapers are limited to five (5) pages plus the cover page and a one-page addendum as discussed below. Evaluators will only review the whitepaper cover page and up to five pages and the addendum.
3. Combine all files and forms into a single PDF before submitting.

#### **TECHNICAL INFORMATION:**

1. A detailed discussion of the effort's scientific research objective, approach, relationship to similar research, and level of effort shall be submitted. Also include the nature and extent of the anticipated results and, if known, the manner in which the work will contribute to the accomplishment of Army's mission and how this would be demonstrated.
2. The type of support, if any, that the offeror requests of the Government, such as facilities, equipment, demonstration sites, test ranges, software, personnel or materials, shall be identified as government furnished equipment (GFE), government furnished information (GFI), government furnished property (GFP), or government furnished data (GFD). Offerors shall indicate any Government coordination that may be required for obtaining equipment or facilities necessary to perform any simulations or exercises that would demonstrate the proposed capability.
3. As an addendum to the whitepaper, include biographical sketches (one page) of the key personnel who will perform the research, highlighting their qualifications and experience.
4. The cost portion of the whitepaper shall contain a brief cost estimate revealing all the component parts of the proposal, including research hours, burden, material costs, travel, etc.

#### RESTRICTIVE MARKINGS ON WHITEPAPERS:

1. Any proprietary data that the offeror intends to be used only by the Government for evaluation purchases must be identified. The offeror must also identify any technical data or computer software contained in the whitepaper that is to be treated by the Government as limited rights in technical data and restricted rights in computer software. In the absence of such identification, the Government will assume to no limitations or restrictions on technical data or computer software included in the whitepaper. Records or data bearing a restrictive legend may be included in the whitepaper. It is the intent of the Army to treat all whitepapers as privileged information before the award and to disclose their contents only for the purpose of evaluation.
2. The offerors are cautioned, however, that portions of the whitepapers may be subject to release under terms of the Freedom of Information Act, 5 U.S.C. 552, as amended.

#### EVALUATION AND DISPOSITION OF WHITEPAPERS:

1. Evaluation Process: Offerors are advised that invitations for complete proposals will be made based on the initial whitepaper submission and the availability of funding. As stated above, the whitepaper will be evaluated for the concept's scientific merit and potential contributions of the effort to the Army mission. Offerors whose whitepapers are evaluated as having significant scientific merit may be invited to submit a complete detailed proposal. Care must be exercised to ensure that classified, sensitive, critical technologies are not included. If such information is required, appropriate restrictive markings and procedures should be applied.
2. Disposition Process: After completion of the evaluation, the offeror will be notified in writing of the results.

#### **Section 4: WhitePaper Submission**

All WhitePapers should be submitted electronically and should be emailed directly to the Technical Point of Contact. Include the BAA number W911NF-12-R-0011-03 in the email subject line.

Whitepapers submitted via email must be in the following format but do not require any special forms:

- Single PDF formatted file as an email attachment
- Page Size: 8 ½ x 11 inches
- Margins – 1 inch
- Spacing – single
- Font – Times New Roman, 12 point



## **Section 5: Preparation of Complete Research Proposals**

COVER PAGE ARO FORM 51 for Contract proposals submitted by email. The Form SF 424 (R&R) is for all proposals submitted through Grants.gov (Assistance Instruments must submit through Grants.gov):

1. A Cover Page is required. Proposals will not be processed without either: (1) a signed Cover Page, ARO Form 51, or (2) an SF 424 R & R Form. More information regarding the Cover Page can be found in Section 6.
2. Should the project be carried out at a branch campus or other component of the submitting organization, that branch campus or component should be identified in the space provided (Block 11 on the ARO Form 51 and Block 12 on the SF424 R&R).
3. The title of the proposed project should be brief, scientifically representative, intelligible to a scientifically literate reader, and suitable for use in the public domain.
4. The proposed duration for which support is requested should be consistent with the nature and complexity of the proposed activity. For Core Competencies listed at Section II, A, 1, offerors shall discuss the preferred performance period with the TPOC. For Research Areas listed at Section II, A, 2, the ARO normally awards research agreements for periods up to three (3) years (1 basic year of performance with two 1-year options). Nevertheless, the federal awarding agency reserves the right to make awards with shorter or longer periods of performance.
5. Specification of a desired starting date for the project is important and helpful however, requested effective dates cannot be guaranteed.
6. Pursuant to 31 U.S.C. 7701, as amended by the Debt Collection Improvement Act of 1996 [Section 31001(I)(1), Public Law 104-134], federal agencies shall obtain each awardees' Taxpayer Identification Number (TIN). This number may be the Employer Identification Number for a business or non-profit entity or the Social Security Number for an individual. The TIN is being obtained for purposes of collecting and reporting on any delinquent amounts that may arise out of an awardees' relationship with the Government.
7. Offerors shall provide their organization's Data Universal Numbering System (DUNS) number. The DUNS number is a nine-digit number assigned by Dun and Bradstreet Information Services.
8. Offerors shall provide their assigned Commercial and Government Entity (CAGE) Code. The CAGE Code is a 5-character code assigned and maintained by the Defense Logistics Service Center (DLSC) to identify a commercial plant or establishment.

TABLE OF CONTENTS:

Use the following Format for the PROPOSAL TABLE OF CONTENTS

Forms are available at

<http://www.arl.army.mil/www/default.cfm?page=218#forms>

SECTION	PAGE NUMBER
Table of Contents	A-1
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Current and Pending Support	G-1 - G-☐
Facilities, Equipment, and Other Resources	H-1 - H-☐
Proposal Budget	I-1 - I-☐
Contract Facilities Capital Cost of Money (DD Form 1861)	J-1
Appendices	K-☐
List Appendix Items: _____	
_____	

This format applies to proposals submitted via email and via Grants.gov. Offerors' proposals should show the location of each section of the proposal, as well as major subdivisions of the project description.

STATEMENT OF DISCLOSURE PREFERENCE (FORM 52 OR 52A): Complete and sign ARO Form 52 (Industrial Contractors) or ARO Form 52A (Educational and Nonprofit Organizations).

RESEARCH AND RELATED Other Project Information: Must be completed and signed by all organizations.

PROJECT ABSTRACT:

1. The Project Abstract shall include a concise statement of work and basic approaches to be used in the proposed effort. The abstract should include a statement of scientific objectives, methods to be employed, and the significance of the proposed effort to the advancement of knowledge.
2. The abstract should be no longer than one (1) page and be in a form that is releasable under the Freedom of Information Act, 5 U.S.C. 552, as amended. The abstract should indicate the effort intended for each 12-month period of research, where applicable.

TECHNICAL PROPOSAL (PROJECT DESCRIPTION): The technical portion of the proposal shall contain the following:

1. A complete discussion stating the background and objectives of the proposed work, the scientific approaches to be considered, the relationship to competing or related research, and the level of effort to be employed. Include also the nature and extent of the anticipated results and how they will significantly advance the scientific state-of-the-art. Also, if known, include the manner in which the work will contribute to the accomplishment of the Army's mission. Ensure the proposal identifies any scientific uncertainties and describes specific approaches for the resolution of the uncertainties.
2. A brief description of your organization. If the offeror has extensive government contracting experience and has previously provided the information to the ARL, the information need not be provided again. A statement setting forth this condition should be made.
3. The names of other federal, state, local agencies, or other parties receiving the proposal and/or funding the proposed effort. If none, so state. Concurrent or later submission of the proposal to other organizations will not prejudice its review by the ARL if we are kept informed of the situation.
4. A statement regarding possible impact, if any, of the proposed effort on the environment considering as a minimum its effect upon water, atmosphere, natural resources, human resources, and any other values.
5. The offeror shall provide a statement regarding the use of Class I and Class II ozone-depleting substances. Ozone-depleting substances mean any substance designated as Class I by EPA, including but not limited to chlorofluorocarbons, halons, carbon tetrachloride, and methyl chloroform and any substance designated as Class II by EPA, including but not limited to hydrochlorofluorocarbons. See 40 C.F.R. Part 82 for detailed information. If Class I or II substances are to be utilized, a list shall be provided as part of the offeror's proposal. If none, so state.

