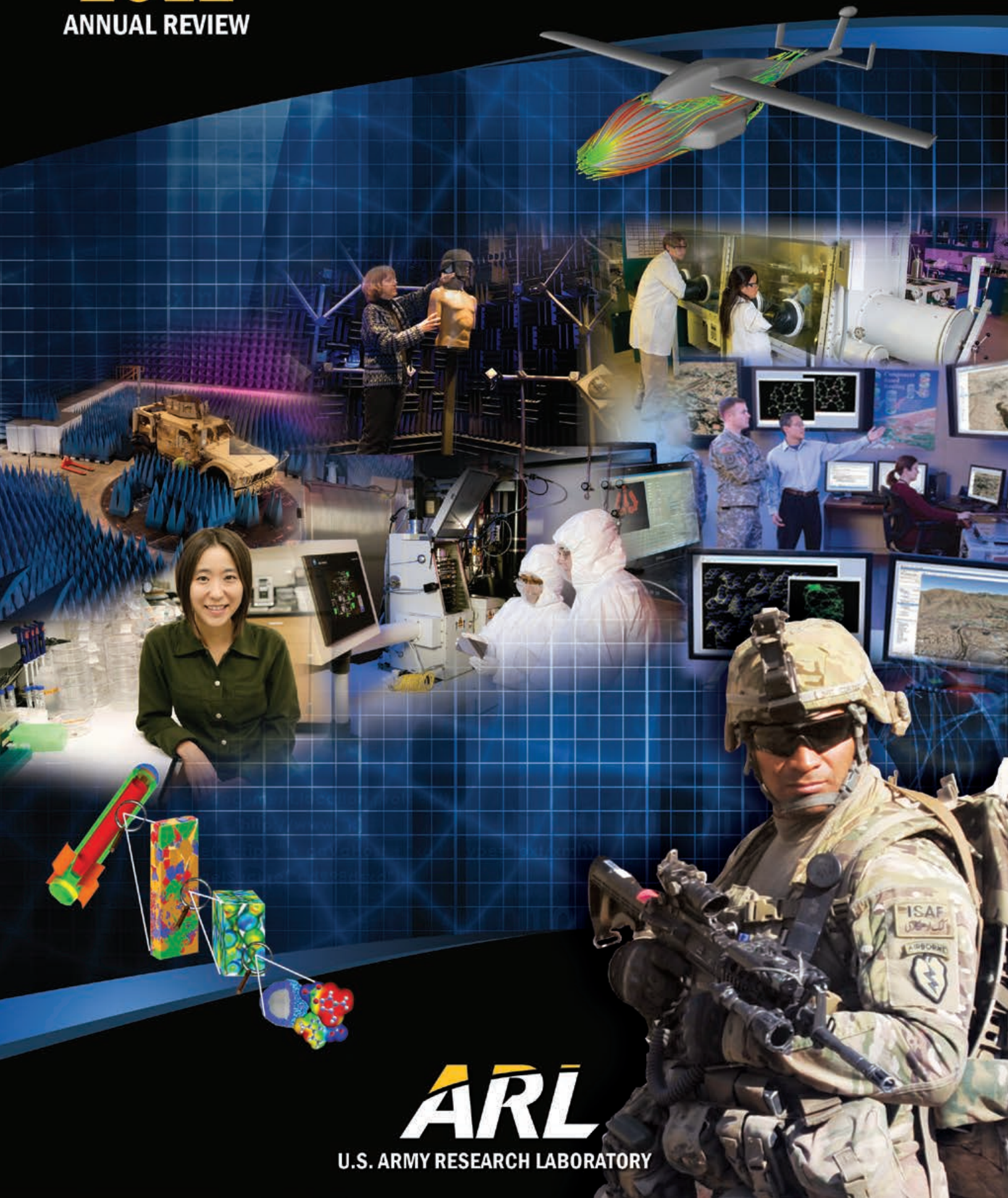
2012
ANNUAL REVIEW



ARL

U.S. ARMY RESEARCH LABORATORY

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Dr. John Pellegrino
Director (A)
U.S. Army Research Laboratory

Welcome to the Fiscal Year 2012 edition of the Army Research Laboratory (ARL) Annual Review. This publication briefly describes who we are and highlights some of our significant scientific and technical achievements of the last year. The size of this organization – seven distinct laboratories and offices with over two thousand military and civilian members - and the scope of research and analysis in which we are involved, limits us to select only a few items to present here as a representative sample of our overall accomplishments. ARL's research continuum stretches from early, long-term, basic research to evolving new technologies to supporting current operations. For this year's publication, we have organized our efforts against our six core technical competencies (CTC): Extramural Basic Research, Information Sciences, Human Sciences, Ballistics and Aeromechanic Sciences, Material Sciences and Survivability/Lethality/Vulnerability Assessment and Analysis – the sciences that tie to our enabling technology areas in support of the Soldier.

This review begins with an introduction that includes our organization, personnel, awards and other recognition earned by ARL and its personnel and the partnerships that round out our research efforts. The remainder of the publication is structured around the six CTCs identified above. Again, the accomplishments presented here, while only a small sample of our efforts over the past year, are representative of the skill, dedication, and teamwork of our in-house staff and our partners in academia and industry.

ARL

The Army Research Laboratory of the U.S. Army Research, Development and Engineering Command (RDECOM) is the Army's corporate laboratory. Its diverse assortment of unique facilities and dedicated workforce of government and private sector partners make up the largest source of world-class integrated research and analysis in the Army.

The mission of ARL is to "Provide the underpinning science, technology and analysis that enable full-spectrum operations." Within ARL we have teams working in partnership with the RDECs to mature and transition technologies in the two- to five-year timeframe for existing systems, and generate scientific discoveries that will provide the foundation for Soldier capabilities 15-20 years in the future. In addition we partner with Rapid Equip Force (REF), Joint Improvised Explosive Device Defeat Organization (JIEDDO), and others to support: current operational technical challenges facing Soldiers in Iraq (OND – Operation New Dawn) and Afghanistan (OEF – Operation Enduring Freedom).

RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND (RDECOM)

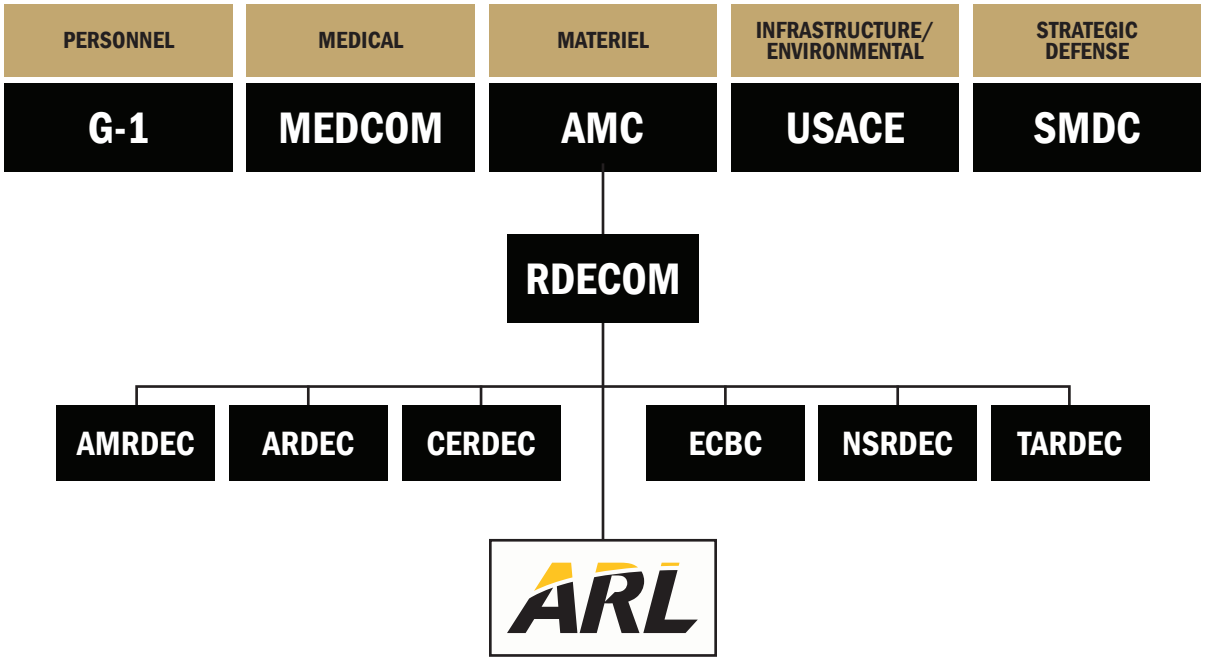
Mission Statement:

Empower, unburden and protect the Warfighter to enable the dominance of the Army.

Vision Statement:

To be the Army's primary source for integrated research, development and engineering capabilities.

Army S&T Performing Organizations



ARL provides underpinning Science, Technology and Analysis to the ARMY.

Since 1996, ARL has had a relationship with the National Research Council (NRC) of the National Academy of Sciences. As part of this relationship with the NRC, ARL has in place a Technical Assessment Board (TAB). The charge of this Board is to provide biennial assessments of the scientific and technical quality of ARL. These assessments include the development of findings and recommendations related to the quality of ARL's research, development and analysis programs. We use their input to ensure our work is at the leading edge.

The TAB consists of leading scientists and engineers whose experience collectively spans the major topics within the scope of ARL. Six panels, one for each of ARL's directorates, report to the board chairman. Each board member sits on a panel, six of them as panel chairs (pictured here with the TAB chair). The number of members on each panel varies, but their members' expertise is tailored to the technical fields covered by the directorates they review. Approximately 90 subject-matter experts participate across all panels.

DR. LYLE H. SCHWARTZ, NAE, TAB CHAIR

Director (retired),
Air Force Office of Scientific Research

DR. DONALD M. CHIARULLI

Professor of Computer Science and Computer Engineering,
Department of Computer Science,
University of Pittsburgh

DR. DAVID E. CROW, NAE

Senior Vice President of Engineering (retired),
Pratt and Whitney

Professor Emeritus, Department of Mechanical Engineering,
University of Connecticut

DR. MARJORIEANN ERICKSONKIRK

President,
Phoenix Engineering Associates, Inc.

DR. DEBASIS MITRA, NAE

Vice President,
Global Research and University Partnerships

Chief Scientist's Office,
Bell Labs, Alcatel-Lucent

DR. R. BYRON PIPES, NAE

John Leighton Bray Distinguished Professor of Engineering,
School of Aeronautics and Astronautics,
School of Chemical Engineering,
School of Materials Engineering,
College of Engineering,
Purdue University

DR. JEREMY M. WOLFE

Professor of Ophthalmology,
Visual Attention Laboratory,
Harvard Medical School,
Brigham and Women's Hospital

The Fellows' mission is to achieve, promote and maintain technical excellence in science and engineering (S&E) at ARL. The Fellows serve as advisors and consultants on technical matters to the ARL Director and the Directorate Directors. The Fellows are carefully chosen from the ARL community, itself a distinguished collection of some of the top scientific minds in our Nation. The selection criteria include an emphasis on nominating those researchers performing the very highest quality ongoing S&E work that also has an extremely high impact on Army needs, the mission and their fields of endeavor. There are currently 26 Fellows. Among some of their more important contributions have been evaluations of ARL technical awards, organizing special symposia and chairing directorate promotion panels. In addition, each year the Fellows review proposals for the Director's Research Initiatives, which is designed to support innovative and high-risk research ideas that have the potential to significantly advance mission needs beyond conventional expectations.

Fellow	Technical Specialty
Dr. Jan W. Andzelm	Multiscale Modeling of Macromolecules and Polymers
Dr. Howard E. Brandt	Theoretical Physics
Dr. Kwong-Kit Choi, Co-Chair	Quantum-Well Infrared Technology
Ms. Melanie Will-Cole	Electronic Materials
Dr. Dattatraya P. Dandekar	Shock Wave Interactions and Materials
Dr. Alan S. Edelstein	Magnetic Materials and Devices
Dr. Brad E. Forch	Ballistics and Energetic Materials
Dr. Piotr J. Franaszczuk	Computational Neuroscience and Biomedical Signal Processing
Dr. Kenneth A. Jones	Semiconductor Growth and Microdevice Processing
Dr. T. Richard Jow	Energy Storage
Dr. Shashi P. Karna	Nanomaterials
Dr. Stephen J. Lee	Physical Organic Chemistry
Dr. Tomasz R. Letowski	Auditory Acoustics
Dr. Joseph N. Mait	Electromagnetics and Imaging
Dr. James W. McCauley	Ceramic Engineering
Dr. Nasser M. Nasrabadi	Signal and Image Processing
Dr. Rose A. Pesce-Rodriguez, Co-Chair	Analytical Chemistry/Energetic Materials
Dr. Peter J. Reynolds	Atomic and Molecular Physics
Dr. Betsy M. Rice	Theoretical Chemistry
Dr. Brian M. Sadler	Sensing, Networking and Autonomous Systems
Dr. Paul H. Shen	Semiconductor Optoelectronics
Dr. Ananthram Swami	Signal Processing and Communications
Dr. Don J. Torrieri	Communication Systems and Networks
Dr. Gorden W. Videen	Light Scattering
Dr. Bruce J. West	Mathematics and Statistical Physics
Dr. Michael Wraback	Ultrafast Phenomena in Semiconductor Physics

ARL accomplishes its mission through the work of a highly educated and trained technical and support staff of 1,980 individuals. Of the 1,980 employees, 1,379 are classified as Scientific and Engineering (S&E), 1031 of whom hold advanced degrees.

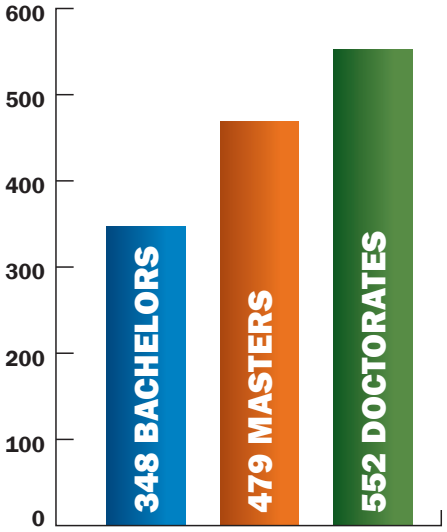
At ARL, we understand that science and technology have been, and will remain, the engines of economic growth and national security in the United States. In addition, we understand that excellence in discovery and innovation in science and engineering are the direct result of a dedicated, experienced and well-educated workforce.

ARL recruits for and fills positions with the highest caliber applicants. Our interaction with ARL's network of research partners provides the opportunity to interact with graduate students and post-docs with the required expertise from which to recruit, and our Personnel Demonstration Project allows starting pay to be negotiated in a competitive range.

1,589 Technical Staff

47	Aerospace Engineers
10	Biologists
7	Biomedical Engineers
92	Chemical Engineers/Chemists
165	Computer Scientists/Engineers
309	Electrical/Electronics Engineers
58	Engineering Psychologists
99	General/Industrial Engineers
79	Materials Engineers
40	Mathematicians/Statisticians
197	Mechanical Engineers
15	Meteorologists
10	Neuroscientists
45	Operations Research Analysts
193	Physicists/Physical Scientists
13	Other S&Es
210	S&E Technicians

1,379 Scientific & Engineering Employees



ARL's technical staff must be highly skilled to accomplish our mission, and our leadership stresses the importance of advanced technical degrees. In FY12, the ARL scientific and engineering staff was composed of 552 (40 percent) doctorates, 479 (35 percent) Master of Science degrees and 348 (25 percent) Bachelor of Science degrees.

Key performance indicators for quality of the research staff include metrics reflecting the attitudes and technical opinions of the external research community. For FY12, ARL performed exceptionally in the number of presentations/proceedings (1,242), refereed journal articles (410), technical reports (539) and patents awarded (36).

The strength of ARL truly lies in its intellectual diversity. Through focused recruiting efforts, we attract scientists and engineers from a large number of academic institutions worldwide. As a result of these efforts, ARL hired 45 new scientists and engineers in FY12 including 24 with doctorates and 9 with Master of Science degrees. ARL strives for diversity of intellectual thought in its new hires and actively recruits from a wide range of schools.

FY12 New Hires

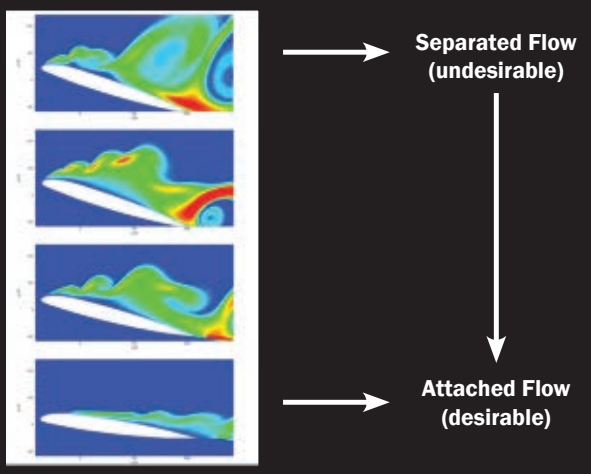
College Student Scores Publication in Major Journal, Thanks to Summer Work at ARL

University of Florida Junior Thomas Underwood was published in the February 26, 2013, edition of the Journal of Applied Physics, a major accomplishment for any post-doctoral researcher, yet achieved by an undergraduate student. His paper, "Physics Based Lumped Element Circuit Model for Nanosecond Pulsed Dielectric Barrier Discharges" (J.Appl.Phys. 2013, 113, 083301), is based on the theoretical developments of the model that Thomas worked on while employed as an intern at ARL in 2011.

Underwood worked to establish a circuit model for approximating the physics of plasma actuators. "Plasma actuators are of interest because they have shown potential for improved control over aerodynamic performance, which could enable Army air vehicles, such as rotorcraft, with next-generation capabilities," said Underwood. "The inherent advantages of plasma actuator flow control devices include fast response time, surface compliance, lack of moving parts, low cost, and light weight."

"The plasma-based approach that Underwood worked on was a very new development in the research community and no one had yet developed a numerical model of the plasma that could be coupled with aerodynamic computer codes and that could run quickly," said Dr. Bryan Glaz, ARL research aerospace engineer and Underwood's mentor. "I was extremely impressed with Underwood's ability to independently and creatively approach solutions to complicated new research problems that no one had yet addressed."