6. The type of support, if any, requested (e.g., facilities, equipment, and materials).

#### BIOGRAPHICAL SKETCHES:

1. This Section shall contain the biographical sketches for senior personnel only.
  - a. Primary Principal Investigator: The “Primary” PI provides a single or initial point of communication between the sponsoring agency(s) and the awardee organization(s) about scientific matters. If not otherwise designated, the first PI listed will serve as the “Primary” PI. This individual can be changed with notification of the agency. The sponsoring agency(s) does not infer any additional scientific stature to this role among collaborating investigators.
  - b. Co-Principal Investigators: The individual(s) a research organization designates as having an appropriate level of authority and responsibility for the proper conduct of the research and submission of required reports to the agency. When an organization designates more than one PI, it identifies them as individuals who share the authority and responsibility for leading and directing the research, intellectually and logistically. The sponsoring agency(s) does not infer any distinction among multiple PIs.
2. The following information is required:
  - a. Relevant experience and employment history including a description of any prior Federal employment within one year preceding the date of proposal submission.
  - b. List of up to five (5) publications most closely related to the proposed project and up to five (5) other significant publications, including those being printed. Patents, copyrights, or software systems developed may be substituted for publications.
  - c. List of persons, other than those cited in the publications list, who have collaborated on a project or a book, article, report or paper within the last four (4) years. Include pending publications and submissions. Otherwise, state "None."
  - d. Names of each investigator's own graduate or post graduate advisors and advisees. The information provided in "c" and "d" is used to help identify potential conflicts or bias in the selection of reviewers.
3. For the personnel categories of postdoctoral associates, other professionals, and students (research assistants), the proposal may include information on exceptional qualifications of these individuals that merit consideration in the evaluation of the proposal.
4. The biographical sketches are limited to three (3) pages per investigator and other individuals that merit consideration.

**BIBLIOGRAPHY:** A bibliography of pertinent literature is required. Citations must be complete (including full name of author(s), title, and location in the literature).

**CURRENT AND PENDING SUPPORT:**

1. All project support from whatever source must be listed. The list must include all projects requiring a portion of the principal investigator's and other senior personnel's time, even if they receive no salary support from the project(s).
2. The information should include, as a minimum: (i) the project/proposal title and brief description, (ii) the name and location of the organization or agency presently funding the work or requested to fund such work, (iii) the award amount or annual dollar volume of the effort, (iv) the period of performance, and (v) a breakdown of the time required of the principal investigator and/or other senior personnel.

**FACILITIES, EQUIPMENT, AND OTHER RESOURCES:** The offeror should include in the proposal a listing of facilities, equipment, and other resources already available to perform the research proposed.

**BUDGET PROPOSAL (including DD Form 1861):**

1. Each proposal must contain a budget for each year of support requested and a cumulative budget for the full term of requested support. The budget form (Form 99) may be reproduced as needed. Locally produced versions may be used, but you may not make substitutions in prescribed budget categories nor alter or rearrange the cost categories as they appear on the form. The proposal may request funds under any of the categories listed so long as the item is considered necessary to perform the proposed work and is not precluded by applicable cost principles. In addition to the forms, the budget proposal should include budget justification for each year.
2. A signed summary budget page must be included. The documentation pages should be titled "Budget Explanation Page" and numbered chronologically starting with the budget form. The need for each item should be explained clearly.
3. All cost data must be current and complete. Costs proposed must conform to the following principles and procedures:

2 Code of Federal Regulations (CFR) part 200, "Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards," as modified and supplemented by the Department of Defense's (DoD) interim implementation found at 2 CFR part 1103, "Interim Grants and Cooperative Agreements Implementation of Guidance in 2 CFR part 200" (79 FR 76047, December 19, 2014).

\*For those nonprofit organizations specifically exempt from the provisions of 2 CFR Part 230, FAR Part 31 and DFARS Part 231 shall apply.

4. Sample itemized budgets and the information they must include for a contract and for grants and cooperative agreements can be found at Section II. H. (Other Information). Before award it must be established that an approved accounting system and financial management system exist.

APPENDICES: Some situations require that special information and supporting documents be included in the proposal before funding can be approved. Such information and documentation should be included by appendix to the proposal.

### **Section 6: Submission of Complete Research Proposals**

Proposals must be submitted through the offeror's organizational office having responsibility for Government business relations. All signatures must be that of an official authorized to commit the organization in business and financial affairs.

Proposals must be submitted electronically using one of the two following formats. The content will remain the same whether using email or Grants.gov.

#### EMAIL SUBMISSION (for Contracts only)

- a. Contracts may be E-mailed directly to [usarmy.rtp.aro.mbx.baa@mail.mil](mailto:usarmy.rtp.aro.mbx.baa@mail.mil). Do not email full proposals to the TPOC. All e-mailed proposals must contain the information outlined in Section II, D, 2 (Section 5), entitled "Table of Contents" including the electronic forms as follows: (1) ARO Form 51, Proposal Cover Page; (2) ARO Form 99, Summary Proposal Budget or equivalent, (3) ARO Current and Pending Support (unnumbered form), (4) ARO Form 52 or ARO Form 52a, and (5) Research and Related Other Project Information. (6) Representation by Corporations Regarding conviction of a Felony Criminal Violation under any Federal or State Law and Representation by Corporations Regarding an Unpaid Delinquent Tax Liability. These forms may be accessed at <http://www.arl.army.mil/www/default.cfm?page=218#forms> under BAA Forms. The fillable PDF forms may be saved to a working directory on a computer and opened and filled in using the latest compatible Adobe Reader software application found at this Grants.Gov hot-link: <http://www.grants.gov/web/grants/support/technical-support/software/adobe-reader-compatibility.html>. **Note:** Representation by Corporations Regarding Conviction of a Felony Criminal Violation and Unpaid Delinquent Tax Liability require POC information and signature of the authorized representative.
- b. All forms requiring signature must be completed, printed, signed, and scanned into a PDF document. All documents must be combined into a single PDF formatted file to be attached to the e-mail.
- c. Proposal documents (excluding required forms) must use the following format:
  - Page Size – 8 ½ x 11 inches

- Margins – 1 inch
- Spacing – single
- Font – Times New Roman, 12 point

GRANTS.GOV SUBMISSION (For all Assistance Instruments. Contracts may be submitted via Grants.gov or via e-mail submission.)