Underwood is scheduled to graduate in 2014 with a double major in nuclear engineering and physics and a minor in mathematics. He is currently applying to graduate school with the goal of working toward a doctorate degree in applied plasma physics or biological physics. In 2011, Thomas Underwood was selected as the ARL Vehicle Technology Directorate's top undergraduate intern.



RECOGNITIONS AND AWARDS

LEGION OF MERIT

COL CRAIG LANGHAUSER

MERITORIOUS SERVICE MEDAL

MAJ BRYON MANSFIELD

SSG DASHAWNA WINGATE

ARMY COMMENDATION MEDAL

SSG TIFFANY GREEN

SSG DASHAWNA WINGATE

ARMY ACHIEVEMENT MEDAL

SFC ANTWON GHOLSON

SGT STEVEN MCGLOIN

NATO MEDAL

SFC ANTWON GHOLSON

SFC ALPI REYESCRUZ

JOINT SERVICE COMMENDATION MEDAL

SFC ALPI REYESCRUZ

BALTIMORE FEDERAL EXECUTIVE BOARD EXCELLENCE IN FEDERAL CAREER AWARDS

"GOLD" AWARD RECIPIENT

1. Dr. Kristopher Darling, Category 10b - Rookie Employee of the Year - Technical Scientific and Program Support

"SILVER" AWARD RECIPIENTS

1. Dr. John J. La Scala, Category 1a - Outstanding Supervisor - Grade 13 and above
2. Karen Pizzolato, Category 2a - Outstanding Professional (Non-Supv) - Technical, Scientific & Program Support
3. Dr. John D. Powell, Category 9 - Distinguished Public Service Career

"BRONZE" AWARD RECIPIENTS

1. Thomas E. Braswell, Category 3a - Outstanding Para-Professional (Non-Supv) - Technical, Scientific & Program Support (Individual)
2. Todd Brinkman, Paul Duvall, Travis Payne, Benjamin Showalter & Eric Wilson (Energetic Response Experimental Team), Category 3b - Outstanding Para-Professional (Non-Supv) - Technical, Scientific & Program Support (Team)
3. John Hightower, Category 4a - Outstanding Administrative/Management Assistant (Individual)
4. Heidi Maupin, Category 8a - Volunteer Service/Community Outreach (Individual)

HENAAC

Dr. Leticia J. Pacheco - Special STEM Recognition

2011 ARMY MODELING & SIMULATION AWARD — *1. MULTIPLE AMPUTATION TRAUMA TRAINER (MATT)

NOMINEES:

Dr. Teresita Marie Sotomayor, ARL HRED STTC

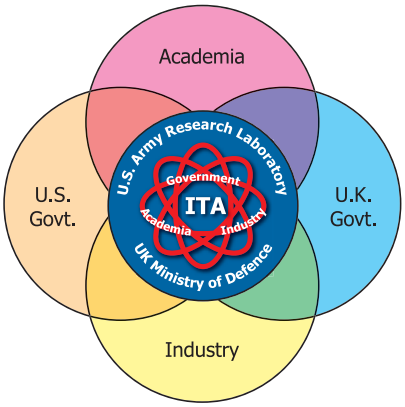
Mr. Jack Norfleet, ARL HRED STTC

Mr. Alex Hill, Kforce Government Solutions, Corporation

** Also won the 2011 Interservice/Industry Training, Simulation and Education Conference Governor's Award*

ARL is partnering and collaborating with academia, industry and other government organizations through a variety of continuing and new innovative programs. Our intent is to maximize the use of our limited research dollars by leveraging the resource investments of our partners using a variety of approaches ranging from single investigator grants with individual university faculty, to large centers with groups and consortia, to direct collaborations between university research personnel and ARL in-house scientists, engineers and analysts.

ARL's partnership programs include the Single Investigator Program, Multidisciplinary University Research Initiative Program, Collaborative Technology/Research Alliances, Centers of Excellence, Historically Black Colleges and Universities/Minority Institutions, Army Research Office core grants, Small Business Innovation Research/Small Business Technology Transfer Program, University Affiliated Research Centers, Defense Experimental Program to Stimulate Competitive Research, Short Term Innovative Research and International Technology Alliance.



INTERNATIONAL TECHNOLOGY ALLIANCE

CENTERS OF EXCELLENCE

- HIGH PERFORMANCE COMPUTING
- FLEXIBLE DISPLAYS
- MATERIALS

COLLABORATIVE TECHNOLOGY/RESEARCH ALLIANCES

- MICRO AUTONOMOUS SYSTEMS & TECHNOLOGY
- ROBOTICS
- COGNITION & NEUROERGONOMICS
- NETWORK SCIENCE
- MULTI-SCALE MODELING

UNIVERSITY AFFILIATED RESEARCH CENTERS

BIOTECHNOLOGY

ICB: Institute of Collaborative Biotechnologies

Biologically derived:
- Sensors
- Electronics
- Information Processing

NANOTECHNOLOGY

ISN: Institute of Soldier Nanotechnologies

- Protection
- Performance Enhancement
- Injury Intervention and Cure

ELECTROMECHANICS & HYPERVELOCITY PHYSICS

IAT: Institute for Advanced Technology

- Electromagnetic Launch
- Pulsed Power
- Electric Armaments

IMMERSIVE ENVIRONMENTS

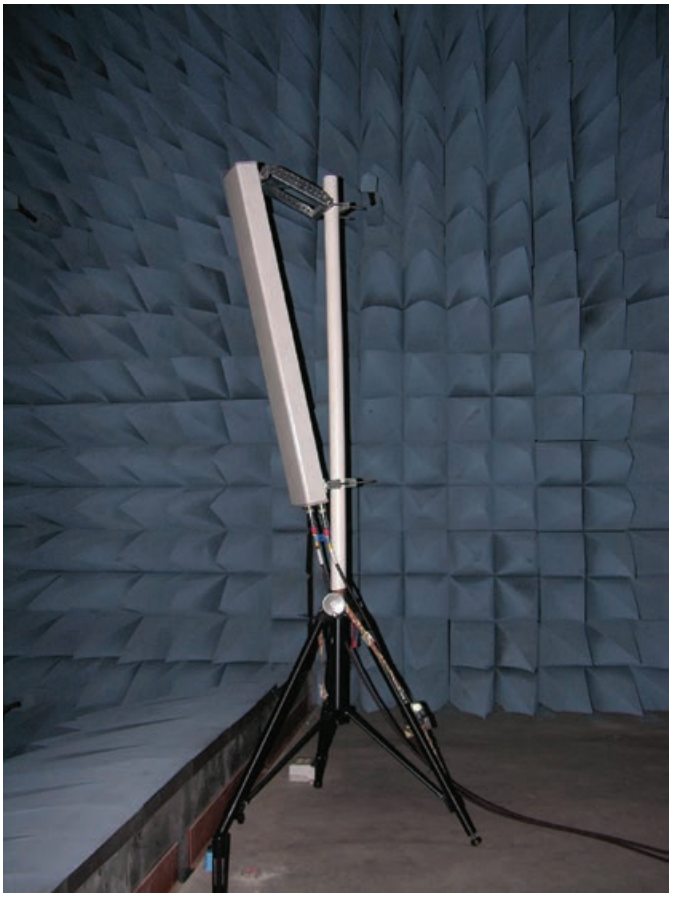
ICT: Institute for Creative Technologies

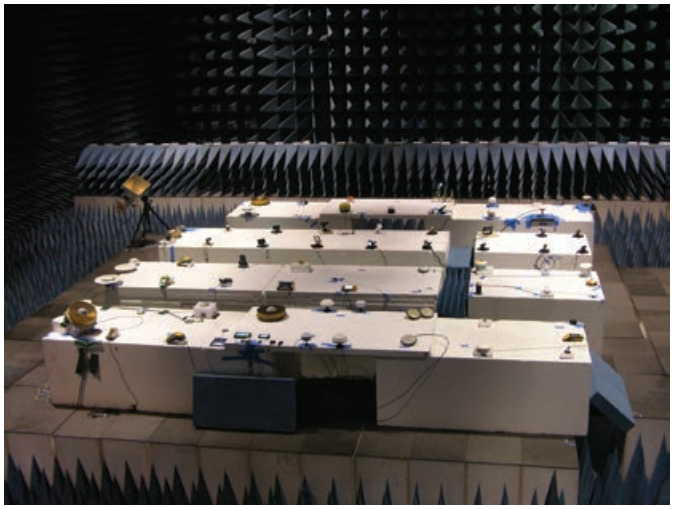
- Full Sensory Immersion
- 3-D Mobility
- Compelling Interactive Stories

Assessment of New Cellular Network Prevents Interference with Global Positioning Systems, Increasing Combat Effectiveness

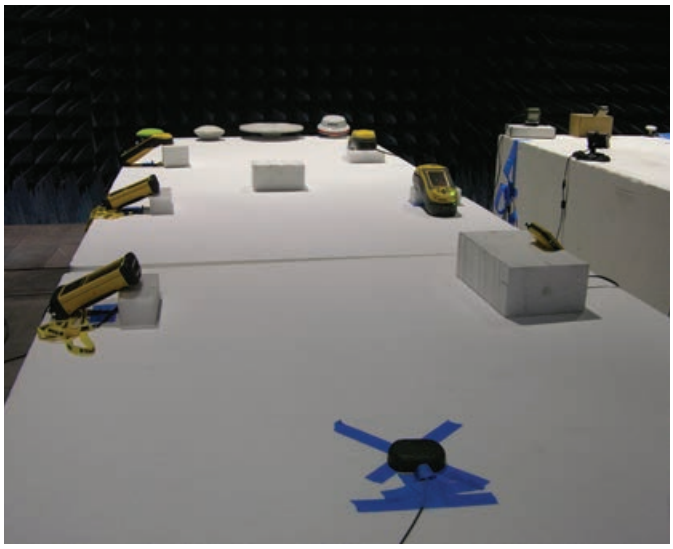
Many weapons and communication systems rely on Global Positioning Systems (GPS) to a large extent for position and time information. To prevent civilian cellular wireless systems under development by LightSquared, Inc. from interfering with GPS systems, ARL teamed with LightSquared and the Air Force Space and Missile Systems Center to assess the proposed high-powered, high-speed 4G cellular transmitters operating in the lowest band of their spectrum. A similar set of measurements made by ARL in April 2011 had indicated that, when operating in the highest band of their spectrum, LightSquared's transmitters degrade the performance of civilian GPS receivers. In response, LightSquared, Inc. proposed to limit itself to the lowest band. Results from the second set of measurements in November 2011 indicated that even in their lowest band, the transmitters impact performance of the majority of navigation devices tested. These results informed the FCC's final decision to deny LightSquared, Inc. permission to operate their nationwide 4G network, due to the unacceptable interference with GPS. The ARL, Air Force, and Lightsquared, Inc. assessment, which resulted in the prevention of significant interference to GPS receivers, helped to ensure the continued availability of GPS and, thus, combat effectiveness.

LightSquared, Inc. high-speed 4G cellular transmitter antenna located on the mezzanine of ARL's Electromagnetic Vulnerability Assessment Facility (EMVAF) transmitting to an array of GPS antennas and receivers below.





GPS receiver test array, including both military and civilian receivers, located in ARL's Electromagnetic Vulnerability Assessment Facility (EMVAF). An ARL high-gain horn antenna used to monitor the LightSquared, Inc. transmitted power levels is located at the left rear of the picture.



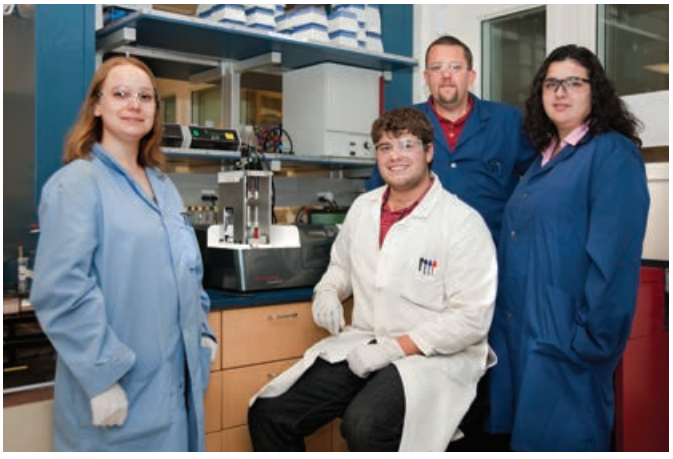
Close-up of the GPS receiver test array located in ARL's Electromagnetic Vulnerability Assessment Facility (EMVAF).

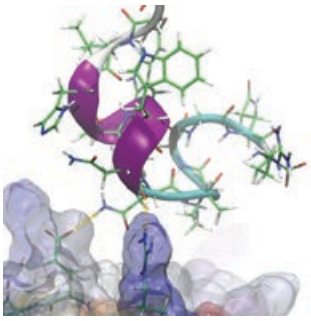
Synthetic Recognition for Rapid, Adaptable Biothreat Detection

Current state-of-the-art biothreat detection methods require several months to generate new sensor recognition materials, leaving the DoD without biothreat sensor capabilities for any new threat that emerges. ARL, in collaboration with partners from the University of California, Santa Barbara and Cynvenio Biosystems, has established a new capability in peptide synthetic recognition for rapid, adaptable biothreat detection. Using the newly established capability, a variety of materials can be targeted at the molecular level, addressing this critical gap. The power of the synthetic recognition technique lies in its ability to probe billions of different protein variants simultaneously, while harnessing the embedded genetic code of the isolated variant for identification. ARL's unique approach combines bacterial display of peptide variants and semi-automated rare cell recovery to enable development of robust reagents in days, with enhanced environmental stability and reduced cost. With support from the Defense Threat Reduction Agency's (DTRA) chemical and biological defense basic research program, ARL developed a supporting multi-scale modeling toolkit to uncover the forces driving synthetic peptide interactions, thereby enabling "smart" reagent evolution with superior performance. These new capabilities will have a significant impact on chemical/biological defense and food safety.

Disposable microfluidic cartridge enables rapid isolation of synthetic recognition reagents used for sensing biological threats.

ARL researchers, Ms. Deborah Sarkes, Mr. Joseph Pennington, Dr. Joshua Kogot, and Dr. Dimitra Stratis-Cullum (left-to-right) are developing peptide reagents using ARL's rapid affinity reagent technology.





A cross-directorate collaboration using multi-scale biophysics modeling uncovers the forces driving synthetic peptide-target protein interactions.

JIGSAW – a Tool for Continuous Monitoring and Cyber Risk Assessment in Deployed Networks

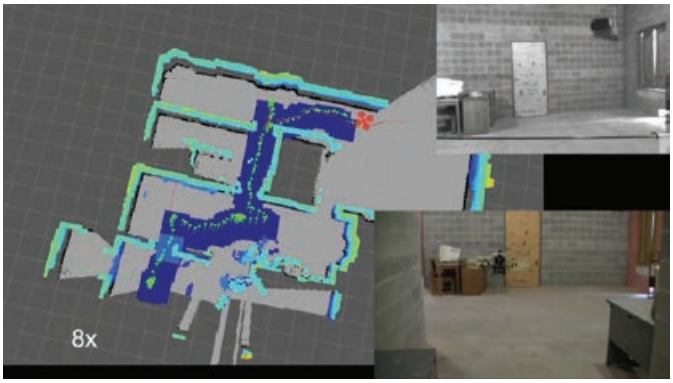
A collaborative effort between the ARL, DoD High Performance Computing Modernization Program, National Security Agency and Massachusetts Institute of Technology, JIGSAW integrates a number of the security tools deployed throughout an Army enterprise into a single point of view that Soldiers and decision-makers can use to generate risk scores for each of a network's sites. The tool is designed to accept data in multiple formats, including raw text files, XML, SCAP/OVAL, online databases, web pages, RSS feeds, and system logs. JIGSAW watches activities over time, thereby recording history; allows distributed indexing of collected data and distributed searching, so the work of a query can be distributed across the enterprise; and provides for building new dashboards quickly to react to new threats. Collaboration between ARL and Lincoln Labs explores additional algorithms and metrics that aggregate a broad range of cyber sensor observable measurements into the most appropriate characterization of cyber risks to a network.

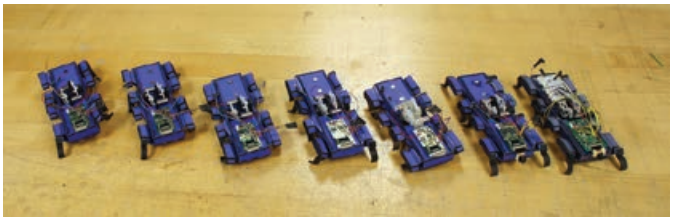
Artistic Vision of MAST concept.

Micro Autonomous Systems and Technology (MAST) Collaborative Technology Alliance Extends Warfighter Situational Awareness

The MAST Collaborative Technology Alliance (CTA) provides the basic research to expand the Warfighter's situational awareness in complex terrain and confined environments through the use of palm-sized and smaller autonomous robotic platforms. The CTA made specific advancements using biological principals of body and appendage design to enhance aerial and ground maneuverability in complex environments. Innovative algorithms and control architectures were developed that enable enhanced obstacle detection and mapping for 3-D perception and navigation in cluttered environments. Electronics research included development of multi-channel, multi-protocol, low power radios and drop-off repeater nodes that are critical to both reconnaissance and surveillance missions because they maintain communication with the Soldier.

MAST surrogate aerial vehicle autonomously navigating and mapping a building.





Group of ground platforms for research in terramechanics.

The MAST CTA's advances are critical steps toward realizing small scale autonomous robotic systems that provide operational capabilities to the Warfighter which would otherwise be costly, impossible or deadly to achieve. CTA participants in the first 5 years include: BAE Systems (CTA Lead), NASA Jet Propulsion Laboratory, University of Maryland, University of Michigan, University of Pennsylvania, Georgia Institute of Technology, University of California-Berkeley, University of New Mexico, North Carolina A&T, Massachusetts Institute of Technology and Harvard University.

Electromagnetic Vulnerability Assessment Facility

This facility addresses the complete electromagnetic threat being encountered in theater and anticipated for the Future Force.

Novel Energetics Research Facility

This facility contains a processing complex with energetics processing and manufacturing labs and an explosives casting lab. It also has explosives x-ray capability.

Shooting Simulator

This indoor small arms shooting performance simulator with a high-speed weapon tracking system provides real-time continuous weapon aim point data.

Robotics Research Facility

This 13-acre course is used for unmanned vehicles and indirect driving studies. Driving paths include straightaways, slaloms, tight turns, and straight and broad paths in which obstacles such as logs and rocks must be avoided.

Laser Optics Testbed

This laboratory is equipped to support sophisticated investigations in adaptive and nonlinear optics, advanced imaging and image processing and laser communications for ground-to-ground applications.

Rotorcraft Survivability Assessment Facility

This state-of-the-art facility provides accurate and timely test and evaluation information that will lead to improvements in aircraft design and reduce injury and death.

Pulse Power Facility

This facility provides a full-scale testbed for development, evaluation and demonstration of pulse power components.

Mobility/Portability Research Facility

This facility sets the Army standard for measuring the effects of various equipment configurations and loads on Soldier mobility and physiological performance.

Vertical Impulse Measurement Facility

This facility is used for accurately measuring the combined debris and blast impulse produced in landmine detonations. Data are used to validate models and develop technologies for improved survivability of future lightweight tactical and combat vehicles.

Tactical Environment Simulation Facility

This facility is used to study the effect of Soldier equipment on physical and cognitive performance in a completely immersive simulation environment including an Omni Directional Treadmill.

Rodman Materials Research Laboratory

The Rodman has nearly 300,000 sq. ft. of laboratories that enable the pursuit of disruptive and challenging research and characterization in advanced materials technologies for potential applications in Army weapons systems.

Transonic Experimental Research Facility

This facility evaluates aerodynamics and fluid dynamics of projectiles, smart munitions systems and sub-munitions dispense systems.

Zahl Physical Sciences Laboratory

The Zahl's cornerstone is its clean room. The lab enables basic and applied research and analysis in nanobiotechnologies; flexible electronics; advanced specialty electronics material growth; nonlinear material research and characterization; and power electronics.

SFC Paul Ray Smith Simulation and Training Technology Center

This facility provides for advanced simulation technology capabilities, enhancing the Soldier experience in training environments, increasing training system performance and cost effectiveness.

DSRC and Scientific Visualization Facility

This facility features state-of-the-art scalable parallel architectures and large vector-parallel systems supporting missions throughout the DoD's RDT&E community.

Airbase Experimental Facility

This modern, centralized complex provides analysts, program managers and decision makers with experimental data that addresses the survivability, lethality and vulnerability of air combat systems.

Vehicle Technology Facility

Completed in 2011, this new Aberdeen Proving Ground facility is enhancing air and ground vehicle systems.

ARL HAS FIVE PRIMARY SITES

Aberdeen Proving Ground, Md.

Adelphi Laboratory Center, Md.

White Sands Missile Range, N.M.

Raleigh-Durham, N.C.

Orlando, Fla.

Unique facilities at our primary sites provide our scientists and engineers access to world-class research centers.

The U.S. Army has evolved into a high-technology fighting force, relying on cutting-edge research and analysis to maintain its dominance. The research ARL performs to sustain such a force is inherently long-term in nature and may require years before innovative capabilities are delivered to our Warfighters. The seven high-payoff Strategic Research Initiatives (SRIs) depicted below can expand existing competencies or establish new core competencies.

The ARL Director's Strategic Initiatives (DSIs) are three-year funded efforts ($500K–$1M/yr) for emerging (revolutionary) research areas in support of ARL's Strategic Research Initiatives. These programs have the potential to produce radical, game-changing advances in analysis, technology and warfighting capabilities. DSIs support higher risk research that is collaborative, multidisciplinary and multi-directorate. These initiatives present the opportunity to attract new researchers and develop new infrastructure and have long-term potential to deliver unprecedented capabilities for the Soldier.

MATERIALS & DEVICES IN EXTREME ENVIRONMENTS

- Structural Materials by Design
- Multiscale Multidisciplinary Modeling of Electronic Materials
- Materials in Extreme Dynamic Environments
- Novel Magnetics
- Disruptive Energetics
- System-on-a-Chip (Flexible and Printable Electronics)
- Graphene Nanoelectronics
- Metamaterials & Metastructures
- Heterogeneous Devices

TRANSLATIONAL NEUROSCIENCE

- Cognitive Performance & Measurement
- Brain Structure-Function Coupling
- Neuroergonomic System Designs
- Neuro-Cognitive Measurement
- Neurally Inspired Systems
- Multi-Dimensional Modeling of Individual Performance

NETWORK SCIENCES

- Cognitive/Information – Decision Making
- System of Systems Analysis (S4/ WEL Integration/ Interoperation)
- Cyber Systems Architectures (Behaviors & Defenses) (INVA/DE – Interrogator Experiments)
- Battlefield Actionable Intelligence (Sentient Intelligence & Information Systems)
- Graduated Computational Representations of Human Decision Making in Networked Domains

HIERARCHICAL COMPUTING

- Commodity Computing
- Nonlinear HPC/ Scalable Algorithms
- Reduced Order Models

EXTREME ENERGY SCIENCE

- Networked Energy
- Energy Harvesting & Scavenging
- Novel Energy Storage
- Hydrogen Production of Water
- Pulsed Power
- High Temperature Thermal-to-Electric Energy Conversion

AUTONOMOUS SYSTEMS TECHNOLOGY

- Autonomous Tactical Navigation & Manipulation
- Cognitive Robotics
- Scalable Autonomy
- Intelligent Behavior & Systems

EMERGING SCIENCES

- Quantum Information (Computing, Comms, Sensing, Imaging & Simulation)
- Bio-inspired Systems
- Simulation, Training & Immersive Technologies
- Human Response Modeling – Physics-Based Mechanical to Bio-Functional Coupling
- Predicting Social, Cultural & Behavioral Small & Large Scale Dynamics

DSIs highlighted in yellow

In FY12, ARL funded ten DSIs in the areas of Structural Materials by Design, Multiscale Multidisciplinary Modeling of Electronic Materials; Graphene Nanoelectronics; Metamaterials & Metastructures; Heterogeneous Devices; Brain Structure-Function Coupling; Cyber Systems Architectures; Hydrogen Production of Water; High Temperature Thermal-to-Electric Energy Conversion; and Quantum Information.

The success of the ARL DSIs will help ensure decisive warfighting superiority for our Soldiers.

Pursuing High-risk, High-payoff Research

The Director's Research Initiative (DRI) program is designed to support innovative and possibly high-risk research ideas that have the potential to significantly advance mission needs beyond conventional expectations. The program encourages thinking "outside the box" in pursuing emerging or alternative technologies for which direct application to today's problems might not be possible, but which could have potential to address military needs in the long term.

The DRI program annually funds about 20 high-risk, high-payoff seed projects. The competition for the DRI funds is stiff and the selections are made upon the recommendation of the ARL Fellows. The proposals are independently evaluated by at least four panel members most knowledgeable in the field that the proposal was written. They are then scored with respect to originality of scientific approach, soundness of scientific methodology, importance to the scientific field or technology, importance to the Army in terms of improved materiel or operational capability, and potential value to the ARL mission program. The resultant rankings are provided to the ARL Director, and his selections are made accordingly.

2012 DRI Programs:

New Efforts:

Development of the Next Generation of Adaptive Interfaces

Synthetic Biology and Protein Engineering for Enhanced Extremophile Stability and Spectral Tuning

Coherent Optical Control of Electronic Excitations in Wide-Band-Gap Semiconductor Structures

Innovative Processing of Highly Efficient Rare Earth Free Magnetocarolic Materials

Films, Needles, and Particles: a Comparative Study on the Ferroic Properties of Complex Oxides Nano-Structured in One, Two, and Three Dimensions

Renewals: (Second of 2-yr proposal)

Detection of Bioaerosols using Single Particle Thermal Emission Spectroscopy

Efficient Terahertz Detectors Using Optical Anisotropy in Nonpolar and Semipolar Nitride Semiconductors

Lightweight, Low-Profile Army Antennas Using Carbon Nanotube Technology

Understanding Intercellular Signaling of Biofilms in Army Logistics Fluids

Atom-Spintronics on an Atom Chip

Multifunctional Structural-Energy Storage Nanocomposites for Ultra-Lightweight Micro Autonomous Systems

Dislocation Transport in Continuum Crystal Plasticity Simulations

Hierarchical Elastomers with Tunable Microstructures - Molecular Modeling from Robust Mechanical Strengthening to Multi-Functionalities

Branched Polymers for Enhancing Polymer Gel Strength and Toughness

Easily Processed Host-Guest Polymer Systems with High-Tg Characteristics

Nondestructive Early Detection of Metal Corrosion in Pigmented Coatings with Fluorescent Smart Materials

Control of Defects in (Al)GaN Films Grown on AlN Substrates

CORE TECHNICAL COMPETENCIES

Extramural Basic Research - Is focused on steering and oversight of Army-relevant technical programs executed by ARL's academic and corporate partners. This core technical competency (CTC) heavily relies on ARL's expertise in identifying and programmatically managing instantiated single investigator grants, Multi-disciplinary University Research Initiatives (MURIs), University Affiliated Research Centers (UARCs), and cooperative agreements. Discoveries generated through these programs, primarily embodied as knowledge products, are leveraged as the foundation for future Army technologies. Exemplary of Army and DoD-relevant high interest research areas supported through these efforts include biological science, nano-scale materials, and advanced mathematical methods.

Ballistics and Aeromechanic Sciences - The basic and applied research focused on gaining a fundamental understanding of explosive materials behavior, propulsion mechanisms, armor mechanics, blue asset susceptibility, and aeromechanics. This core technical competency (CTC) heavily relies on ARL's research expertise and facilities in Energetics and Propulsion Science, launch and flight sciences, Impact Physics, Ballistic Vulnerability, and Aeromechanics. Discoveries and innovations made in this area are expected to exert a significant impact on the Army's capabilities through efficient energetic and propellant systems, enhanced lethality, resilient protective systems, and robust air platform structures & propulsion systems.

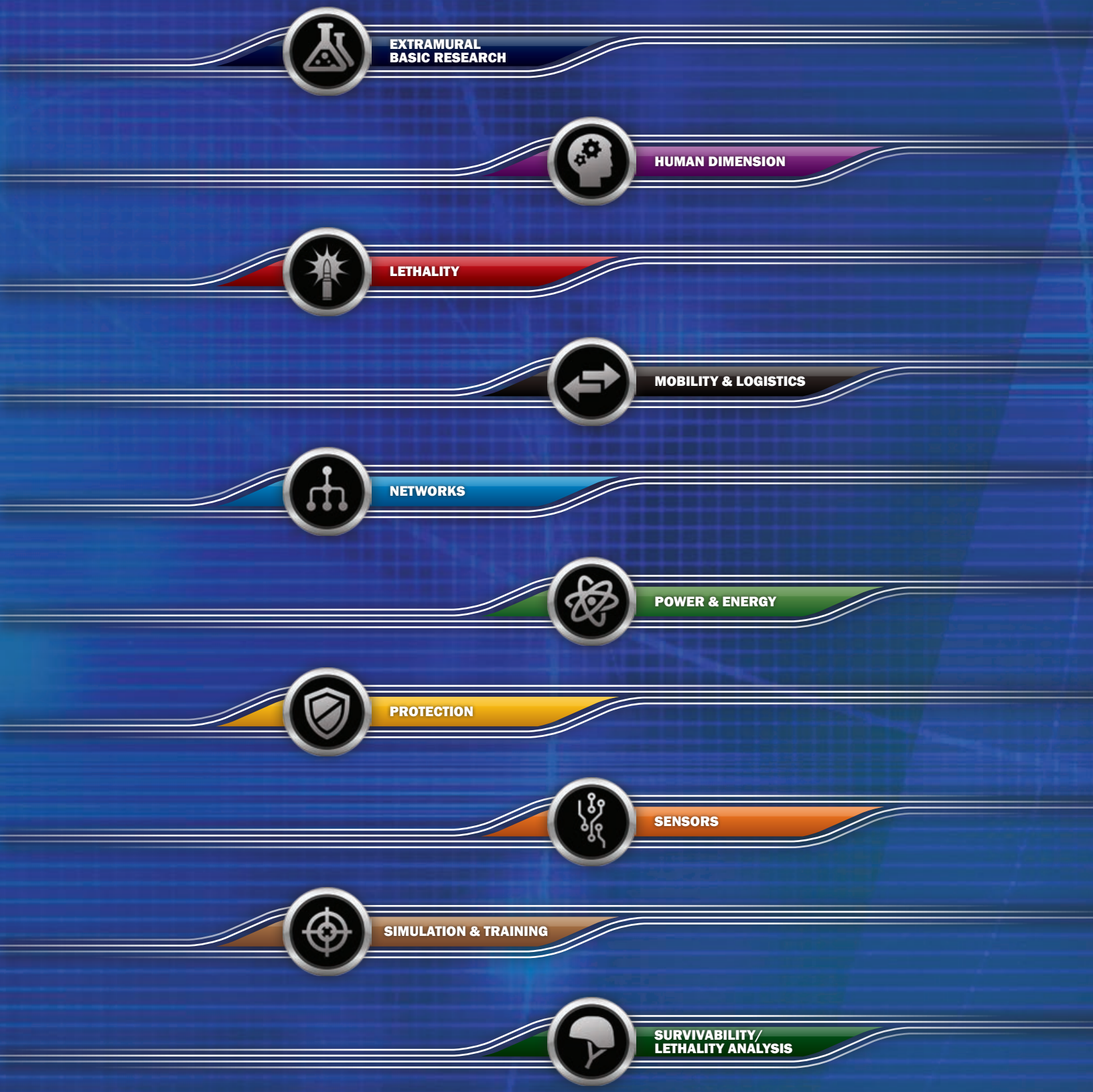
Human Sciences - The basic research, applied research, and development focused on gaining a fundamental understanding of warfighter performance enhancement, training aids, and man-machine integration. This core technical competency (CTC) heavily relies on ARL's research expertise and facilities in Soldier Performance, Simulation and Training Technologies, and Human Systems Integration. Discoveries, innovations, and developments made in this area are expected to exert a significant impact on the Army through improved warfighter physical and cognitive performance, efficient training technologies, and effective warfighter-machine integration approaches.

Information Sciences - The basic and applied research focused on gaining a fundamental understanding of information generation, collection, assurity, distribution, and exploitation. This core technical competency (CTC) heavily relies on ARL's research expertise and facilities in Network Science, Decision Support Sciences, Autonomy, Atmospheric Sciences, and Electronic & Info Warfare Vulnerability. Discoveries and innovations made in this area are expected to exert a significant impact on the Army embodied as improved tactical networks, improved Commander's decision support aids, adaptive man-machine teaming, and robust computational recourses.

Materials Sciences - The basic and applied research focused on gaining a fundamental understanding of structural, electronic, photonic, and energy materials & devices. This core technical competency (CTC) heavily relies on ARL's research expertise and facilities devoted to computational modeling, synthesis & fabrication, and characterization of novel materials. Discoveries and innovations made in this area are expected to exert a significant impact on persistent and emerging Army needs including vehicle & personnel protection, improved sensing capabilities, and efficient power generation & management.

Survivability, Lethality & Vulnerability (SLV) Assessment & Analysis - is focused on generation and application of analytical tools and methodologies to quantitatively assess the survivability, lethality, and vulnerability of Army, DoD, and select foreign combat systems. This core technical competency (CTC) heavily relies on ARL's analysis expertise and facilities in Ballistic Vulnerability and Electronic & Information Warfare Vulnerability to understand the failure conditions relevant to Army, DoD, and select foreign military systems challenged by electronic, information, conventional ballistic, and directed energy threats.

ENABLING TECHNOLOGY AREAS



CORE TECHNICAL COMPETENCIES

EXTRAMURAL BASIC RESEARCH

Unique Biochemical Pathway Activates Cell Death in Bacteria, Potentially Overcoming Antibiotic Resistance

Novel Laser Development Offers 10,000-fold Improvement in Communications, Navigation and Sensing Accuracy

Optimal Locking for Multi-core Processing Exponentially Increases Performance of Critical Battlefield Systems

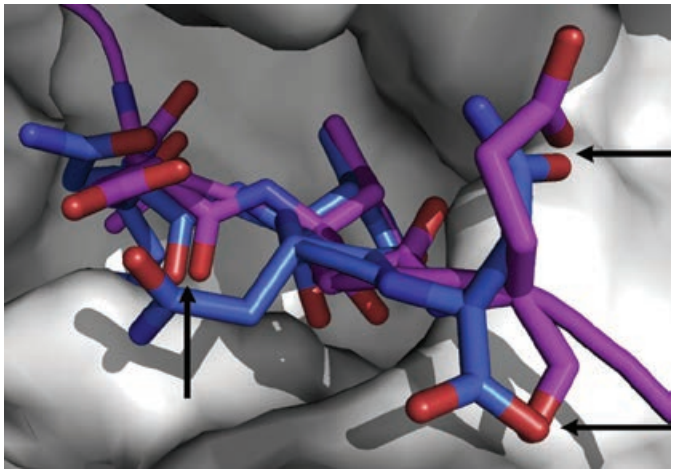
Unique Biochemical Pathway Activates Cell Death in Bacteria, Potentially Overcoming Antibiotic Resistance

ARL-funded researchers led by the Hebrew University of Jerusalem have discovered a unique biochemical pathway in bacteria that may ultimately lead to a revolutionary approach for treating bacterial infections. The unique pathway activates genetically pre-programmed cell death. The investigators found that when Escherichia coli cells are facing starvation, the cells release extracellular death factor (EDF), which activates a toxin within the cells and leads to the death of a majority of the population. Interestingly, this mechanism may allow a remnant of the original bacterial population to survive until additional nutrients become available, suggesting that EDF activation may be a natural process to control bacterial growth.