1. Grants.gov Registration (See Section 7 below) must be accomplished prior to application through this process. Note- All web links referenced in this section and Section 7 are current as of 24 JAN 2015, but are subject to change by grants.gov and may not be updated here.
2. Specific forms are required for submission of a proposal. The forms are contained in the Application Package available through the Grants.gov application process. To access these materials, go to <http://www.grants.gov>, select "Apply for Grants," and then select "Download Application Package." A Grant Application Package and Application Instructions are available for download through the Grants.Gov Apply portal under CFDA Number 12.431/Funding Opportunity Number W911NF-12-R-0011-03. The following documents are mandatory: (1) Application for Federal Assistance (Research and Related) (SF 424 (R&R)), and (2) Attachments form.
  - (a) The SF 424 (R&R) form is to be used as the cover page for all proposals. Authorized Organization Representative (AOR) usernames and passwords serve as “electronic signatures” when your organization submits applications through Grants.gov. By using the SF 424 (R&R), proposers are providing the certification required by 32 CFR Part 28 regarding lobbying. The SF 424 (R&R) must be fully completed. Block 11, “Descriptive Title of Applicant’s Project,” **must reference the research topic area being addressed in the effort** by identifying the specific paragraph from Section II, A 1 (ARL) or Section II, A, 2 (ARO).
  - (b) The Attachments form must contain the information outlined in Section II, D, 2 (Section 5), entitled “Table of Contents” of this BAA including the electronic forms as follows: (1) Research and Related Other Project Information; (2) ARO Form 99, Summary Proposal Budget; (3) ARO Current and Pending Support (unnumbered form), (4) Representation by Corporations Regarding conviction of a Felony Criminal Violation under any Federal or State Law and Representation by Corporations Regarding an Unpaid Delinquent Tax Liability. Items (1)-(3) forms may be accessed at <http://www.arl.army.mil/www/default.cfm?page=218#forms>. Item (4) “Representation relating to Tax Liability and Felony Convictions” may be submitted on a word document and attached to available field within the attachments form. The fillable PDF forms may be saved to a working directory on a computer and opened and filled in using the latest compatible Adobe Reader software application found at this Grants.Gov hot-link: <http://www.grants.gov/web/grants/support/technical-support/software/adobe-reader-compatibility.html>. **Note:** Representation by Corporations Regarding Conviction of a Felony Criminal Violation and Unpaid Delinquent Tax Liability require POC information and signature of the authorized representative.

- (c) All documents must be combined into separate and single PDF formatted files titled using the Table of Contents names listed in “Section 5: Preparation of complete Research Proposals”. Include “W911NF-12-R-0011-03” in title so the proposal will be distinguished from other BAA submissions and upload using the mandatory Attachments form.
- (d) The training demonstration at <http://www.grants.gov/documents/19/23905/GrantsGovApplicantGeneralOverview.pdf/a57fc764-d310-410d-a8c1-057986464745> will assist AORs in the application process. Remember that you must open and complete the Application for Federal Assistance (Research and Related) (SF 424 (R&R)) first, as this form will automatically populate data fields in other forms. If you encounter any problems, contact customer support at 1-800-518-4726 or at [support@grants.gov](mailto:support@grants.gov). If you forget your user name or password, follow the instructions provided in the Credential Provider tutorial. Tutorials may be printed by right-clicking on the tutorial and selecting “Print”.
- (e) As it is possible for grants.gov to reject the proposal during this process, it is strongly recommended that proposals be uploaded at least two days before any established deadline in the BAA so that they will not be received late and be ineligible for award consideration. It is also recommended to start uploading proposals at least two days before the deadline to plan ahead for any potential technical and/or input problems involving the applicant’s own equipment.

### **Section 7: Grants.Gov Registration**

Registration. Each organization that desires to submit applications via Grants.Gov must complete a one-time registration. There are several one-time actions your organization must complete in order to submit applications through Grants.gov (e.g., obtain a Dun and Bradstreet Data Universal Numbering System (DUNS) number, register with the System for Award Management (SAM), register with the credential provider, register with Grants.gov and obtain approval for an Authorized Organization Representative (AOR) to submit applications on behalf of the organization). To registered please see <http://www.grants.gov/web/grants/applicants/organization-registration.html>

Please note the registration process for an Organization or an Individual can take between three to five business days or as long as four weeks if all steps are not completed in a timely manner.

Questions relating to the registration process, system requirements, how an application form works, or the submittal process should be directed to Grants.gov at 1-800-518-4726 or [support@grants.gov](mailto:support@grants.gov).



### **3. Submission Dates and Times:**

#### **WhitePapers and Proposals:**

Whitepapers and proposals will be considered through the methods noted previously until and including 31 March 2017 except for special programs identified in this BAA that may announce specific opening/closing dates.

### **4. Intergovernmental Review**

Not Applicable

### **5. Funding Restrictions:**

There are no specific funding restrictions associated with this BAA, e.g., direct, indirect costs, etc.

### **6. Other Submission Requirements:**

Information To Be Requested From Successful Offerors- Offerors whose proposals are accepted for funding will be contacted before award to provide additional information required for award. The required information is normally limited to clarifying budget explanations, representations, certifications, and some technical aspects.

For Contracts Only- Performance Work Statements (PWS)- prior to award the Contracting Officer may request that the contractor submit a PWS for the effort to be performed, which will be incorporated into the contract at the time of award.

## **E. Application Review Information:**

### **1. Criteria:**

**Proposals submitted in response to the ARL portion of this BAA (Section II.A.1) will be evaluated using the factors listed below (in descending order of importance):**

- a. The overall scientific and/or technical merits of the proposal.
- b. The potential contributions of the effort to the Army mission and the extent to which the research effort will contribute to balancing the overall ARL/ARO research program.
- c. The offeror's capabilities, related experience, facilities, techniques, or unique combinations of these, which are integral factors for achieving the proposed objectives.

- d. The qualifications, capabilities, and experience of the proposed principal investigator, team leader, or other key personnel who are critical to achievement of the proposed objectives.
- e. The offeror's record of past performance.
- f. The reasonableness and realism of proposed costs and fee.

**Note: Proposals submitted to the ARMY RESEARCH OFFICE (Section II.A.2) and OTHER PROGRAMS (Section II.A.3) portions of this BAA will be evaluated using the following factors:**

- a. Potential of the proposal to achieve the stated objective of the research.
- b. Likelihood of the proposed method to develop new capabilities or enhance existing capabilities.
- c. Qualifications, capabilities, experience, and past research accomplishments of the investigator(s) and key personnel who are critical to achieving the objectives of the proposal.
- d. Realism and reasonableness of budget.
- e. Potential of the proposal to achieve the stated goals of the program and the extent to which the proposed effort would enhance related studies.
- f. Actual or potential relevance of the proposed research to any part of the mission of your activity.
- g. Overall potential of the proposed effort

## **2. Review and Selection Process:**

- a. Upon receipt of a proposal, the ARL/ARO staff will perform an initial review of its scientific merit and potential contribution to the Army mission and also determine if funds are expected to be available for the effort. Proposals not considered having sufficient scientific merit or relevance to the Army's needs or those in areas for which funds are not expected to be available may be declined without further review.
- b. Prior to award all proposals and contents are treated as proprietary information and are disclosed only for the purpose of evaluation. Proposals not declined as a result of an initial review will be subject to a peer review by highly qualified scientists. While the offeror may restrict the evaluation to scientists from within the Government, to do so may prevent review of the proposal by those most qualified in the field of research covered by the proposal. The offeror must indicate on the appropriate proposal form

(Form 52 or 52A) any limitation to be placed on disclosure of information contained in the proposal.

- c. Each proposal will be evaluated based on all the evaluation criteria rather than against other proposals for research in the same general area.

### **3. Recipient Qualification**

For CONTRACT Proposals:

The Federal Awardee Performance and Integrity Information System (FAPIIS) will be checked prior to making an award. The web address is: <http://www.fapiis.gov/fapiis/index.jsp>. The applicant representing the entity may comment in this system on any information about itself that a Federal Government Official entered. The information in FAPIIS will be used in making a judgment about the entity's integrity, business ethics, and record of performance under Federal awards that may affect the official's determination that the applicant is qualified to receive an award.

#### **252.209-7998 Representation Regarding Conviction of a Felony Criminal Violation under any Federal or State Law.**

See [Class Deviation 2012-O0007](#), Prohibition Against Contracting with Corporations that Have a Felony Conviction, dated March 9, 2012. Contracting officers shall include the provision at 252.209-7998 in all solicitations that will use funds made available by Division H of the Consolidated Appropriations Act, 2012, including solicitations for acquisition of commercial items under FAR part 12, and shall apply the restrictions included in the deviation. This deviation is effective beginning March 9, 2012, and remains in effect until incorporated in the FAR or DFARS or otherwise rescinded.

#### **252.209-7999 Representation by Corporations Regarding an Unpaid Delinquent Tax Liability or a Felony Conviction under any Federal Law.**

See [Class Deviation 2012-O0004](#), Prohibition Against Contracting With Corporations That Have an Unpaid Delinquent Tax Liability or a Felony Conviction under Federal Law, dated January 23, 2012. Contracting officers shall include this provision in all solicitations that will use funds made available by Division A of the Consolidated Appropriations Act, 2012, including solicitations for acquisition of commercial items under FAR part 12, and shall apply the restrictions included in the deviation. This deviation is effective beginning January 23, 2012, and remains in effect until incorporated in the FAR or DFARS or otherwise rescinded.

*(Revised May 28, 2014)*

For Assistance awards recipients will be required to submit the following representation prior to award.

**Representations under DoD Assistance Agreements: Appropriations Provisions on Tax Delinquency and Felony Convictions**

The applicant is ( ) is not ( ) a “Corporation” meaning any entity, including any institution of higher education, other nonprofit organization, or for-profit entity that has filed articles of incorporation.

If the applicant is a “Corporation” please complete the following representations:

(1) The applicant represents that it is ( ) is not ( ) a corporation that has any unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or have lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability.

(2) The applicant represents that it is ( ) is not ( ) is not a corporation that was convicted of a criminal violation under any Federal law within the preceding 24 months.

NOTE: If an applicant responds in the affirmative to either of the above representations, the applicant is ineligible to receive an award unless the agency suspension and debarment official (SDO) has considered suspension or debarment and determined that further action is not required to protect the Government’s interests. The applicant therefore should provide information about its tax liability or conviction to the agency’s SDO as soon as it can do so, to facilitate completion of the required considerations before award decisions are made. Applicant’s authorized representative must sign and date form.

**F. Award Administration Information:**

**1. Award Notices:**

Offerors whose proposals are recommended for award will be contacted by a Contract/Grant Specialist to discuss any additional information required for award. This may include representations and certifications, revised budgets or budget explanations, certificate of current cost or pricing data, subcontracting plan for small businesses, and other information as applicable to the proposed award. The anticipated award start date will be determined at this time. The appropriate award document, when signed by the Government Contracting/Grants Officer is the authorizing award document.

## **2. Administrative and National Policy Requirements:**

### **a. Required Certifications**

For CONTRACT Proposals:

Certifications Required for Contract Awards. Certifications and representations shall be completed by successful offerors prior to award. Federal Acquisition Regulation (FAR) Online Representations and Certifications are to be completed through SAM at website <https://www.SAM.gov>. Defense FAR Supplement and contract specific certification packages will be provided to the contractor for completion prior to award.

For GRANT and COOPERATIVE AGREEMENT Proposals:

Grant awards greater than \$100,000 require a certification of compliance with a national policy mandate concerning lobbying. Statutes and Government-wide regulations require the certification to be submitted prior to award. The certification is set forth at Appendix A to 32 CFR 28 regarding lobbying. When submitting your grant through Grants.gov, by completing blocks 17 and 19 of the Standard Form 424 Research and Related (R&R) Form, the grant applicant is providing the certification on lobbying required by 32 CFR Part 28, otherwise a signed copy by the authorized representative must be provided.

Below is the required certification:

#### **1. CERTIFICATION AT APPENDIX A TO 32 CFR PART 28 REGARDING LOBBYING:**

##### **Certification for Contracts, Grants, Loans, and Cooperative Agreements**

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of an agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements) and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by Section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than \$10,000 and not more than \$100,000 for each such failure.

### **b. Policy Requirements**

1) Protection of Human Subjects. Assistance Instruments Only. All research involving human subjects must be conducted in accordance with 32 CFR 219, 10 U.S.C. 980, and DoDI 3216.02, and AR 70-25 as well as other applicable federal and state regulations. Contractors/grantees must be cognizant of and abide by the additional restrictions and limitations imposed on the DoD regarding research involving human subjects, specifically as regards vulnerable populations (32 CFR 219 modifications to subparts B-D of 45 CFR 46), recruitment of military research subjects (32 CFR 219), and surrogate consent (10 U.S.C. 980). The regulations mandate that all DoD activities, components, and agencies protect the rights and welfare of human subjects of study in DoD-supported research, development, test and evaluation, and related activities hereafter referred to as “research”. The requirement to comply with the regulations applies to new starts and to continuing research.

Notwithstanding any other provision contained in an assistance award or incorporated by reference therein, the Recipient is expressly forbidden to use or subcontract for the use of human subjects in any manner whatsoever without the prior express written approval of the applicable protocol proposed for an award as required by AR 70-25 in addition to the institution's approval. Non-compliance with any part of this provision may result in withholding of funds and/or the termination of an award.

The Principal Investigators will notify the Army technical representatives within 24 hours if any of the following occur: (1) the protocol is suspended; (2) a death occurs as a consequence of the research protocol; or (3) a life-threatening, adverse event occurs as a consequence of the research protocol.

For Contracts, the appropriate clauses shall be added.

2) ANIMAL USE. Assistance Instruments Only. DODI 3216.01 and AR 40-33, provides policy and requirements for the use of animals in DOD-funded research. The DoD definition of animal is any live nonhuman vertebrate. All proposals that involve the use of animals must address compliance with DoDI 3216.01 and AR 40-33.

Provisions include rules on animal acquisition, transport, care, handling, and use in 9 CFR parts 1-4, Department of Agriculture rules implementing the Laboratory Animal Welfare Act

of 1966 (7 U.S.C. 2131-2156), and guidelines in the National Academy of Sciences (NAS) "Guide for the Care and Use of Laboratory Animals" (1996), including the Public Health Service Policy and Government Principles Regarding the Care and Use of Animals in Appendix D to the Guide.

Notwithstanding any other provision contained in this award or incorporated by reference therein, the Recipient is expressly forbidden to use or subcontract for the use of laboratory animals in any manner whatsoever without the prior express written approval of the applicable protocol proposed for this award as required by AR 40-33 in addition to the institution's approval. Non-compliance with this provision may result in withholding of funds and/or termination of the award.

The Principal Investigator will notify the Army technical representatives within 24 hours if any of the following occur: (1) the protocol is suspended; or (2) a life-threatening, adverse event occurs as a consequence of the research protocol.

For Contracts, the appropriate clauses shall be added.

3) **BIOLOGICAL DEFENSE SAFETY PROGRAM REQUIREMENTS:** For All Awards. Successful offerors whose Principal Investigators are conducting research with Bio-safety Levels 3 and 4 material must prepare a Facility Safety Plan in accordance with 32 Code of Federal Regulations (CFR) 626.18. See URL: [www.access.gpo.gov/nara/cfr/waisidx\\_99/32cfr626\\_99.html](http://www.access.gpo.gov/nara/cfr/waisidx_99/32cfr626_99.html) for a copy of 32 CFR 626.18, Biological Defense Safety Program.

4) **MILITARY RECRUITING:** For Assistance Instruments Only. This is to notify potential offerors that each grant or cooperative agreement awarded under this announcement to an institution of higher education must include the following term and condition:

"As a condition for receipt of funds available to the Department of Defense (DOD) under this award, the recipient agrees that it is not an institution of higher education (as defined in 32 CFR part 216) that has a policy of denying, and that it is not an institution of higher education that effectively prevents, the Secretary of Defense from obtaining for military recruiting purposes: (A) entry to campuses or access to students on campuses or (B) access to directory information pertaining to students. If the recipient is determined, using the procedures in 32 CFR part 216, to be such an institution of higher education during the period of performance of this agreement, and therefore to be in breach of this clause, the Government will cease all payments of DOD funds under this agreement and all other DOD grants and cooperative agreements to the recipient, and it may suspend or terminate such grants and agreements unilaterally for material failure to comply with the terms and conditions of award."