Scanning electron micrograph of Escherichia coli, grown in culture and adhered to a cover slip. (Rocky Mountain Laboratories, NIAID, NIH)

A significant limitation in antibiotic therapy is the antibiotic resistance displayed by many bacterial strains; however, activation of the EDF-mediated death pathway may provide a method to prevent survival of resistant strains. If the researchers find that this unique biochemical pathway is conserved across many bacterial species, then EDF analogs can be designed and tested in conjunction with antibiotics to potentially overcome antibiotic resistance and increase treatment efficacy for Soldiers and civilians.

ARL-funded researchers are studying biochemical pathways in bacteria that control cell growth and responses to environmental stress.



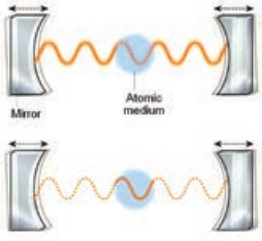
Researchers also discovered that the structure of EDF closely mimics that of another protein, called MazE, which EDF displaces to activate a toxin leading to cell death. (Belitsky M., et al. *Mol. Cell,* **2011**, *41,* 625-635)

In the future, EDF analogs could be tested in conjunction with antibiotics to potentially overcome the antibiotic resistance seen in many bacterial strains.

Novel Laser Development Offers 10,000-fold Improvement in Communications, Navigation and Sensing Accuracy

ARL researchers led by the University of Colorado demonstrated a new laser that can control the wavelength of emitted light with a precision over 10,000 times better than conventional lasers, which may lead to improved accuracy in navigation and sensing devices. The wavelength and coherence of a conventional laser is determined by the length of the cavity as photons are reflected back and forth between the mirrors many times before exiting. However, minute fluctuations in the cavity length, due

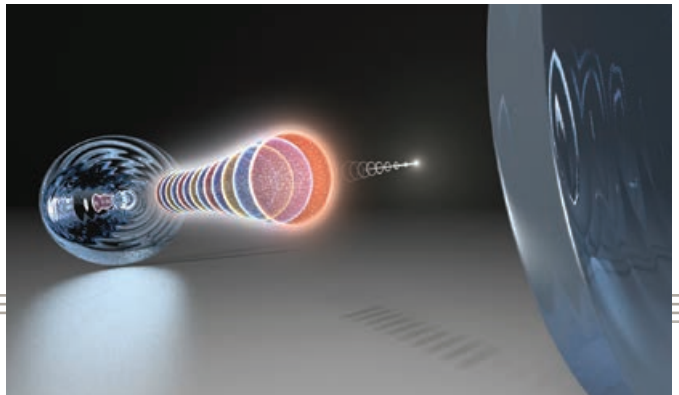
in part to temperature or mechanical vibration of the cavity mirrors, lead to a variation in the wavelength of emitted light. To create the laser, the investigators used ultracold atoms that were made to be coherent independent of mirrors. This fundamental difference provides light with greatly improved stability with regard to frequency and environmental fluctuations. The researchers are attempting to integrate these lasers into atomic clocks. If successful, these new lasers may enable improved communication and sensing devices, such as ultra-precise gradiometers.



In a standard laser (right, top), an atomic medium is used to generate the laser light, but the phase of light is scrambled slightly due to vibrations in the mirrors, which in turn cause fluctuations (imprecision) in the frequency of light emitted. In contrast, in the new laser (right, bottom), the laser frequency depends only very weakly on the distance between the mirrors. (Vladan, V. *Nature,* **2012**, *484,* 43-44)

The laser traps one million rubidium atoms between two mirrors, in a space of about 2 cm (center of image). The ultracold atoms, having synchronized their internal oscillations, will emit coherent laser light without the aid of external mirrors. (Burrus, NIST)

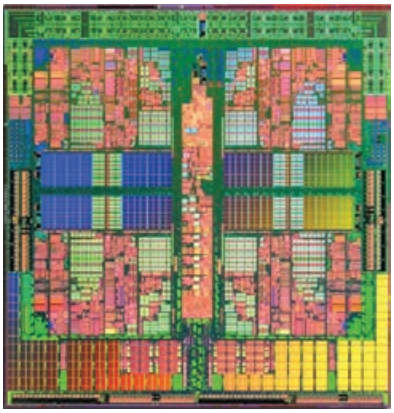
In a typical laser, coherence would result because of the resonance induced by the mirrors of the cavity. ARL-funded investigators engineered a system using ultracold atoms that enables the atoms to emit photons cooperatively rather than independently. The atoms in such a laser are synchronized, resulting in a 10,000-fold increase in their emission rate and coherence without reliance on the mirrors in the cavity. (Thompson Group; Brad Baxley, JILA)



Optimal Locking for Multi-core Processing Exponentially Increases Performance of Critical Battlefield Systems

With the ongoing shift to multi-core technologies, future Army real-time workloads will be deployed on multiprocessor platforms that differ significantly from today's platforms. If properly optimized, the use of these processors will bring super-computing capabilities to the battlefield and fulfill the Army's growing demand for more computationally intense, real-time applications. ARL-sponsored researchers have designed and analyzed the first theoretically optimal multiprocessor locks for real-time systems.

While optimal uni-processor locks have long been known, no provably optimal locks for multi-core processing were known prior to ARL's design. Without the multiprocessor locks, computers coordinating access to shared resources such as I/O devices or shared data structures "block" certain tasks that need access to a resource while waiting for another task currently using the resource to finish executing. Sometimes this results in priority inversions, where a higher priority task waits for a lower priority one. Multiprocessor locks limit the maximum duration of priority inversion.



Picture depicts a Quad-Core AMD (Advanced Micro Devices) Opteron processor, an example of a present day multi-core processor with four cores. Theoretical results apply to present day as well as future processors with 100s to 1000s of cores.

ARL's design proves mathematically that no other locks perform better in correctly scheduling tasks while minimizing the occurrence and duration of priority inversion. In addition, an empirical study using more than one billion task sets shows ARL's locks are not only theoretically optimal, but practical as well. These results allow the use of multi-core processors in timing critical battlefield systems, potentially increasing their performance by orders of magnitude.

CORE TECHNICAL COMPETENCIES

BALLISTICS AND AEROMECHANIC SCIENCES

Advanced Armor Piercing Projectile Technology Offers Significant Performance Increase

First Definitive Temperature and Electrical Conductivity Measurements of In-Flight Projectiles Improve Simulation Accuracy

Computational Research Links Blast and Ballistic Loading to Effects on the Brain

Affordable and Faster Bar Armor Production Enables Rapid Transition to Forward Units

Flight Science and Guidance Breakthrough Technologies Increase Accuracy in GPS-Denied Environments

Improving Body Armor Performance through Advances in Manufacturing

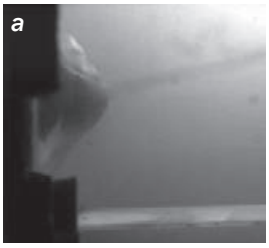
Characterizing Optical Signatures of the Human Eye for Adversary Detection

Advancements in Propulsion Technology Support Logistics and Warfighter Mobility

Vehicle Occupant Models Assess and Reduce Injuries from IEDs

Advanced Armor Piercing Projectile Technology Offers Significant Performance Increase

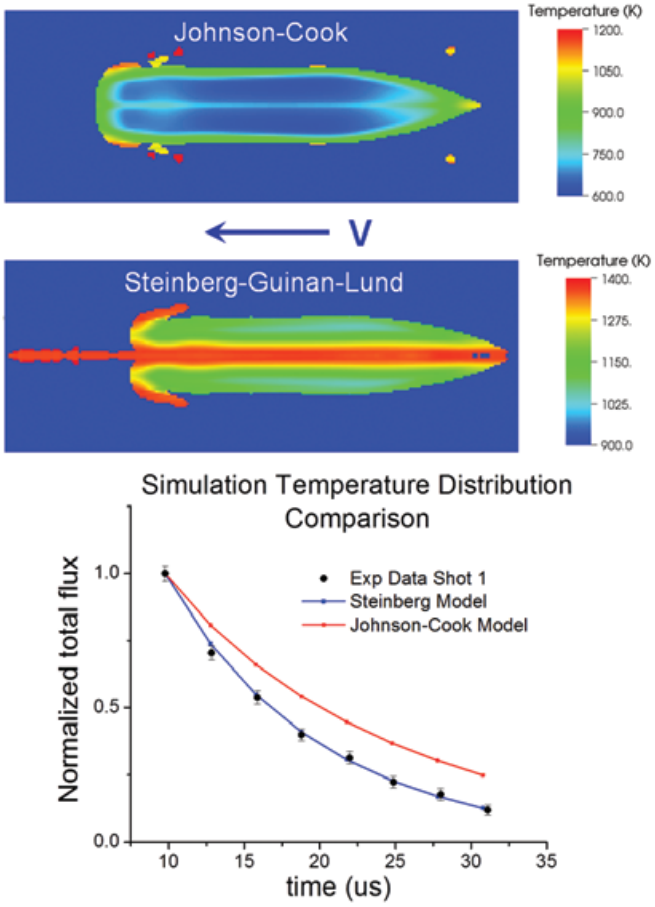
ARL has transitioned to the U.S. Army Armament Research, Development and Engineering Center (ARDEC) and Project Manager Maneuver Ammunition Systems a new projectile technology that significantly enhances performance against increasingly advanced and capable ceramic-based personal armor systems. This advanced armor piercing technology significantly increases the effective range of current weapon systems against these targets when compared to current state-of-the-art armor piercing projectiles. Although first developed and demonstrated in small caliber systems, this technology also has great potential for use in larger caliber systems. ARL is working with ARDEC to combine this technology with the technologies of the M855A1 "Green Bullet" to develop a true "universal" round — one that provides improved lethality mechanisms for use against personnel, advanced body armors and other common battlefield barriers.



High-speed images in gelatin block behind ceramic armor of interest: (a) for conventional state-of-the-art 5.56mm armor piercing impact (no perforation), (b) for 5.56mm advanced armor piercing technology round impact.

First Definitive Temperature and Electrical Conductivity Measurements of In-Flight Projectiles Improve Simulation Accuracy

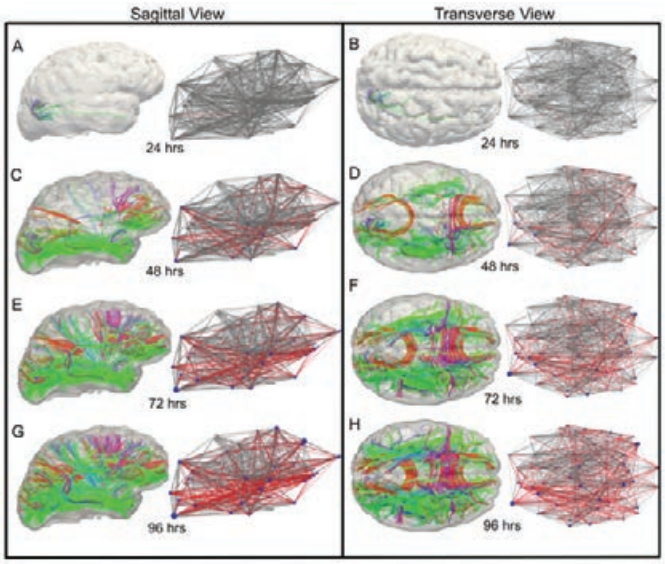
ARL research physicists have developed a novel magnetic diffusion analysis technique and mathematical model to obtain the temperature and electrical conductivity of an in-flight shaped jet charge as well as temperature measurements of 5.56 mm bullets and explosively formed penetrators. In this innovative technique, a conductive projectile is fired through an electromagnetic coil, which saturates the material with a magnetic field. Upon leaving the coil, the projectile passes through a series of sensing coils that detect the decay rate of the magnetic field; the decay rate is dependent on the geometry and electrical conductivity of the projectile. Analysis of the decay rate allows direct measurement of the electrical conductivity profile. Subsequently, the temperature profile can be calculated from the electrical conductivity profile. The experimental temperature data were directly compared to simulations with different material strength models. The magnetic diffusion technique developed is extremely versatile and can be used to investigate various projectiles over a broad dynamic range. This added capability will improve the accuracy of frequently used material models within Department of Energy shock physics computer codes for vehicle-based protection and lethality simulations.



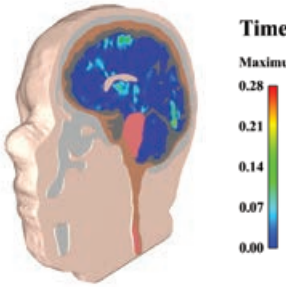
2D-axisymmetric ALEGRA simulations were performed using the Johnson-Cook and Steinberg-Guinan-Lund strength models for direct comparison to shaped charge jet tip temperatures obtained using a novel magnetic diffusion technique. The results show that the temperature distribution produced by the Steinberg model is in excellent agreement with the experimental data.

Computational Research Links Blast and Ballistic Loading to Effects on the Brain

A first-ever link between structural mechanics and connectomics enables the enhanced understanding of spatiotemporal characteristics of brain trauma. ARL has developed a computational methodology to link mechanical loading of the head to computational neuroscience. Diffusion tensor imaging incorporates the structural orientation of neuronal axonal fiber bundles into an individual-specific model of the human head and computationally captures diffuse axonal injury. Finite element simulations predict biomechanical tissue deformation on the mesoscale and approximate the extent of cellular injury. A time-evolving injury model is necessary because the biological response occurs on a longer time scale than the rapid mechanical insult. The edges in the structural network are degraded and analyzed using graph theory measures. This approach could provide insight into traumatic brain injury and how focal mechanical input can have widespread affects in the structural networks of the brain.



Structural Network Degradation from Frontal Impact.



Axonal Strain in the Brain from a Frontal Impact.

Affordable and Faster Bar Armor Production Enables Rapid Transition to Forward Units

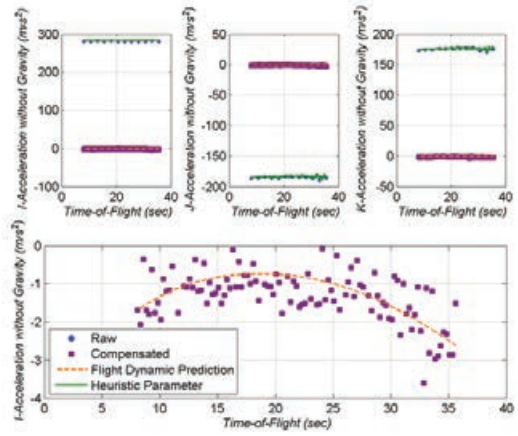
In response to a request from the U.S. Army Tank Automotive Research, Development and Engineering Center's (TARDEC) Route Clearance Vehicle Team and Project Manager Assured Mobility Systems, ARL designed new bar armor with improved manufacturability and decreased cost relative to currently used bar armor. The new Chevron bar armor kit uses mild steel in a carefully designed shape as a substitute for the currently fielded aluminum alloy. The innovative Chevron design provides an armor of equal weight and performance with a reduced production time and a cost savings of $10K–$15K per vehicle kit. The Chevron Bar Armor Kit pictured is on the RG-31 armored personnel carrier. TARDEC is currently in the last stages of integrating the Chevron kit on Mine Resistant Ambush Protected (MRAP) Caiman and Maxxpro Plus armored fighting vehicles. An additional effort to apply the Chevron kit to the MRAP All Terrain Vehicle (M-ATV) front window is currently underway. Faster production times result in the rapid transition of kits to forward units, thereby providing a cost-effective solution to a pressing operational need.

Flight Science and Guidance Breakthrough Technologies Increase Accuracy in GPS-Denied Environments

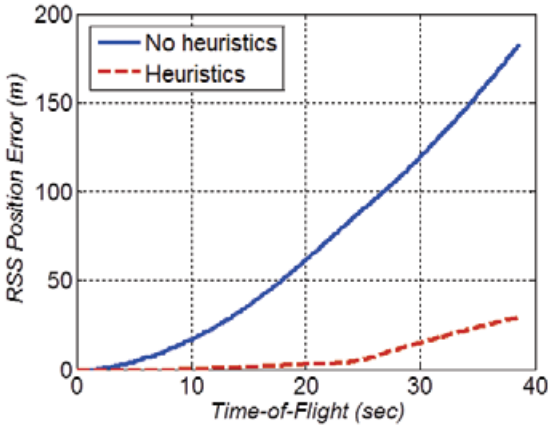
Munitions guidance techniques for Global Positioning System (GPS)-denied environments utilizing projectile dynamics allow the use of low-cost sensors in projectile navigation for the first time. This precision technology enables Soldiers to hit targets with a single projectile and with reduced collateral damage. Due to the enormous technical challenges associated with guiding a smart munition to a target in a GPS-denied environment, current solutions involve highly complex

Experimental projectile

and costly sensors. By mathematically modeling the projectile dynamics, ARL researchers were able to estimate a heuristic inertial measurement bias and, therefore, could calibrate the low-cost sensors in flight, rendering them useful for state estimation. Further, this combination of sensors and dynamics in an extended Kalman filter actually provides an improved state estimate. Using the low-cost sensors, simulations and experimental data indicate a GPS-denied position estimation error of 40 m, which is an approximately 30% decrease in error relative to ballistic position error. Potential applications include GPS anti-jam systems, short time-of-flight projectiles, vision-based navigation aids and GPS-denied indirect fire systems.



By using projectile dynamics, a heuristic inertial measurement unit bias parameter can be estimated, and the algorithm can be mathematically compensated.