If your institution has been identified under the procedures established by the Secretary of Defense to implement Section 558, then: (1) no funds available to DOD may be provided to your institution through any grant, including any existing grant, (2) as a matter of policy, this

restriction also applies to any cooperative agreement, and (3) your institution is not eligible to receive a grant or cooperative agreement in response to this solicitation.

5) **MILITARY RECRUITING: For Contracts Only.** This is to notify potential offerors that each contract awarded under this announcement to an institution of higher education shall include the following clause: Defense Federal Acquisition Regulation Supplement (DFARS) clause 252.209-7005, Military Recruiting on Campus.

6) **SUBCONTRACTING: For Contracts Only.** This section is applicable to contracts where the dollar threshold is expected to exceed to \$650,000.00. Pursuant to Section 8(d) of the Small Business Act [15 U.S.C. 637(d)], it is the policy of the Government to enable small business concerns to be considered fairly as subcontractors under all research agreements awarded to prime contractors. The required elements of the Subcontracting Plan are set forth by FAR 52.219-9 and DFARS 252.219-7003. The offeror's plan shall depict the percentage values of the option requirements separately. The information in the SB Subcontracting Plan must properly correlate with that of the offeror's SB Participation Plan. The Government's subcontracting goals for Fiscal Year 2012 (FY12) are listed below, future year goals can be found at: <http://www.acq.osd.mil/osbp/gov/sbProgramGoals.shtml>.

Subcontracting Plan Goals. The offeror is requested to consider, when appropriate, the Government's subcontracting goals. The goals for FY12 are as follows:

- Small Business 35%
- Small Disadvantaged Business 5% [FY12 goal is 3%; aim for DFARS 219.705-4(d) compliance]
- Women-Owned Small Business 3%
- HUBZone Small Business: 3%
- Service-Disabled Veteran-Owned Small Business 3%
- Historically Black Colleges/Universities or Minority Serving Institutions 3%

### **3. Reporting:**

Additional reports including number and types will be specified in the award document, but will include as a minimum monthly financial status reports. The reports shall be prepared and submitted in accordance with the procedures contained in the award document and mutually agreed upon before award. Reports and briefing material will also be required as appropriate to document progress in accomplishing program metrics. A final report that summarizes the project and tasks will be required at the conclusion of the performance period for the award.

**ARMY MANPOWER CONTRACTOR REPORTING: For Contracts Only.** The Office of the Assistant Secretary of the Army (Manpower & Reserve Affairs) operates and maintains a secure Army data collection site where the contractor will report ALL contractor manpower (including subcontractor manpower) required for performance of this contract. The contractor is required to completely fill in all the information in the format using the following web address: <https://cmra.army.mil/>. The required information includes: (1) Contracting Office, Contracting Officer, Contracting Officer's Technical Representative; (2)



Contract number, including task and delivery order number; (3) Beginning and ending dates covered by reporting period; (4) Contractor name, address, phone number, e-mail address, identity of contractor employee entering data; (5) Estimated direct labor hours (including sub-contractors); (6) Estimated direct labor dollars paid this reporting period (including sub-contractors); (7) Total payments (including sub-contractors); (8) Predominate Federal Service Code (FSC) reflecting services provided by contractor (and separate predominant FSC for each sub-contractor if different); (9) Estimated data collection cost; (10) Organizational title associated with the Unit Identification Code (UIC) for the Army Requiring Activity (the Army Requiring Activity is responsible for providing the contractor with its UIC for the purposes of reporting this information); (11) Locations where contractor and sub-contractors perform the work (specified by zip code in the United States and nearest city, country, when in an overseas location, using standardized nomenclature provided on website); (12) Presence of deployment or contingency contract language; and (13) Number of contractor and sub-contractor employees deployed in theater this reporting period (by country). As part of its submission, the contractor will also provide the estimated total cost (if any) incurred to comply with this reporting requirement. Reporting period will be the period of performance not to exceed 12 months ending 30 September of each government fiscal year and must be reported by 31 October of each calendar year. Contractors may use a direct XML data transfer to the database server or fill in the fields on the website. The XML direct transfer is a format for transferring files from a contractor's systems to the secure web site without the need for separate data entries for each required data element at the web site. The specific formats for the XML direct transfer may be downloaded from the web site.

#### **G. Agency Contacts:**

Questions of a technical nature are to be directed to:

The TPOCs for each area of interest are identified as part of the description of that area and may be contacted as appropriate.

Questions of a business nature are to be directed to:

[usarmy.rtp.aro.mbx.baa@mail.mil](mailto:usarmy.rtp.aro.mbx.baa@mail.mil)

Comments or questions submitted should be concise and to the point, eliminating any unnecessary verbiage. In addition, the relevant part and paragraph of the Broad Agency Announcement (BAA) should be referenced.

#### **H. Other Information:**

Below are 2 separate outlines of the informational requirements for a sample cost proposal. H.1. is for a procurement contract and H.2 for grants, cooperative agreements and TIAs.

##### **1. CONTRACT Proposals:**

Cost Proposal – {No Page Limit}

Cover sheet to include:

(1) BAA number;

- (2) Technical area;
- (3) Lead Organization Submitting proposal;
- (4) Type of business, selected among the following categories: “LARGE BUSINESS”, “SMALL DISADVANTAGED BUSINESS”, “OTHER SMALL BUSINESS”, “HBCU”, “MI”, “OTHER EDUCATIONAL”, OR “OTHER NONPROFIT”;
- (5) Contractor’s reference number (if any);
- (6) Other team members (if applicable) and type of business for each;
- (7) Proposal title;
- (8) Technical point of contact to include: salutation, last name, first name, street address, city, state, zip code, telephone, fax (if available), electronic mail (if available);
- (9) Administrative point of contact to include: salutation, last name, first name, street address, city, state, zip code, telephone, fax (if available), and electronic mail (if available);
- (10) Award instrument requested: cost-plus-fixed-fee (CPFF), cost-award—no fee, cost sharing contract – no fee, or other type of procurement contract (specify).
- (11) Place(s) and period(s) of performance;
- (12) Total proposed cost separated by basic award and option(s) (if any);
- (13) Name, address, and telephone number of the proposer’s cognizant Defense Contract Management Agency (DCMA) administration office (if known);
- (14) Name, address, and telephone number of the proposer’s cognizant Defense Contract Audit Agency (DCAA) audit office (if known);
- (15) Date proposal was prepared;
- (16) DUNS number;
- (17) TIN number; and
- (18) Cage Code;
- (19) Subcontractor Information; and
- (20) Proposal validity period
- (21) Any Forward Pricing Rate Agreement, other such approved rate information, or such other documentation that may assist in expediting negotiations (if available).

### I. Reasoning for Submitting a Strong Cost Proposal

The ultimate responsibility of the Contracting Officer is to ensure that all prices offered in a proposal are fair and reasonable before contract award [FAR 15.4]. To establish the reasonableness of the offered prices, the Contracting Officer may ask the offeror to provide various supporting documentation that assists in this determination. The offeror’s ability to be responsive to the Contracting Officer’s requests can expedite contract award. As specified in Section 808 of Public Law 105-261, an offeror who does not comply with a requirement to submit information for a contract or subcontract in accordance with paragraph (a)(1) of FAR 15.403-3 may be ineligible for award.

### II. DCAA-Accepted Accounting System

- A) Before a contract can be awarded, the Contracting Officer must confirm that the offeror has a Defense Contract Audit Agency (DCAA)-accepted accounting system in place for accumulating and billing costs under Government contracts [FAR 53.209-1(f)]. If the offeror has DCAA correspondence, which documents the acceptance of their accounting system, this

should be provided to the Contracting Officer (i.e. attached or referenced in the proposal). Otherwise, the Contracting Officer will submit an inquiry directly to the appropriate DCAA office and request a review of the offeror’s accounting system.

- B) If an offeror does not have a DCAA-accepted accounting system in place, the DCAA review process can take several months depending upon the availability of the DCAA auditors and the offeror’s internal processes. This will cause a delay in contract award.
- C) For more information about cost proposals and accounting standards, view the link titled “Information for Contractors” on the main menu on their website.

III. Field Pricing Assistance

During the pre-award cost audit process, the Contracting Officer will solicit support from DCAA to determine commerciality and price reasonableness of the proposal [FAR 15.404-2]. Any proprietary information or reports obtained from DCAA field audits will be appropriately identified and protected within the Government.

IV. Sample Cost Proposal – “Piece by Piece”

- A) To help guide offerors through the pre-award cost audit process, a sample cost proposal is detailed below. This sample also allows the offeror to see exactly what the Government is looking for; therefore, all cost and pricing back-up data can be provided to the Government in the first cost proposal submission. Review each cost element within the proposal, and take note of the types of documentation that the Contracting Officer will require from the offeror.
- B) Direct Labor: The first cost element included in the cost proposal is Direct Labor. The Department of Defense (DoD) requires each proposed employee to be listed by name and labor category.

Below is the Direct Labor as proposed by our sample offeror:

DIRECT LABOR:		YEAR 1			YEAR 2		
Employee Name	Labor Category	Direct Hourly Rate	Hours	Total Direct Labor	Direct Hourly Rate	Hours	Total Direct Labor
Andy Smith	Program Manager	\$55.00	720.00	\$39,600.00	\$56.65	720.00	\$40,788.00
Bryan	Senior	\$40.00	672.00	\$26,880.00	\$41.20	672.00	\$27,686.40

Andrew	Engineer						
Cindy	Principal	\$50.00	512.00	\$25,600.00	\$51.50	512.00	\$26,368.00
Thomas	Engineer						
David Porter	Entry Level	\$10.00	400.00	\$4,000.00	\$10.30	400.00	\$4,120.00
Edward	Engineer						
Bean	Project	\$25.00	48.00	\$1,200.00	\$25.75	48.00	\$1,236.00
	Administrat						
	or						
Subtotal							
Direct Labor				\$97,280.00			\$100,198.40
(DL):							

- 1) For this cost element, the Contracting Officer requires the offeror to provide adequate documentation in order to determine that each labor rate for each employee/labor category is fair and reasonable. The documentation will need to explain how these labor rates were derived. For example, if the rates are DCAA-approved labor rates, provide the Contracting Officer with copies of the DCAA documents stating the approval. This is the most acceptable means of documentation to determine the rates fair and reasonable. Other types of supporting documentation may include General Service Administration (GSA) contract price lists, actual payroll journals, or Salary.com research. If an employee listed in a cost proposal is not a current employee (maybe a new employee, or one contingent upon the award of this contract), a copy of the offer letter stating the hourly rate - signed and accepted by the employee - may be provided as adequate documentation. Sometimes the hourly rates listed in a proposal are derived through subjective processes, i.e., blending of multiple employees in one labor category, or averaged over the course of the year to include scheduled payroll increases, etc. These situations should be clearly documented for the Contracting Officer.
  
- 2) Another cost element in Direct Labor is labor escalation, or the increase in labor rates from Year 1 to Year 2. In the example above, the proposed labor escalation is 3% (ex., Andy Smith increased from \$55.00/hr in Year 1, by 3% to \$56.65/hr in Year 2). Often times, an offeror may not propose escalation on labor rates during a 24-month period. Whatever the proposed escalation rate is, please be prepared to explain why it is fair and reasonable [ex., A sufficient explanation for our sample escalation rate would be the Government's General Schedule Increase and Locality Pay for the same time period (name FY) in the same location (name location) was published as 3.5%, therefore a 3% increase is fair and reasonable].

C) Other Direct Costs (ODCs): This section of the cost proposal includes all other directly related costs required in support of the effort i.e., materials, subcontractors, consultants, travel, etc. Any cost element that includes various items will need to be detailed in a cost breakdown to the Contracting Officer.

- 1) Direct Material Costs: This subsection of the cost proposal will include any special tooling, test equipment, and material costs necessary to perform the project. Items

included in this section will be carefully reviewed relative to need and appropriateness for the work proposed, and must, in the opinion of the Contracting Officer, be advantageous to the Government and directly related to the specific topic.

a) The Contracting Officer will require adequate documentation from the offeror to determine the cost reasonableness for each material cost proposed. The following methods are ways in which the Contracting Officer can determine this [FAR 15.403-1].

i) Adequate Price Competition. A price is based on adequate price competition when the offeror solicits and receives quotes from two or more responsible vendors for the same or similar items or services. Based on these quotes, the offeror selects the vendor who represents the best value to the Government. The offeror will be required to provide copies of all vendor quotes received to the Contracting Officer.

Note: Price competition is not required for items at or below the simplified acquisition threshold (\$3,000) [FAR 15.403-1]. If an item’s unit cost is less than or equal to \$3,000, price competition is not necessary. However, if an item’s total cost over the period of performance (unit cost \* quantity is higher than \$3,000, two or more quotes must be obtained by the offeror.

ii) Commercial Prices. Commercial prices are those published on current price lists, catalogs, or market prices. This includes vendors who have prices published on a GSA-schedule contract. The offeror will be required to provide copies of such price lists to the Contracting Officer.

iii) Prices set by law or regulation. If a price is mandated by the Government (i.e. pronouncements in the form of periodic rulings, reviews, or similar actions of a governmental body, or embodied in the laws) that is sufficient to set a price.

b) Below is the list of Direct Material costs included in our sample proposal:

DIRECT MATERIAL COSTS:	YEAR 1	YEAR 2
Raw Materials	\$35,000.00	\$12,000.00
Computer for experiments	\$4,215.00	\$0.00
Cable (item #12-3657, 300 ft)	\$1,275.00	\$0.00
Software	\$1,825.00	\$1,825.00
Subtotal Direct Materials Costs		
(DM):	\$42,315.00	\$13,825.00

ii) “Raw Materials”: This is a generic label used to group many material items into one cost item within the proposal. The Contracts Officer will require a detailed breakout of all the items that make up this cost. For each separate item over \$3,000 (total for Year 1 + Year 2), the offeror must be able to provide either competitive quotes received, or show that published pricing was used.

- iii) “Computer for experiments”: Again, this item is most likely a grouping of several components that make up one system. The Contracts Officer will require a detailed breakout of all the items that make up this cost. For each separate item over \$3,000 (total for Year 1 + Year 2), the offeror must be able to provide either competitive quotes received, or show that published pricing was used.
  - iv) “Cable”: Since this item is under the simplified acquisition threshold of \$3,000, competitive quotes or published pricing are not required. Simply provide documentation to show the Contracting Officer where this price came from.
  - v) “Software”: This cost item could include either one software product, or multiple products. If this includes a price for multiple items, please provide the detailed cost breakdown.  
Note: The price for Year 1 (\$1,825) is below the simplified acquisition threshold; however, in total (Year 1 + Year 2) the price is over \$3,000, so competitive quotes or published pricing documentation must be provided.
- c) Due to the specialized types of products and services necessary to perform these projects, it may not always be possible to obtain competitive quotes from more than one reliable source. Each cost element over the simplified acquisition threshold (\$3,000) must be substantiated. There is always an explanation for HOW the cost of an item was derived; show us how you came up with that price!
- d) When it is not possible for an offeror to obtain a vendor price through competitive quotes or published price lists, a Contracting Officer may accept other methods to determine cost reasonableness. Below are some examples of other documentation, which the Contracting Officer may accept to substantiate costs:
- i) Evidence that a vendor/supplier charged another offeror a similar price for similar services. Has the vendor charged someone else for the same product? (Two (2) to three (3) invoices from that vendor to different customers may be used as evidence.)
  - ii) Previous contract prices. Has the offeror charged the Government a similar price under another Government contract for similar services? If the Government has already paid a certain price for services, then that price may already be considered fair and reasonable. (Provide the contract number, and billing rates for reference.)
  - iii) DCAA approved. Has DCAA already accepted or verified specific cost items included in your proposal? (Provide a copy of DCAA correspondence that addressed these costs.)