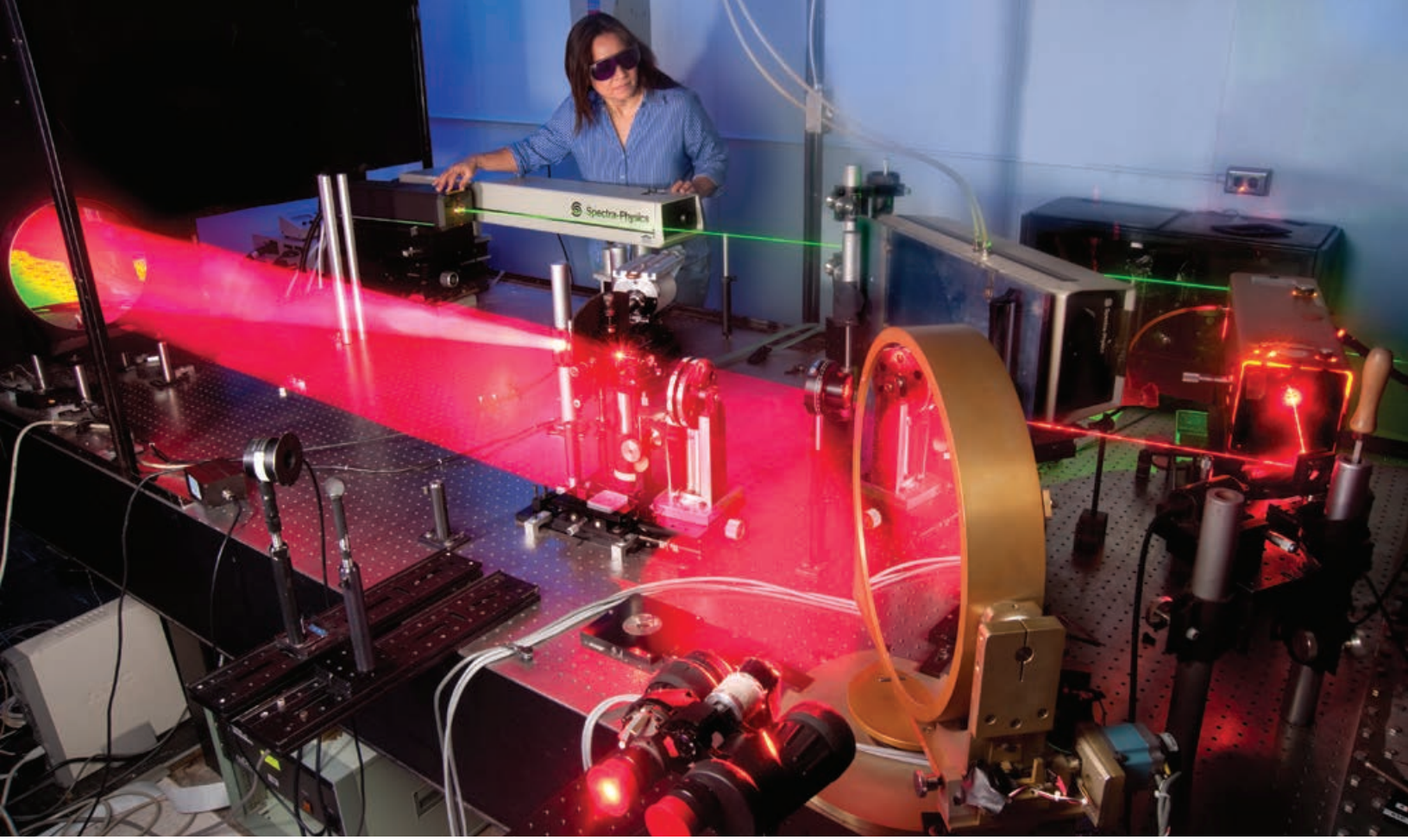
Reduction in position errors obtained from simulation when the effect of heuristics is considered.

Improving Body Armor Performance through Advances in Manufacturing

A conceptual rendering of the Dissimilar Materials Assembly System (DMAS).

Development of the Dissimilar Materials Assembly System (DMAS) machine has resulted in the reduction of processing-related variability and a quantifiable improvement in body armor performance. ARL's DMAS machine automates assembly of the dissimilar materials used in body armor packages. It allows integration of different materials and complex fiber architecture sequences that have been proven to reduce back face deformation in ceramic-based body armor systems. This is a critical step that enables weight reduction in the body armor without increasing the risk of "behind armor" blunt trauma to the torso and vital organs. The DMAS is a key example of ARL's strategy to develop and demonstrate next-generation process technologies and place them in contractor-neutral locations to enable technology transfer with both government stakeholders and DoD contractors.

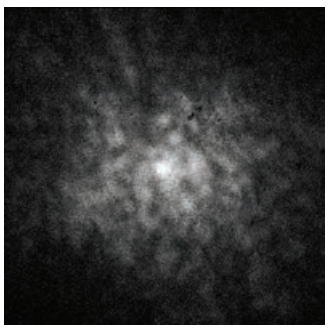
The DMAS machine in operation.



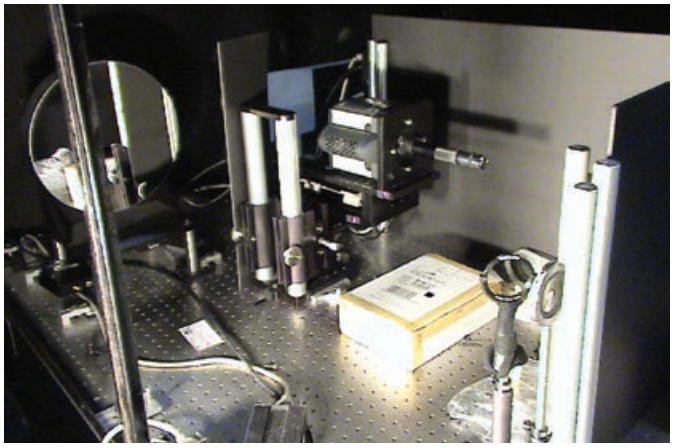
Suzanne Reynolds uses the Fourier Transform Range Simulator (FTRS) to acquire signature data during the eye optical cross-section (OCS) study.

Characterizing Optical Signatures of the Human Eye for Adversary Detection

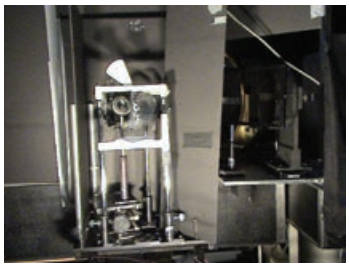
ARL performed a human subject study to measure the optical cross-section signature of the human eye, conventionally known as the red-eye effect in photography. Fifteen volunteers participated in the study, and signature data were collected for a number of illumination conditions and wavelengths in the visible and near-infrared band. The study's primary purpose was to characterize the optical signature to aide in the development of Army active laser systems designed to detect adversaries using the reflection from their eyes.



The image shows the reflected energy pattern as a function of angle collected for one subject during the eye optical cross-section (OCS) study. Note the mottled nature of the reflection which is created by multiple reflections from retinal capillaries in the eye.



Electron-multiplied charged-couple device (CCD) camera on the Fourier Transform Range Simulator (FTRS) table used during the eye optical cross-section (OCS) study to capture optical returns from the eye.



Eye optical cross-section (OCS) study subject location on Fourier Transform Range Simulator (FTRS) table showing pupil adjustment source and chin rest.

Advancements in Propulsion Technology Support Logistics and Warfighter Mobility

Through a joint research program with the NASA Fundamental Aeronautics Program Rotary Wing Project, ARL improved propulsion technologies related to compressor and power-turbine components of gas turbine engines that will enhance Soldier mobility. In 2012, ARL completed the first experimental phase of a multi-year effort to design a stable, compact, efficient, high work-input centrifugal compressor for future high power-density engines. The design approach used tools calibrated to data from an existing high performance centrifugal compressor. Analysis of both overall and subcomponent performance data from the new compressor indicates the effectiveness of particular aerodynamic design elements and computational tools. Variable speed power turbine (VSPT) technology advanced through the concept demonstration phase and is now being transitioned to component development programs. Both computational fluid dynamics and experimental analyses indicate the potential for high performing VSPTs that permit advanced airframe configurations. The U.S. Army Aviation and Missile Research Development and Engineering Center is continuing to advance VSPT technology with participation from NASA through jointly funded component development contracts. Both compressor and turbine research are advancing technologies for Future-Vertical-Lift/Joint-Multi-Role aircraft platforms.

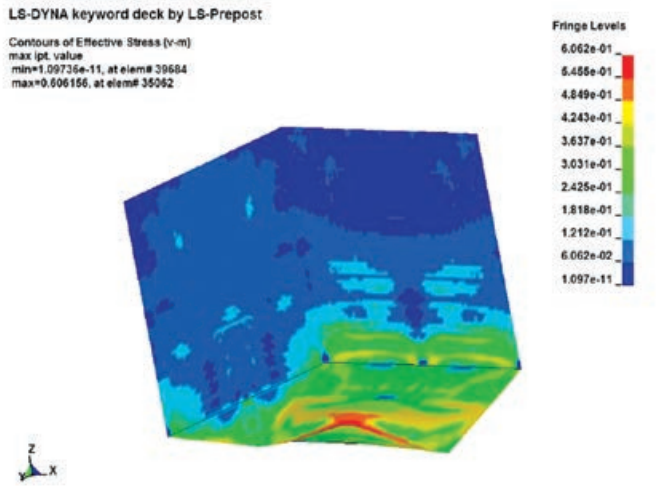
High Efficiency Centrifugal Compressor

The V-22 Osprey is a multi-mission, military tiltrotor aircraft capable of vertical take-off and landing (VTOL).

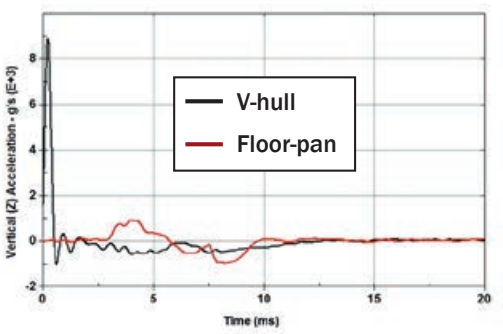
Vehicle Occupant Models Assess and Reduce Injuries from IEDs

Anti-vehicular Improvised Explosive Devices (IEDs) are a significant threat for military vehicles and their occupants. To simulate injuries from IEDs and assess the effectiveness of preventive measures, ARL conducted IED blast analysis on an in-house-developed lumped parameter physical model of a human body seated within a mock vehicle. Blast-induced injuries to vulnerable body regions were modeled with multi-body dynamic simulation software. In their simulations, ARL evaluated the effectiveness of preventive measures — specifically, passive seat and footrest damper devices — to determine their effectiveness in protecting a seated occupant during a blast event. Analytical results show the presence of seat dampers significantly influences neck and spine injuries, but has less influence on lower leg injuries. To protect the lower leg from injury, a separate footrest with a passive spring-damper system is more effective than a seat damper alone. These conclusions provide for retrofitting and redesigning military vehicles to enhance protection for the Warfighter.

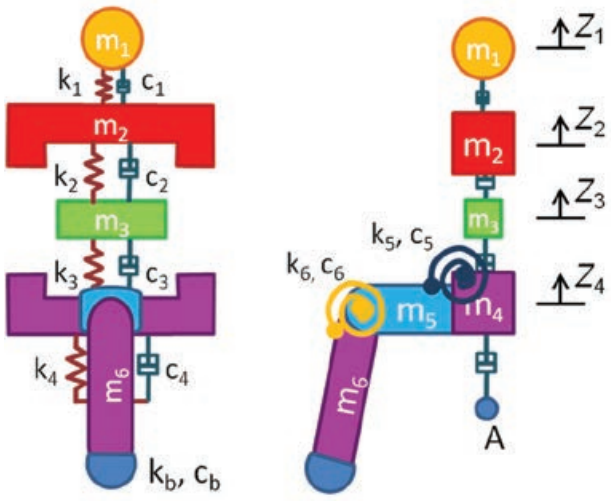
Lumped-Parameter Human Body Model on a Vehicle



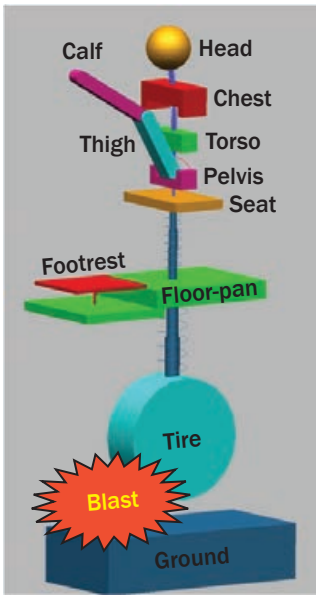
Structural Blast Response Model



V-Hull and Floor-pan acceleration response



Human Body Bio-dynamic Model



Lumped-parameter human body blast response during underbody blast of a vehicle

CORE TECHNICAL COMPETENCIES

HUMAN SCIENCES

Air Soldier System Helmet-Mounted Display Prevents Fatalities and Aircraft Losses

Human Figure Modeling Improves System Design for Enhanced Operational Effectiveness

MATREX Technologies Reduce Cost, Schedule and Technical Risk Across Acquisition Programs

Characterizing the Effects of Advanced Combat Helmets on Auditory Spatial Perception

Combat Medical Simulation and Training Research Yields Increased Authenticity and Effectiveness

IMOPAT Partnerships Advance Military Technologies and Warfighter Performance

Executable Architecture Systems Engineering (EASE) Optimizes Complex Military Simulations

Augmented Reality Training for the Dismounted Soldier Increases Training Authenticity while Decreasing Cost

Air Soldier System Helmet-Mounted Display Prevents Fatalities and Aircraft Losses

Aircraft operations in a degraded visual environment (DVE) are a major problem for rotary wing pilots as DVEs disrupt the pilot's normal visual cues and force them to rely on inadequate cockpit instrumentation. ARL conducted an investigation of rotary wing display modalities and helmet-mounted display (HMD) symbology for the Air Soldier System program. Six Army Aviators flew a UH-60L flight simulator through realistic mission scenarios, including very challenging takeoffs and landings in a brown-out DVE. Pilots evaluated various display modality concepts including combinations of HMD symbology cues (legacy 2-D vs. 3-D head-tracked conformal HMD), 3-D audio, moving map displays and tactile feedback. The investigation indicated the 3-D head-tracked conformal symbology significantly improved crew situation awareness, reduced pilot workload and improved takeoff and landing safety over the legacy 2-D symbology. Most critically, with 3-D symbology, pilots never crashed compared to four crashes out of 54 DVE landings (7.4%) observed with 2-D symbology condition. This result alone represents prevention of up to 60 fatalities and approximately $80 million in airframe losses. These results have been instrumental to the success of the Air Soldier System program and will lead to fielding technological advancements that enhance the capability of the Army Aviation Soldier.

The left and right sides show localization performance without and with a helmet, respectively. Each ellipse represents the error observed for that azimuth angle (0°, ±22.5°, ±45°, ±67.5°, ±90°, ±112.5°, ±135°, ±157.5°, 180°). The angular width and height of the ellipses represents the 25th, median and 75th quartiles of azimuth and elevation error, respectively (at 0° elevation).

Human Figure Modeling Improves System Design for Enhanced Operational Effectiveness

Computer models of the human figure improve the ergonomic design and functionality of Army Aviation systems and ground vehicle platforms, develop and assess anthropometric requirements and reduce analysis timelines. Key to the effectiveness of human figure modeling is its performance early in the acquisition cycle, before physical prototypes are built. This allows for rapid investigation of multiple design options at a reduced cost compared to using physical prototypes. ARL conducted human figure modeling early in the development of the Future Vertical Lift/ Joint Multi-Role Helicopter; Ground Combat Vehicle; Joint Lightweight Tactical Vehicle; and the Occupant Centric Platform program. To aid in the development of Army Aviation systems and ground vehicle platforms, ARL created a digital library of Soldier clothing and equipment computer models to assess whether or not the proposed system design met human factors engineering standards. Human figure modeling will play an increasingly important role as Army program managers work to improve systems, minimize costs and shorten design, development and production timelines.

MATREX Technologies Reduce Cost, Schedule and Technical Risk Across Acquisition Programs

Modeling Architecture for Technology, Research and EXperimentation (MATREX) is a research and prototype development effort that provides the foundation for distributed modeling and simulation environments employed to reduce program cost, schedule and technical risk across Army acquisition programs. MATREX provides a unifying architecture, supporting tools and infrastructure that ease the integration and use of multi-resolution live, virtual, and constructive applications. It provides capabilities to support the examination of system-of-systems solutions at the entity level to facilitate studies and technology demonstrations that assess the operational impact of network-centric warfare concepts and technologies. MATREX creates a simulation environment that models the current and future force tactical network systems, the information that flows through that network and the impact of this information on force

effectiveness. MATREX technologies supported the U.S. Army Training and Doctrine Command (TRADOC) Battle Laboratory Collaborative Simulation Environment Gain and Maintain Operational Access experiment in June 2012. TRADOC credited MATREX technologies for the successful conclusion of the experiment. Additionally, the MATREX Federation Object Model was transitioned throughout the Army, and other MATREX tools transitioned to several DoD partners. Continued implementation of MATREX technologies will further reduce costs and risks of DoD acquisition programs.

Characterizing the Effects of Advanced Combat Helmets on Auditory Spatial Perception

Wearing helmets and hearing protection alters the acoustics of the region near the ear, thus changing the spectral content of sounds arriving at the ear. This can affect Soldiers' auditory spatial perception negatively. Soon, developers of Soldier protective equipment will be able to predict the true impact of a design on Soldier auditory perception using a physics-based model rather than through costly human factors testing. ARL auditory researchers have measured the direction-dependent spectral changes caused by advanced combat helmets and their impact on sound localization performance. These data were transitioned to developers of the Infantry Warrior Simulation (IWARS), allowing it to account for auditory capabilities on individual and squad mission success. Having these sensory data incorporated into models of Soldier performance allows decision-makers to evaluate the costs and benefits of a Soldier's headgear on mission performance, thus furthering optimal equipment choices.

Combat Medical Simulation and Training Research Yields Increased Authenticity and Effectiveness

A pressing challenge for today's medical community is the need to develop authentic severe trauma simulation prototypes for combat medic training purposes. In response to this need, ARL researched animatronics and olfaction to enhance training authenticity; developed new measures of self-efficacy to assess training effectiveness; created a high-fidelity human upper airway simulation keying on, in addition to anatomical features, task-specific requirements for training combat medics; developed a non-compressible high-volume hemorrhage training prototype, which underwent expert face and content validation studies; and created a pain cue facial expression prototype, which is a significant, but under-researched, source of diagnostic information for doctors and medics. Researchers worked closely with combat medics, nurses, physicians, two Combat Casualty Care Training Consortia and the Joint Program Committee of medical and military technical experts to execute experiments, socialize prototypes and identify additional needs of the military medical community. To improve medical functionality, ARL transitioned its virtual Tactical Combat Casualty Care Simulation into the Program Executive Office for Simulation, Training, and Instrumentation (PEO STRI) Virtual Battle Space 2 Trainer. ARL also transitioned stand-alone medical simulations to PEO STRI consisting of the Severe Trauma Moulage kit, which comprises many different kinds of moulages for use in medical simulations, and Combat Medic, Combat Lifesaver, and Improved First Aid Kit (IFAK) educational card games, which are used to train medics in the use of actual First Aid Kits carried into combat. PEO STRI directly provides these simulations to the 19 Medical Simulation Training Centers at major Army posts and to Brigade Combat Teams worldwide.

IMOPAT Partnerships Advance Military Technologies and Warfighter Performance

The Improved Mobility and Operational Performance through Autonomous Technologies (IMOPAT) project is designed to explore advanced technologies for enhancing vehicle mobility, crewmember situational awareness and mission performance of ground vehicle crew and dismounting infantry. The project is a collaborative effort between the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC); the Communications-Electronics Research, Development and Engineering Center Night Vision and Electronic Sensors Directorate (CERDEC NVESD); the Natick Soldier Research, Development and Engineering Center (NSRDEC); and the U.S. Army Research Laboratory (ARL). Recently, IMOPAT partners developed a 360° indirect vision and driving system within a manned modified Stryker vehicle and conducted evaluations of system design, functionality and usability. ARL guided development of the display concepts for the 360° sensor system through simulations and vehicle-based mission scenarios of urban reconnaissance. The mission scenarios were conducted by Stryker crewmembers based in Fort Lewis, WA, and Bradley crewmembers from the West Virginia National Guard. The crewmembers assessed core IMOPAT capabilities including the 360° indirect vision system, advanced targeting capabilities (Commander's Gimbal and Projectile Detection and Cueing systems), indirect drive-by-wire and advanced touchscreen displays. Human factors assessments used varied crewmember team configurations to evaluate information flow and display concepts. Through these contributions to the advancement, functionality and design of military technology, IMOPAT partnerships continue to enhance Warfighter situational awareness and performance.

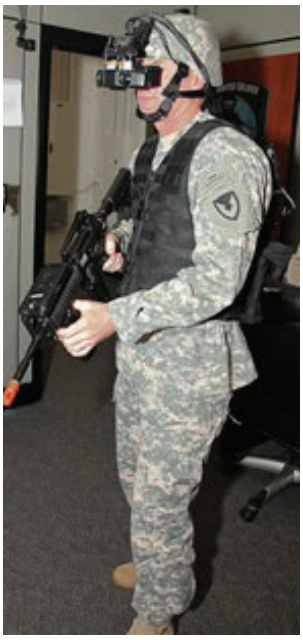
Executable Architecture Systems Engineering (EASE) Optimizes Complex Military Simulations

In an effort to improve cost and operational efficiencies and to optimize the use of simulations, ARL has developed the Executable Architecture for Systems Engineering (EASE). EASE facilitates systems engineering processes to enhance accuracy and automation of complex military simulations used in training events, experiments and analyses. EASE captures relevant data, beginning with the technical specifications driven by user requirements, and uses these data to automate the design, interoperability and execution of the simulation experiment. First implemented in 2012 at the Virtual Defense Base Operating Center, Maneuver Support Center of Excellence, Fort Leonard Wood, MO, EASE supported Force Protection Experimentations and allowed Center staff to focus on analysis, rather than attending to complex simulation integration issues. Continued implementation of EASE is planned in 2013.

Mr. Chris Gaughan briefs collaborators on a future EASE experiment.

Augmented Reality Training for the Dismounted Soldier Increases Training Authenticity while Decreasing Cost

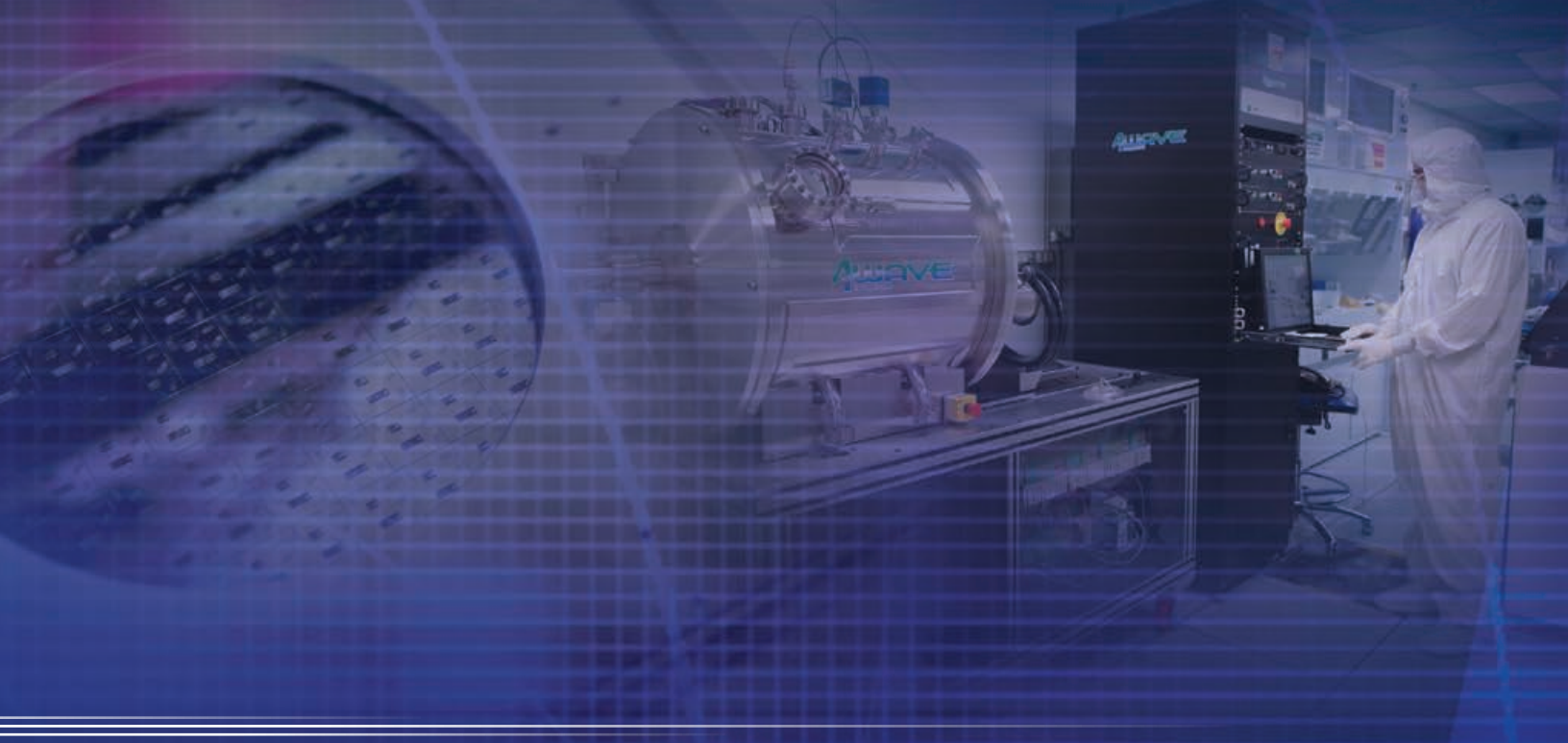
ARL completed initial collaboration on the Augmented Reality Training for the Dismounted Soldier prototype. The Augmented Reality Training system uses computer graphics and special head-mounted displays to insert virtual entities and effects into a scene viewed by each Soldier wearing augmented reality eyewear. Virtual entities respond in realistic ways



to actions of dismounted Soldiers by taking cover, firing back or responding to verbal communication. Soldiers wear helmet-mounted sensors, a helmet-mounted display and a compact computer worn on their back. The Augmented Reality system, which is infrastructure free and range independent, tracks the actions, locations and weapon poses of each Soldier in detail so the system can appropriately position virtual objects in the Soldier's field of view. Synthetic entities such as opposing forces, objects and effects are rendered by a game engine on the eyewear, and speech recognition algorithms enable verbal communication. With Augmented Reality, Soldiers train in simulated live environments without the need for additional role players and at considerable cost savings.

CORE TECHNICAL COMPETENCIES

INFORMATION SCIENCES



Weather and Environmental Impacts Routing Web Applications Enhance Survivability and Movement Efficiency

High Performance Software Applications Institute Mobile Network Modeling Institute Provides Robust Communication Capabilities for Soldiers

Mobile Application Helps Damage Assessors Collect Field Data in Afghanistan

Statistical Machine Translation for Security Needs Increases Speed, Accuracy and Precision

Ultraviolet (UV) Light Enhances Communications Capabilities

Ladar in Small Ground Robots Reduces Risk and Workload for the Soldier

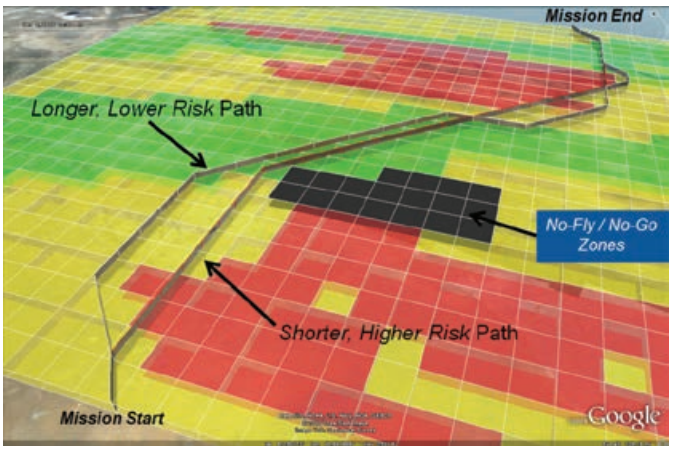
Fusion3D Software Increases Soldier Situational Awareness

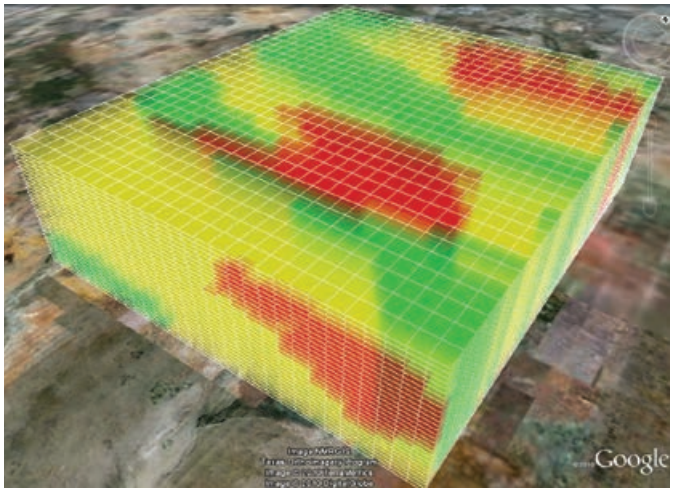
Weather and Environmental Impacts Routing Web Applications Enhance Survivability and Movement Efficiency

In support of Program Executive Office aviation requirements for avoidance of weather hazards and non-weather obstacles, ARL has developed web applications that enhance survivability and movement efficiency. The My Weather Impacts Decision Aid (MyWIDA) generates weather impact grids, and the Automated Impacts Routing (AIR) application calculates 3-D optimized paths around weather impacts and other non-weather obstacles. MyWIDA and AIR applications enhance mission planning and execution by considering environmental factors such as adverse weather, threat activity, conflicting friendly operations, difficult terrain, no-fly zones and other obstacles that could adversely affect systems during combat operations.

Using MyWIDA-generated weather impact grids, which are supplemented with obstacles by the Tactical Airspace Integration System's conflict resolution services, the optimized routing produced by the AIR application improves survivability and movement efficiency of both air and ground platforms and systems. AIR has been tested, verified and validated for incorporating route input data such as from the Aviation Mission Planning System (AMPS) or the Joint Mission Planning System (JMPS). AIR is documented in an ARL technical report (ARL-TR-5792) and a patent has been submitted for the design/implementation of the application's routing technology.

AIR-optimized 3-D flight path output in Google Maps/Earth KML format, using MyWIDA weather impacts grid (green = no weather impacts; yellow = marginal impacts; red = unfavorable impacts) supplemented by TAIS conflict/no-fly/ obstacles area (black)

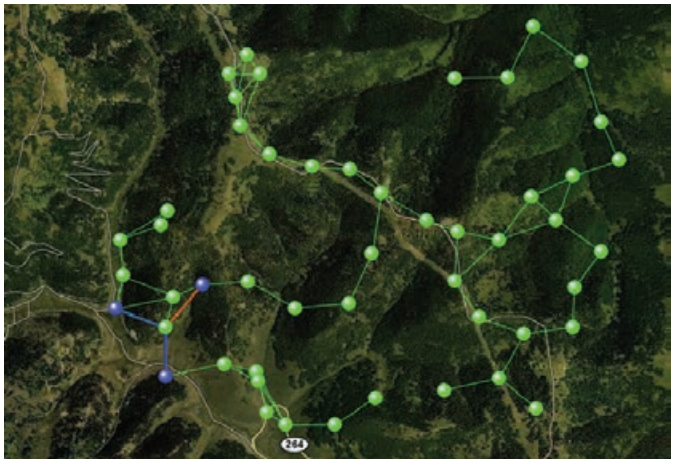


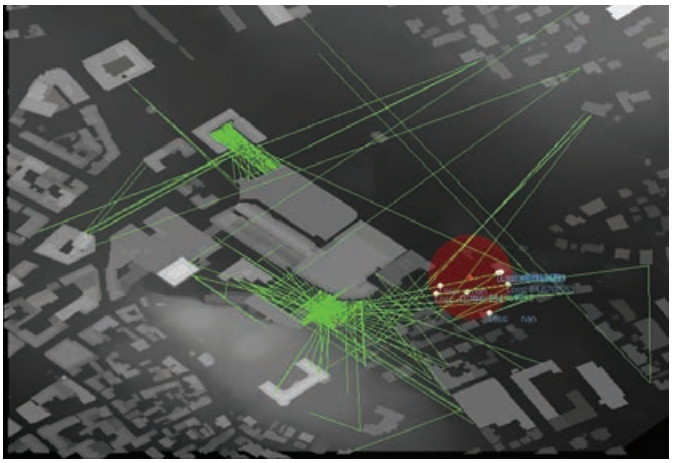


MyWIDA 3-D weather impacts grid (green = no weather impacts; yellow = marginal impacts; red = unfavorable impacts)

High Performance Software Applications Institute Mobile Network Modeling Institute Provides Robust Communication Capabilities for Soldiers

ARL is engaged in a research and development effort directed toward understanding and optimizing deployed digital networked systems for environments common in Army operational domains. The Mobile Network Modeling Institute (MNMI), led by ARL, made significant progress in being able to simulate and emulate current and proposed digital radio systems that will form the backbone of tactical mobile ad hoc networks (MANETs), all without the cost and delays of using real prototypes. ARL specialized





algorithms were executed on a hybrid computer containing 6,576 CPU cores along with 456 Graphics Processing Units to provide real-time high-fidelity Radio Frequency propagation loss (factoring in parameters such as terrain) for thousands of radios in a virtual environment. In addition, ARL successfully modeled a virtual brigade to augment the live Network Modernization exercises conducted at Ft. Dix, NJ. Close coupling of network simulation and emulation capabilities with C4ISR simulation tools enabled bi-directional communication between the ARL virtual entities and the live tactical assets; the virtual entities provided situational awareness information to C4ISR, and C4ISR sent mission tasks to the virtual entities. The MNMI toolset will enable the DoD to design and test large scale MANETs at sufficient levels of fidelity to better understand the behaviors of Network-Centric Warfare (NCW) technologies for the full range of conditions in which they will be employed.

Mobile Application Helps Damage Assessors Collect Field Data in Afghanistan

User-defined locations are marked with red and white spheres, as seen on the driver's door, and can be selected to annotate additional information. The vehicle exterior is rendered transparent to allow crew positions to be seen.

A new mobile application assists forward damage assessment teams and live-fire test evaluators in collecting field data. ARL's application provides a display of 3-D models of vehicle structures and occupants that allows users to select locations on the model and annotate them with text and photographs. ARL demonstrated the application in Afghanistan for forward damage assessment teams from the National Ground Intelligence Center as well as personnel from Task Force Paladin and the U.S. Army Test and Evaluation Command (ATEC). Their initial response has been very positive. The damage assessment teams have already identified additional capabilities they would like to see added to the application and are providing ARL with a prioritized list. ATEC personnel have also expressed interest in using the application for planning and reporting live-fire test events. ARL will further develop the application based on the feedback from these teams and continued collaboration with these organizations.

Information about the selected point on the driver's door being annotated. The user can take pictures of related objects by pressing the "Photos" button.

Mr. Lee Butler demonstrates the mobile application's data collection capability about specific points, the blue "x" marks, on the exterior of a vehicle.

Statistical Machine Translation for Security Needs Increases Speed, Accuracy and Precision

Producing high-quality translated texts in specialized topics of military interest, such as small unit leadership and training in legal/criminal justice and medical domains, requires subject matter expertise as well as expert knowledge of languages. ARL uses a form of supervised machine learning to produce software that achieves high levels of accuracy for the translation of texts needed for security transition in CENTCOM. The work of more than 8,000 contract linguists in theater is expedited and made more precise by the use of this newly available, advanced translation technology. Conventional methods of producing such translations use a short-sighted approach in which expert human knowledge is generated at the moment of translation, then discarded. The new method deliberately captures this expert knowledge in the form of parallel aligned text that is then used to train an updated statistical machine translation engine specific to a domain. Translation sequences, correction by human experts, and retraining of translation software are repeated in short cycles, emphasizing re-use of terminology and consistency throughout a translated text. Developed first to translate a technical medical manual from English into Dari in support of Combined Security Transition Command-Afghanistan Embedded Training

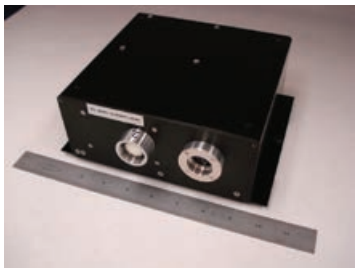
Teams, this method has been extended to include Pashto translations and to address the needs of security transition in other domains including the rule of law, detention operations and most recently in agri-business development.