- 2) Below is the remaining ODC portion of our proposal including equipment, subcontractors, consultants, and travel. Assume in this scenario that competitive quotes or catalog prices were not available for these items:

OTHER DIRECT COSTS:	YEAR 1	YEAR 2
Equipment Rental for Analysis	\$5,500.00	\$5,600.00
Subcontractor – Lockheed	\$25,000.00	\$0.00
Consultant: John Bowers	\$0.00	\$12,000.00
Travel	\$1,250.00	\$1,250.00
Subtotal Other Direct Costs		
(ODC):	\$31,750.00	\$18,850.00

- a) “Equipment Rental for Analysis”: The offeror explains that the Year 1 cost of \$5,500 is based upon 250 hours of equipment rental at an hourly rate of \$22.00/hr. One (1) invoice from the vendor charging another vendor the same price for the same service is provided to the Contracting Officer as evidence. Since this cost is over the simplified acquisition threshold, further documentation to determine cost reasonableness is required. The offeror is able to furnish another invoice charging a second vendor the same price for the same service.
- b) “Subcontractor – Widget, Inc.”: The offeror provides a copy of the subcontractor quote to the Contracting Officer in support of the \$25,000 cost. This subcontractor quote must include sufficient detailed information (equivalent to the data included in the prime’s proposal to the Government), so that the Contracting Officer can make a determination of cost reasonableness.
- i) As stated in Section 3.5(c)(6) of the DoD Cost Proposal guidance, “All subcontractor costs and consultant costs must be detailed at the same level as prime contractor costs in regards to labor, travel, equipment, etc. Provide detailed substantiation of subcontractor costs in your cost proposal.”
- ii) In accordance with FAR 15.404-3, “the Contracting Officer is responsible for the determination of price reasonableness for the prime contract, including subcontracting costs”. This means that the subcontractor’s quote/proposal may be subject to the same scrutiny by the Contracting Officer as the cost proposal submitted by the prime. The Contracting Officer will need to determine whether the subcontractor has an accepted purchasing system in place and/or conduct appropriate cost or price analyses to establish the reasonableness of proposed subcontract prices. Due to the proprietary nature of cost data, the Subcontractor may choose to submit their pricing information directly to the Contracting Officer and not through the prime. This is understood and encouraged.
- iii) When a subcontractor is selected to provide support under the prime contract due to their specialized experience, the Contracting Officer may request sole source justification from the offeror.

- c) “Consultant – John Bowers”: Again, the offeror shall provide a copy of the consultant’s quote to the Contracting Officer as evidence. In this example, the consultant will be charging an hourly rate of \$125 an hour for 96 hours of support. The offeror indicates to the Contracting Officer that this particular consultant was used on a previous contract with the Government (provide contract number), and will be charging the same rate. A copy of the consultant’s invoice to the offeror under the prior contract is available as supporting evidence. Since the Government has paid this price for the same services in the past, determination has already been made that the price is fair.
- d) “Travel”: The Contracting Officer will require a detailed cost breakdown for travel expenses to determine whether the total cost is reasonable based on Government per diem and mileage rates. This breakdown shall include the number of trips, the destinations, and the number of travelers. It will also need to include the estimated airfare per round trip, estimated car rental, lodging rate per trip, tax on lodging, and per diem rate per trip. The lodging and per diem rates must coincide with the Joint Travel Regulations. Please see the following website to determine the appropriate lodging and per diem rates: <http://www.defensetravel.dod.mil/> . Additionally, the offeror must provide why the airfare is fair and reasonable as well. Sufficient back up for both airfare and car rental would include print outs of online research at the various travel search engines (Expedia, Travelocity, etc.) documenting the prices for airfare and car rentals thus proving why your chosen rate is fair and reasonable.
- i) Below is a sample of the travel portion:

TRAVEL		Trips	Travelers	Nights	Days	Unit Cost	Total Travel
Airfare	per roundtrip	1	1			\$996.00	\$996.00
Lodging	per day	1	1	1		\$75.00	\$75.00
Tax on Lodging (12%)	per day	1	1	1		\$9.00	\$9.00
Per Diem	per day	1	1		2	\$44.00	\$88.00
Automobile Rental	per day	1	1		2	\$41.00	\$82.00
Subtotal							
Travel							\$1,250.00

- D) Indirect Rates: Indirect rates include elements such as Fringe Benefits, General & Administrative (G&A), Overhead, and Material Handling costs. The offeror shall indicate in the cost proposal both the indirect rates (as a percentage) as well as how those rates are allocated to the costs in the proposal.

Below is the Indirect portion of our sample proposal:



INDIRECTS	YEAR 1	YEAR 2
Subtotal Direct Labor (DL):	\$97,280.00	\$100,198.40
Fringe Benefits, if not included in Overhead, rate (15.0000 %) X DL =	\$14,592.00	\$15,029.76
Labor Overhead (rate 45.0000 %) X (DL + Fringe) =	\$50,342.40	\$51,852.67
Total Direct Labor (TDL):	\$162,214.40	\$167,080.83

- 1) In this example, the offeror includes a Fringe Benefit rate of 15.00% that is allocated to the Direct Labor costs. They also propose a Labor Overhead rate of 45.00% that is allocated to the Direct Labor costs plus the Fringe Benefits.
  - 2) All indirect rates and the allocation methods of those rates must be verified by the Contracting Officer. In most cases, DCAA documentation supporting the indirect rates and allocation methods can be obtained through a DCAA field audit or proposal review. Many offerors have already completed such reviews and have this documentation readily available. If an offeror is unable to participate in a DCAA review to substantiate indirect rates, the Contracting Officer may request other accounting data from the offeror to make a determination.
- E.) Cost of Money (COM): If Cost of Money (an imputed cost that is not a form of interest on borrowings (see FAR 31.205-20); an “incurred cost” for cost-reimbursement purposes under applicable cost-reimbursement contracts and for progress payment purposes under fixed-price contracts; and refers to— (1) Facilities capital cost of money (48 CFR 9904.414); and (2) Cost of money as an element of the cost of capital assets under construction (48 CFR 9904.417)) is proposed in accordance with FAR 31.205-10, a DD Form 1861 is required to be completed and submitted with the contractor’s proposal.
- F.) Fee/Profit: The proposed fee percentage will be analyzed in accordance with DFARS 215.404, the Weighted Guidelines Method.
- G.) Subcontracting Plan: If the total amount of the proposal exceeds \$650,000 and the offeror is a large business or an institute of higher education (other than HBCU/MI) and the resultant award is a contract, the offeror shall be prepared to submit a subcontracting plan for small business and small disadvantaged business concerns. A mutually agreeable plan will be included in and made a part of the contract (see the goals listed at Section II, F, 2, b).

## **2. GRANT and COOPERATIVE AGREEMENT Proposals:**

Before award it must be established that an approved accounting system and financial management system exist.

A.) Direct Labor: Show the current and projected salary amounts in terms of man-hours, man-months, or annual salary to be charged by the principal investigator(s), faculty, research associates, postdoctoral associates, graduate and undergraduate students, secretarial, clerical, and other technical personnel either by personnel or position. State the number of man-hours used to calculate a man-month or man-year. For proposals from universities, research during the academic term is deemed part of regular academic duties, not an extra function for which additional compensation or compensation at a higher rate is warranted. Consequently, academic term salaries shall not be augmented either in rate or in total amount for research performed during the academic term. Rates of compensation for research conducted during non-academic (summer) terms shall not exceed the rate for the academic terms. When part or all of a person's services are to be charged as project costs, it is expected that the person will be relieved of an equal part or all of his or her regular teaching or other obligations. For each person or position, provide the following information:

- (1) The basis for the direct labor hours or percentage of effort (e.g., historical hours or estimates).
- (2) The basis for the direct labor rates or salaries. Labor costs should be predicted upon current labor rates or salaries. These rates may be adjusted upward for forecast salary or wage cost-of-living increases that will occur during the agreement period. The cost proposal should separately identify the rationale applied to base salary/wage for cost-of-living adjustments and merit increases. Each must be fully explained.
- (3) The portion of time to be devoted to the proposed research, divided between academic and non-academic (summer) terms, when applicable.
- (4) The total annual salary charged to the research project.
- (5) Any details that may affect the salary during the project, such as plans for leave and/or remuneration while on leave.

Note: There is no page limitation for budget proposals or budget justifications.

B.) Fringe Benefits and Indirect Costs (Overhead, General and Administrative, and Other): The most recent rates, dates of negotiation, the base(s) and periods to which the rates apply must be disclosed and a statement included identifying whether the proposed rates are provisional or fixed. If the rates have been negotiated by a Government agency, state when and by which agency. A copy of the negotiation memorandum should be provided. If negotiated forecast rates do not exist, offerors must provide

sufficient detail to enable a determination to be made that the costs included in the forecast rate are allocable according to applicable OMB Circulars or FAR/DFARS provisions. Offerors' disclosure should be sufficient to permit a full understanding of the content of the rate(s) and how it was established. As a minimum, the submission should identify:

- (1) All individual cost elements included in the forecast rate(s);
- (2) Bases used to prorate indirect expenses to cost pools, if any;
- (3) How the rate(s) was calculated;
- (4) Distribution basis of the developed rate(s);
- (5) Bases on which the overhead rate is calculated, such as "salaries and wages" or "total costs," and
- (6) The period of the offeror's fiscal year.

C.) Permanent Equipment: If facilities or equipment are required, a justification why this property should be furnished by the Government must be submitted. State the organization's inability or unwillingness to furnish the facilities or equipment. Offerors must provide an itemized list of permanent equipment showing the cost for each item. Permanent equipment is any article or tangible nonexpendable property having a useful life of more than one year and an acquisition cost of \$5,000 or more per unit. The basis for the cost of each item of permanent equipment included in the budget must be disclosed, such as:

- (1) Vendor Quote: Show name of vendor, number of quotes received and justification, if intended award is to other than lowest bidder.
- (2) Historical Cost: Identify vendor, date of purchase, and whether or not cost represents lowest bid. Include reason(s) for not soliciting current quotes.
- (3) Engineering Estimate: Include rationale for quote and reason for not soliciting current quotes. If applicable, the following additional information shall be disclosed in the offeror's cost proposal:
- (4) Special test equipment to be fabricated by the awardee for specific research purposes and its cost.
- (5) Standard equipment to be acquired and modified to meet specific requirements, including acquisition and modification costs, listed separately.
- (6) Existing equipment to be modified to meet specific research requirements, including modification costs. Do not include equipment the organization will

purchase with its funds if the equipment will be capitalized for Federal income tax purposes. Proposed permanent equipment purchases during the final year of an award shall be limited and fully justified.

- (7) Grants and cooperative agreements may convey title to an eligible institution for equipment purchased with project funds. At the discretion of the contracting/grants officer, the agreement may provide for retention of the title by the Government or may impose conditions governing the equipment conveyed to the organization per the governing laws and regulations.
- D.) Travel: Forecasts of travel expenditures (domestic and foreign) that identify the destination and the various cost elements (airfare, mileage, per diem rates, etc.) must be submitted. The costs should be in sufficient detail to determine the reasonableness of such costs. Allowance for air travel normally will not exceed the cost of round-trip, economy air accommodations. Specify the type of travel and its relationship to the research project. Requests for domestic travel must not exceed \$3,000 per year per principal investigator. Separate, prior approval by the ARL is required for all foreign travel (i.e., travel outside the continental U.S., its possessions and Canada). Foreign travel requests must not exceed \$1,800 each per year per principal investigator. Special justification will be required for travel requests in excess of the amounts stated above and for travel by individuals other than the principal investigator(s). Individuals other than the principal investigator(s) are considered postdoctoral associates, research associates, graduate and undergraduate students, secretarial, clerical, and other technical personnel. Additional travel may be requested for travel to Army laboratories and facilities to enhance agreement objectives and to achieve technology transfer.
- E.) Participant Support Costs: This budget category refers to costs of transportation, per diem, stipends, and other related costs for participants or trainees (but not employees) in connection with ARL-sponsored conferences, meetings, symposia, training activities, and workshops (see the "Other Programs" section as described earlier in this BAA). Generally, indirect costs are not allowed on participant support costs. The number of participants to be supported should be entered in the parentheses on the budget form. These costs should also be justified in the budget justification page(s) attached to the cost proposal.
- F.) Materials, Supplies, and Consumables: A general description and total estimated cost of expendable equipment and supplies are required. The basis for developing the cost estimate (vendor quotes, invoice prices, engineering estimate, purchase order history, etc.) must be included. If possible, provide a material list.
- G.) Publication, Documentation, and Dissemination: The budget may request funds for the costs of preparing, publishing, or otherwise making available to others the findings and products of the work conducted under an agreement, including costs of reports, reprints, page charges, or other journal costs (except costs for prior or early publication); necessary illustrations, cleanup, documentation, storage, and indexing of data and databases; and development, documentation, and debugging of software.

- H.) Consultant Costs: Offerors normally are expected to utilize the services of their own staff to the maximum extent possible in managing and performing the project's effort. If the need for consultant services is anticipated, the nature of proposed consultant services should be justified and included in the technical proposal narrative. The cost proposal should include the names of consultant(s), primary organizational affiliation, each individual's expertise, daily compensation rate, number of days of expected service, and estimated travel and per diem costs.
- I.) Computer Services: The cost of computer services, including computer-based retrieval of scientific, technical, and educational information, may be requested. A justification/explanation based on the established computer service rates at the proposing organization should be included. The budget also may request costs, which must be shown to be reasonable, for leasing automatic data processing equipment. The purchase of computers or associated hardware and software should be requested as items of equipment.
- J.) Subawards (subcontracts or subgrants): A precise description of services or materials that are to be awarded by a subaward must be provided. For subawards totaling \$10,000 or more, provide the following specific information:
- (1) A clear description of the work to be performed.
  - (2) If known, the identification of the proposed subawardee and an explanation of why and how the subawardee was selected or will be selected.
  - (3) The identification of the type of award to be used (cost reimbursement, fixed price, etc.).
  - (4) Whether or not the award will be competitive and, if noncompetitive, rationale to justify the absence of competition.
  - (5) A detailed cost summary.
- K.) Other Direct Costs: Itemize and provide the basis for proposed costs for other anticipated direct costs such as communications, transportation, insurance, and rental of equipment other than computer related items. Unusual or expensive items shall be fully explained and justified.
- L.) Profit/ Fee: Profit/ fee is not allowed for the Recipient of or subaward to an assistance instrument, where the principal purpose of the activity to be carried out is to stimulate or support a public purpose (i.e., to provide assistance), rather than acquisition (i.e., to acquire goods and services for the direct benefit of the United States Government). A subaward is an award of financial assistance in the form of money, or property in lieu of money, made under a DoD grant or cooperative agreement by a recipient to an eligible subrecipient. The term includes financial assistance for substantive program

performance by the subrecipient of a portion of the program for which the DoD grant or cooperative agreement was made. It does not include the recipient's procurement of goods and services needed to carry out the program.

M.) Subcontracting Plan: Subcontracting plans do not apply to assistance instruments.

**CONTRACT FACILITIES CAPITAL COST OF MONEY:** If cost of money is proposed, a completed Contract Facilities Capital Cost of Money (FCCM) (DD Form 1861) is required.