Ultraviolet (UV) Light Enhances Communications Capabilities

Employing ultraviolet (UV) light for communications offers the Warfighter the potential for a new means of communication and networking that can supplement conventional systems. This is true particularly in challenging (e.g. urban, mountainous, radio-frequency (RF)-denied or bandwidth-congested) environments where today's technologies may provide extremely limited functionality. A specific novelty of UV communications is their ability to establish non-line-of-sight (NLOS) optical communications links, made possible by atmospheric effects in deep-UV wavelengths. Strong atmospheric absorption of deep-UV radiation (e.g. solar) results in a virtually noiseless channel, allowing for the use of highly-sensitive photon-counting receivers, while rich atmospheric scattering of deep-UV radiation provides the channel mechanism for NLOS UV communications. ARL scientists are engaged in a multi-year research program that explores the fundamental science of UV communications and networking, advancing the state of the art and leading the research community in developing this field. Specialized models have been developed to characterize the nontraditional and complex NLOS UV atmospheric communications channel, allowing for the prediction of communication performance and guiding the formulation of communication methods and system designs for such novel applications as hybrid UV/RF networking.

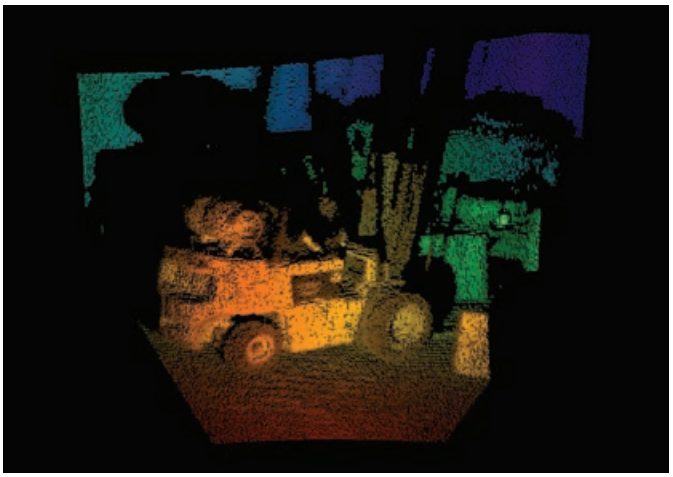
Ladar in Small Ground Robots Reduces Risk and Workload for the Soldier

Future Army combat operations will team with small robotic ground and air vehicles to minimize risk and reduce Soldier workload by performing a variety of intelligence, surveillance, reconnaissance and logistic missions. To perform these tasks, robotic vehicles will use sophisticated algorithms that require high resolution 3-D imagery from ladar sensors. Current ladars for small ground and air platforms are flawed by high cost and performance issues. ARL's research on adapting commercial microelectrical mechanical system-scanned mirrors to create new compact ladars solves many of these shortcomings and has led to a brassboard design that is a leading candidate for such applications. The ladar forms 256 x 128 x 300 voxel images to 30 m range at a 5-6 Hz rate. This year, much of the breadboard subassemblies and circuit boards were simplified and reduced in size to enable a far more compact package. ARL is building a small number of brassboard ladars and will loan them to the autonomy research community for test and evaluation, including partners in ARL's Robotics Collaborative Technology Alliance (CTA) program. Additionally, ARL established a Cooperative Research and Development Agreement (CRADA) with Boeing Spectrolab, Inc. to build a productized version of the ladar for military applications.



Ladar Brassboard

ARL Ladar Image



Fusion3D Software Increases Soldier Situational Awareness

A novel technique to visualize 3-D terrain imagery makes complex scenes more realistic and easier to interpret. The ARL-patented Fusion3D software displays Digital Elevation Models (DEMs) and fuses them with high-resolution orthophotos (geo-registered photos such as those in Google Maps, but with higher resolution), lidar point clouds, and other data such as video and radar moving target indicator data. These data types have traditionally been viewed in separate stove pipes. This hybrid technique combines the traditional method of draping data on a surface for displaying smooth areas with a point cloud-like method for displaying rough areas such as trees. Combining these data in a single viewer provides a significantly higher level of situational awareness for the Soldier.

ARL is collaborating with the Army Geospatial Center Buckeye program to offer this software on their map distribution website. BuckEye provides unclassified DEMs and orthophotos for theater; therefore, it has a large and diverse user base.

Researchers viewing a 3-D terrain map that uses the Fusion3D software.

Before and after images of a bridge, where the point cloud is draped to improve visualization for the user.

CORE TECHNICAL COMPETENCIES

MATERIALS SCIENCES

Ear Plug-Sized Sensors for Assessment of Traumatic Brain Injury

Advances in Infrared Imaging Enhance Military Surveillance

Palladium Composite Membranes for Portable Fuel Cell Applications

Novel Technique Allows for Faster Next-generation Energetic Materials Transitioning to the Soldier

Micromachined Ultra-Low Profile Inductors for Soldier-Borne Portable Electronics

Ultra-Energetic Materials for Enhanced Battlespace Awareness

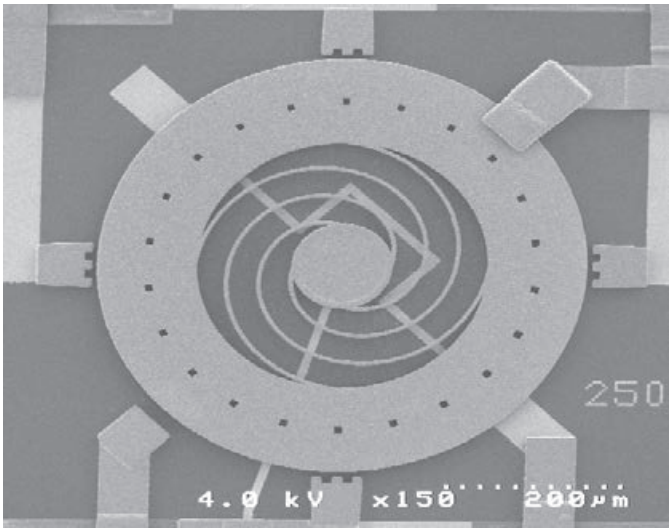
Technique to Stabilize Disruptive Energetic Materials Results in Ten Times Higher Energy Content for Future Weapon Systems

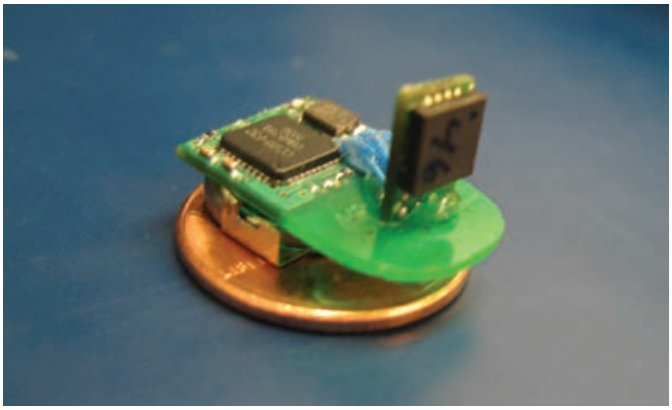
Graphene-Based Supercapacitors Enhance Electronic and Munitions Systems Performance

Ear Plug-Sized Sensors for Assessment of Traumatic Brain Injury

Microelectrical Mechanical Systems (MEMS) acceleration switch arrays developed by ARL have been integrated into an ear plug-sized sensor and transitioned to Program Manager-Soldier Protection and Individual Equipment for assessment of traumatic brain injury (TBI). Ear plug sensors measure the acceleration of the skull much more closely than existing helmet-mounted systems, which will ultimately lead to better understanding of TBI as well as faster diagnosis and more effective triage care. ARL has integrated the acceleration switch arrays in the ear plug sensor with low-power microcontrollers, wireless data transfer and a power supply. The sensors were tested on mannequin heads exposed to a simulated explosive blast from shock tubes at Duke University, one of the top TBI research teams in the world. The sensors performed well in this challenging environment. Planned improvements include lowering power consumption for longer battery life.

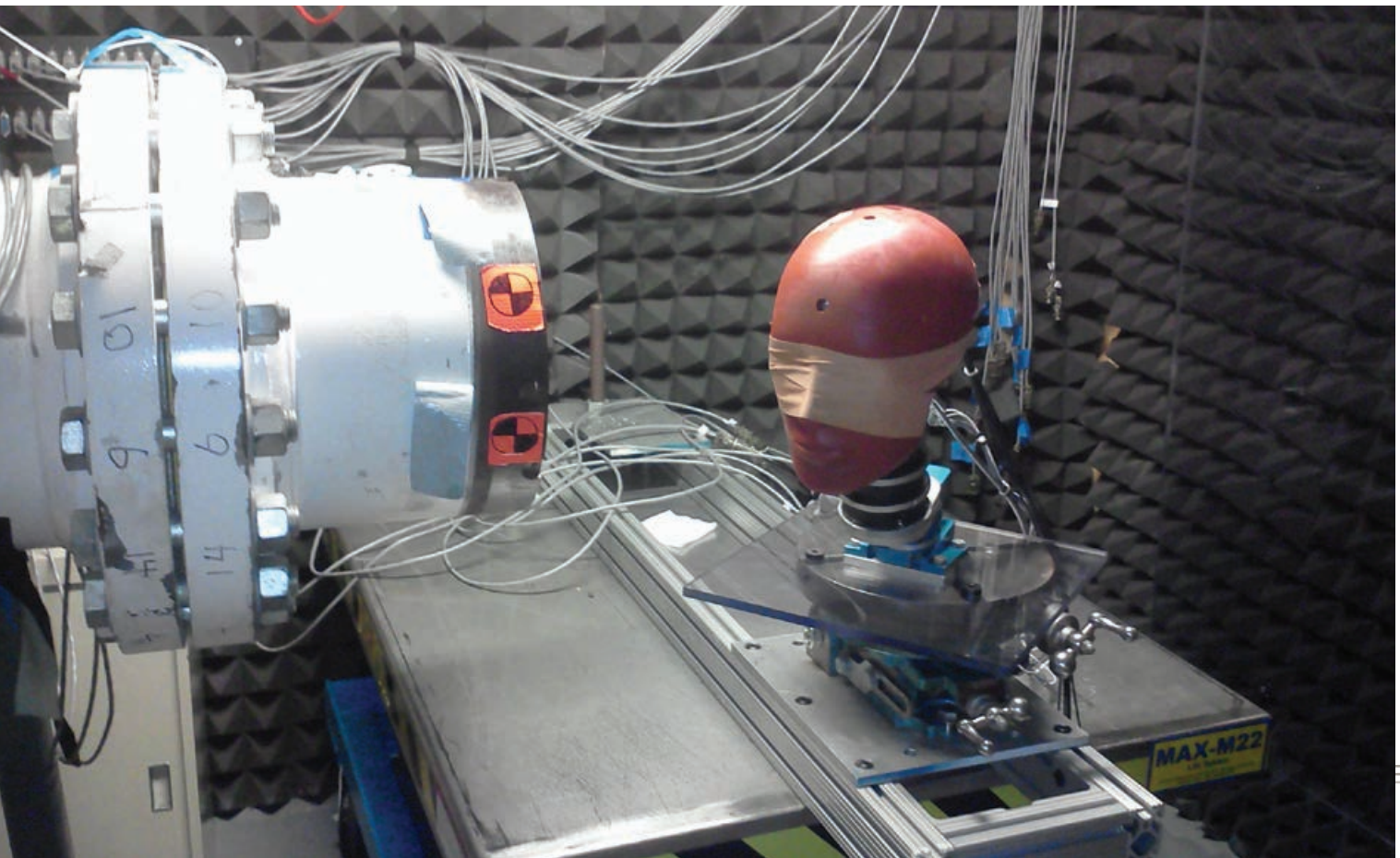
ARL 3-axis MEMS acceleration switch





Ear plug-sized TBI sensing system

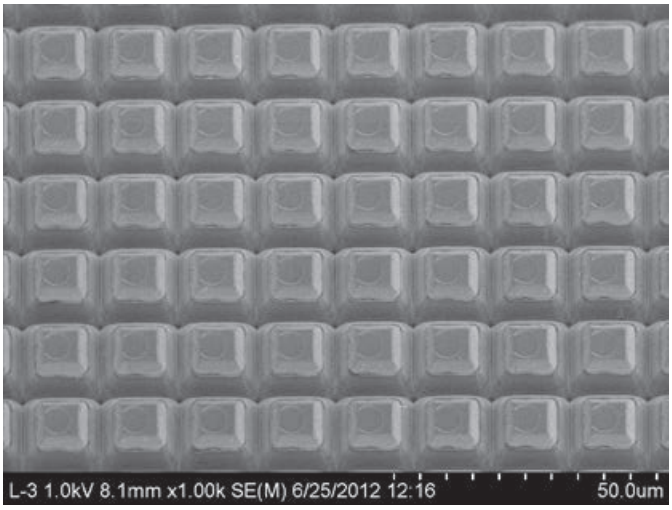
Shock tube testing of a TBI sensor system at Duke University



Advances in Infrared Imaging Enhance Military Surveillance

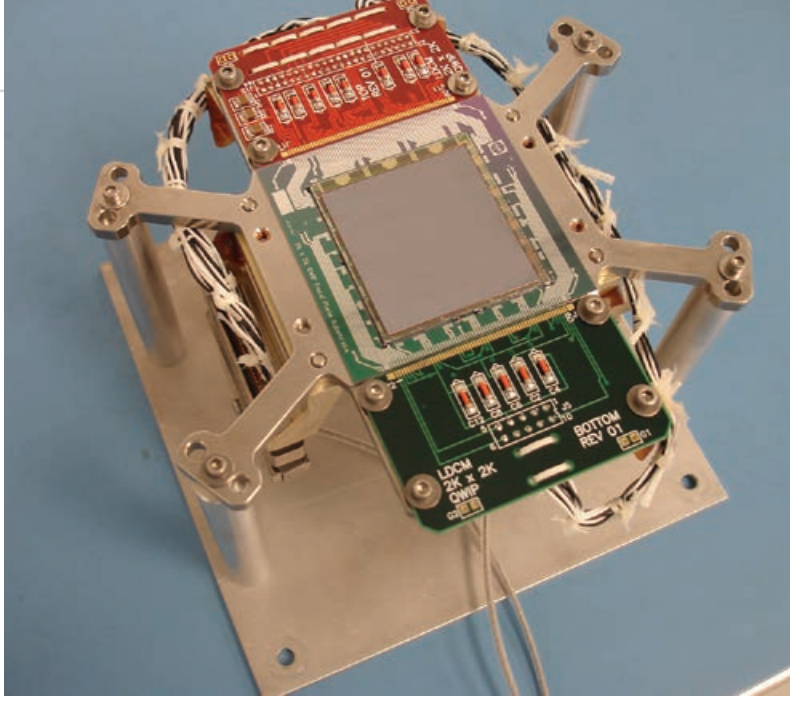
The modeling, fabrication and testing of new state-of-the-art photodetectors has led to significant advances in infrared (IR) imaging. Focal plane arrays (FPAs) for IR imaging and improvements to size, weight and sensitivity are key ARL areas of research. ARL fabricated and delivered state-of-the-art Corrugated-Quantum Well IR Photodetector (C-QWIP) FPAs to L3, Inc., which has established a C-QWIP production line based on ARL research. These high density FPAs have the same resolution as the standard 25-micron FPAs, but the smaller pitch of 15 microns will reduce the size, weight and power consumption by a factor of three for an equivalent camera. These improvements will make the cameras much more portable for Soldiers.

Concurrently, ARL produced and demonstrated the world's highest resolution, 4-megapixel, broadband, long wave infrared (LWIR), C-QWIP FPAs under



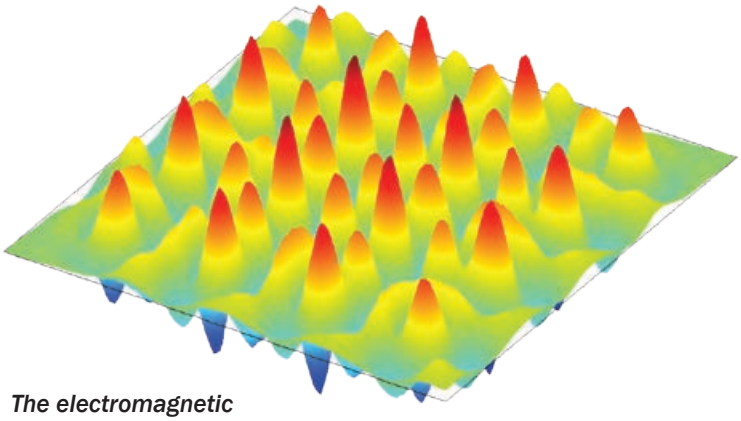
C-QWIP pixels in a 15-micron C-QWIP FPA.

NASA's Landsat program, improving today's satellite standard by a factor of four and offering a much wider field of view and surveillance for various Army operations. ARL also contributed by further increasing the density and resolution of QWIP FPAs (10-micron pitch, 5.2-megapixel) by helping to develop a dedicated electronic readout circuit, which will further miniaturize the highly sensitive and high resolution handheld infrared cameras for Soldiers.



4-MP (2K x 2K) C-QWIP FPA developed under the Landsat Data Continuity Mission (LDCM) project.

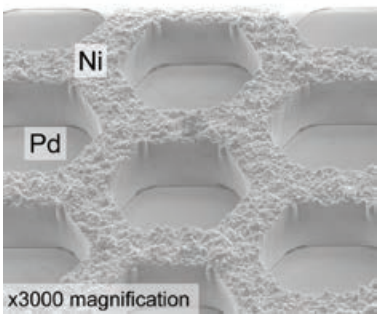
Beyond C-QWIPs, ARL established the world's first highly accurate electromagnetic model to predict detector quantum efficiency (QE), regardless of the device type. ARL subsequently invented a new sensor structure, the resonator-QWIP (R-QWIP), which is predicted to have a QE > 70%. The ability to model arbitrary detector structures will ensure ARL maintains a leading role in this critical technology, because it is able to design detector structures that are ten times more sensitive than the current technology.



The electromagnetic field distribution model within a resonator-QWIP pixel.

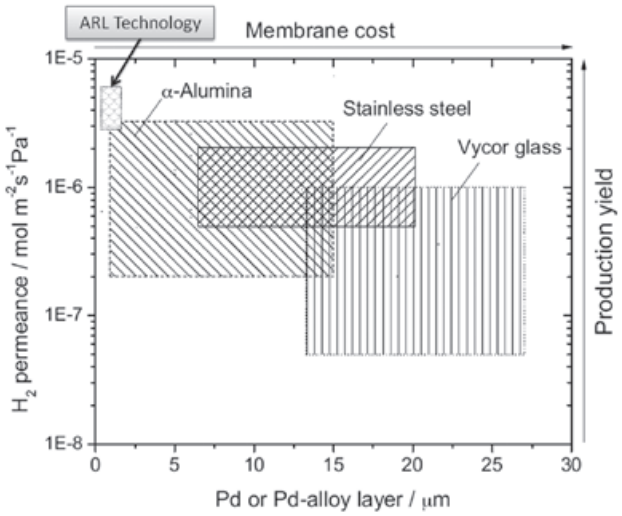
Palladium Composite Membranes for Portable Fuel Cell Applications

Small fuel cell systems are highly desirable for military applications due to their ability to provide quiet, high efficiency and low maintenance electrical power for the Soldier. For logistical simplicity, the fuel cells run on widely available JP-8 fuel. However, operating fuel cells on JP-8 requires converting the fuel into a mixture of hydrogen (the input needed by the fuel cell) and various by-products. This separation process typically relies on expensive palladium-based catalyst membranes that rapidly degrade due to poisonous by-products like carbon monoxide and hydrogen sulfide.



Composite palladium membrane for hydrogen purification with electroplated nickel honeycomb structure for mechanical support.

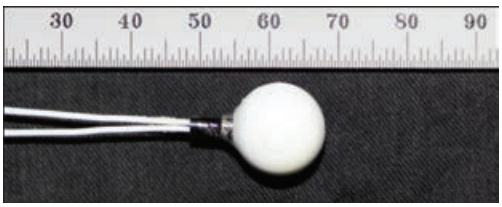
To protect the fuel cell, ARL developed lower cost, robust, palladium-based purification membranes for portable fuel cells that separate hydrogen from the gas mix. This enables the palladium film to be self-supporting, dramatically reducing the total palladium usage and cost — exceeding the Dept of Energy's 2015 cost target for palladium membranes nearly eight-fold. ARL testing has shown the new membranes can provide enough hydrogen to power a fuel cell drawing over 9 amps/cm^2; have demonstrated durability over 500 hours; and exhibit a greater than 3000 to 1 selectivity of hydrogen over impurities.

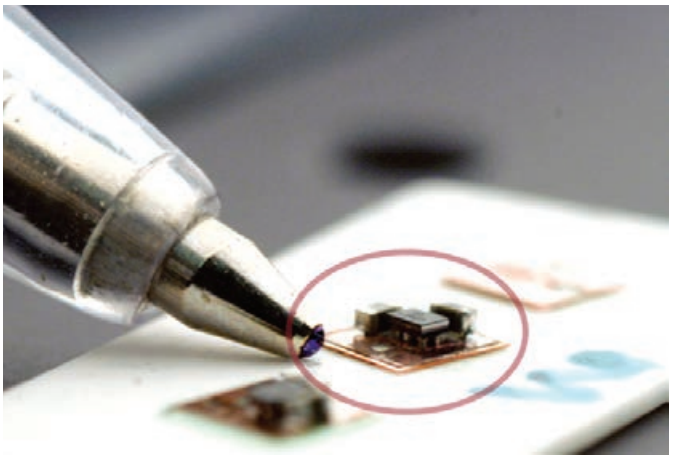


***ARL technology compared to existing state-of-the-art palladium membrane technology. Modified from: Yun; Oyama. Correlations in Palladium Membranes for Hydrogen Separation: A Review. J. Membr. Sci.* 2011.**

Novel Technique Allows for Faster Next-generation Energetic Materials Transitioning to the Soldier

A recently developed laboratory-scale detonation and air-blast characterization technique provides a promising approach to characterizing future insensitive energetic materials. ARL's technique circumvents conventional detonation characterization experiments that require full-scale right-circular-cylinder charges by incorporating spherical laboratory-scale charges, thus requiring only a few grams of material to perform a fundamental characterization. A major advantage of spherical charges is they eliminate the critical diameter effect associated with energetic materials characterization. Charges are detonated in atmospheric air and imaged by a streak camera to record the radial shock wave expansion rate produced at the energetic material-air interface. The measured expansion rate is used in conjunction with material properties and governing relationships to determine fundamental detonation wave and air shock wave properties (pressure, velocity, particle velocity, and density) for an energetic material of interest. Experimental results for PBXN-5 and two densities of pressed Class V RDX energetic materials were found to be in good agreement (< 3% difference) with published data. This technique provides a highly accurate, cost-effective alternative to conventional full-scale experiments, thus permitting an increased number of novel energetic materials to be developed. As a result, next generation energetic materials can be more rapidly developed, tested and transitioned to the Soldier.



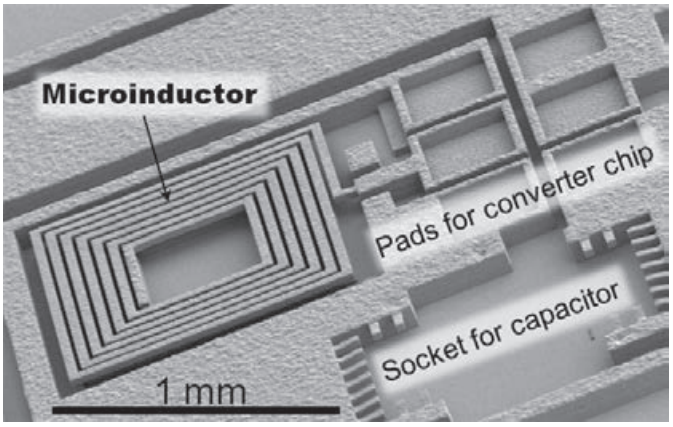


Power converter module photographed next to ballpoint pen tip for size reference.

Micromachined Ultra-Low Profile Inductors for Soldier-Borne Portable Electronics

By replacing inefficient linear regulators in Soldier-borne portable electronics such as radios, power converter modules can decrease the size and weight of electronics while increasing battery life. This technology is also critical to the development of ultra-miniaturized sensors, providing heightened levels of tactical awareness with greater stealth and permeation. ARL uses 3-D micromachining technology to create miniaturized power inductors with the highest power density (1.4 μH/mm^3) known among chip-scale power converter circuits. An ultra-low profile less than 0.1 mm enables the micromachined inductors to be integrated underneath a surface-mount converter chip for further space savings, resulting in high power density of the complete power converter (77 mW/mm^3). With a total volume of less than 2 mm^3, self-contained power converter modules using these inductors occupy a tenth to a hundredth of the size of printed circuit board-level converters and can simultaneously lead to lower cost, higher performance and new capabilities.

Scanning electron micrograph of microinductor platform for self-contained power converter module.

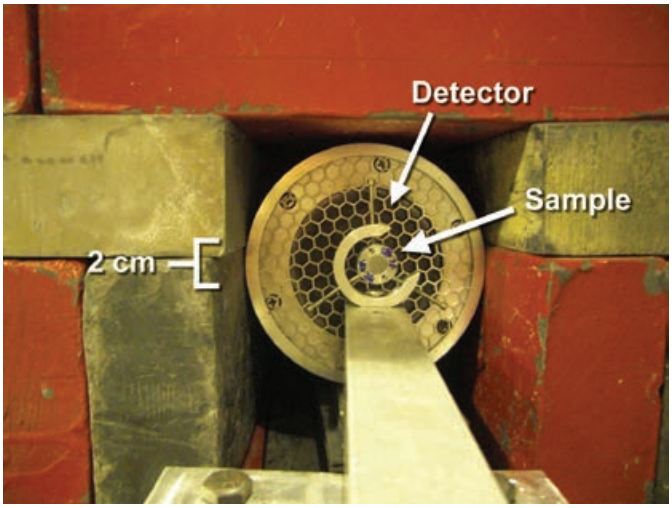


Dr. Chris Meyer processes a silicon wafer in the ARL cleanroom to test fabrication methods for realizing high density, efficient power microinductors.

Ultra-Energetic Materials for Enhanced Battlespace Awareness

In a breakthrough toward enabling compact power sources for battlespace environments, ARL scientists have conducted the world's first demonstration of switching between the long-lived energy storing state (a nuclear isomer) of the silver isotope ^{108}Ag and its ground state. The ultra-energetic nuclear isomer exhibits energy storage approximately one million times higher than commercial off-the-shelf batteries, but the 438 year half-life means the energy is difficult to extract quickly. Switching a nucleus to the ground state (half-life of 2.4 minutes) enables the long-stored energy to release at 10^8 times higher power. High-energy photons from a linear accelerator shined onto a 12 μg (10^{16} atoms) sample of the isomer subsequently emitted a burst of beta radiation. The 2.4 minute decay of this burst was proof that the dual time scales provided by isomers can be harnessed for storing and releasing energy. The silver isotope was selected based on its half-lives, sample availability

Drs. James Carroll and Marc Litz prepare an isomer switching experiment, using an electron linear accelerator in ARL's Power Conditioning Facility.



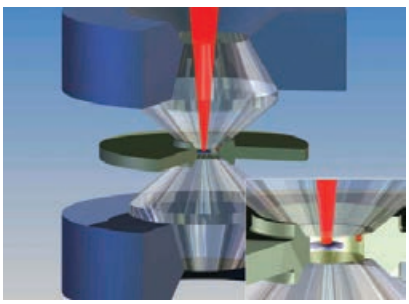
Sample containing ^{108}Ag isomers in the detection position, during the switching test.

and previous nuclear structure data that hinted at the possibility of switching. While only a small fraction of the stored energy was released in this initial demonstration, further research is underway to better understand the switching process. Improvements to compact power sources, which can be warehoused at lower power and radiation levels than conventional power sources, will ultimately enable drop-and-forget sensors with lifetimes of many decades for enhanced battlespace awareness.

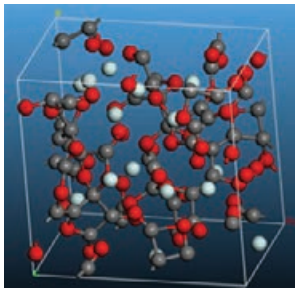
Technique to Stabilize Disruptive Energetic Materials Results in Ten Times Higher Energy Content for Future Weapon Systems

Energetic materials developed within ARL's Disruptive Energetics program are a minimum of ten times higher in energy content compared to conventional energetics. Current state-of-the-art weapons using conventional carbon (C)-, hydrogen (H)-, nitrogen (N)-, and oxygen (O)-based energetic materials, such as RDX, HMX, and CL-20, have reached a plateau in terms of energy content. ARL's approach uses high pressure physics and chemistry in conjunction with modeling and

Diamond Anvil Cell



simulation. Under extremely high pressures (7 GPa or higher) in a diamond anvil cell, materials such as carbon monoxide (CO) and nitrogen undergo polymerization and form meta-stable materials that have very high energy content. Previously, polymeric CO was prepared in an amorphous phase, which was unstable at ambient conditions and in the presence of light. To overcome this issue, ARL recently developed a process to obtain all crystalline polymeric CO that, in addition to being stable, has a higher density relative to the amorphous polymeric CO. This development allows for scale-up of polymeric CO to multi-gram quantities. ARL has started the planning process to transition synthesis technology of polymeric CO in collaboration with the U.S. Army Armament Research, Development and Engineering Center (ARDEC) and the U.S. Army Aviation and Missile Research, Development and Engineering Center (AMRDEC) and eventually integrate it into future weapon systems.

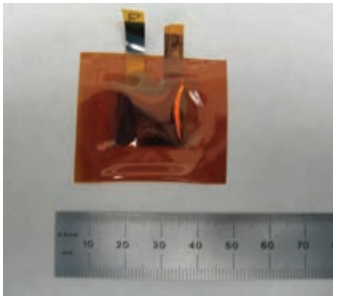


Polymeric CO

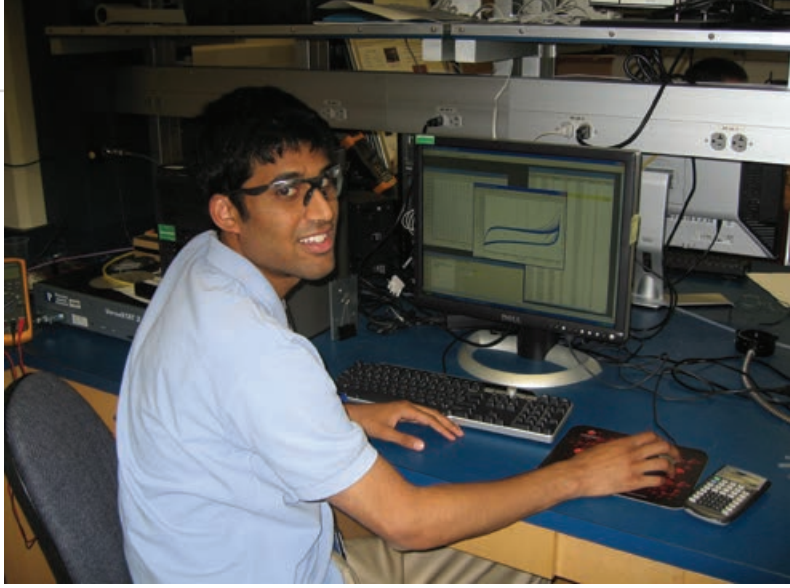
Graphene-Based Supercapacitors Enhance Electronic and Munitions Systems Performance

Efficient and compact electrical energy storage is critical to many Army electronic and munitions systems. Supercapacitors are extremely promising because they have higher power density and longer lives than batteries and higher energy density than other types of capacitors. ARL is investigating graphene and other nanomaterials with the goal of increasing supercapacitor performance while decreasing size.

Inkjet-printed flexible supercapacitor prototype



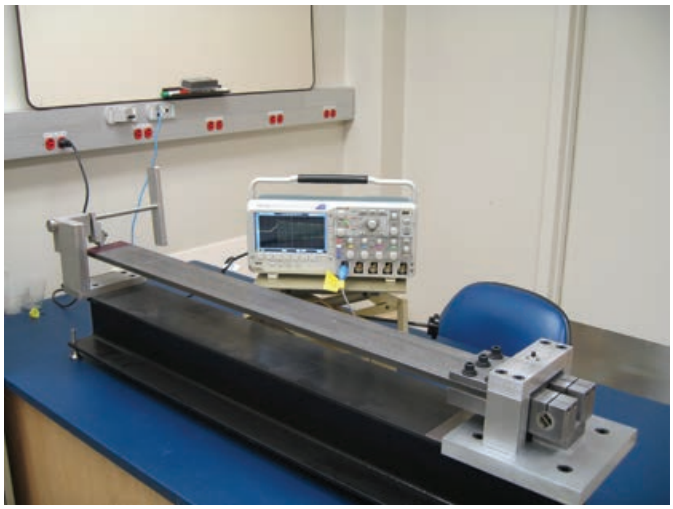
In collaboration with Stevens Institute of Technology, ARL has demonstrated the first inkjet printing of graphene supercapacitor electrodes onto flexible substrates for making flexible supercapacitors. Early prototypes measure 4 cm x 4 cm with capacities of 10-20 millifarads. These flexible supercapacitors will enable printed, flexible munitions initiation circuits being developed by ARDEC.



Student intern, Vinay Raju, evaluating supercapacitor electrodes.

To further push this technology for military applications, ARL leveraged unique high-speed supercapacitors from Small Business Innovation Research (SBIR) partner JME, Inc. to demonstrate energy storage from a munitions energy harvesting system under development by ARDEC. These supercapacitors operate at a 15,000 times higher frequency than traditional supercapacitors, making them viable for energy harvesting applications, while being ten times smaller than traditional electrolytic capacitors. These combined advances mean that ARL-developed supercapacitor technology enables size and weight savings for munitions electronic systems, while simultaneously yielding improvements in reliability and shelf life over electrolytic capacitors.

Mechanical simulator of a munition energy harvesting system



CORE TECHNICAL COMPETENCIES

SURVIVABILITY, LETHALITY & VULNERABILITY (SLV) ASSESSMENT & ANALYSIS

Advanced Injury Criteria and Instrumentation to Minimize Soldier Casualties from Underbody Blast Events

Reconstruction of Chinook's Downing in Afghanistan Reduces Future Combat Losses

Analysis of Alternatives Leads to Potential Improvements in Ground Combat Systems Performance

Combat Injury Analysis Leads to Safer Personal Protective Equipment for the Warfighter

Fielding of Improved Strykers Protects Soldiers from Improvised Explosive Devices

Advanced Injury Criteria and Instrumentation to Minimize Soldier Casualties from Underbody Blast Events

As part of the Army's Warrior Injury Assessment Manikin program (WIAMan), ARL provided vital information about the underbody blast environment to medical researchers working to develop enhanced injury criteria and an advanced test manikin for underbody blast events. Data on vehicle loading regimes at the floor and seat that were based on hundreds of vehicle and anthropomorphic test device

The current anthropomorphic test device is the Hybrid III, which was designed for injury assessment in frontal crash testing of automobiles. It is not designed and validated for the extreme vertical loading seen in under-body blast events.

High speed video capture of underbody blast test using a generic hull to demonstrate the under-body blast environment to medical researchers.

data from past underbody blast events were provided to the medical researchers. ARL and its partners, U.S. Army Tank Automotive Research, Development and Engineering Center, U.S. Army Test and Evaluation Command and the U.S. Army Aeromedical Research Laboratory also conducted a coordinated underbody blast test using a generic hull to demonstrate the underbody blast environment. These data and test results will help researchers develop the injury criteria and advanced test manikin necessary for the system development, test and evaluation communities to more accurately assess and minimize Soldier casualties from underbody blast events.

As the DoD fields vehicles that are less susceptible to underbody blast, the assessment of injuries caused by accelerative loading has become a priority. Accelerative loading has caused thousands of injuries.

The CH-47 Chinook is the Army's primary heavy-lift transport helicopter used in Afghanistan.

Reconstruction of Chinook's Downing in Afghanistan Reduces Future Combat Losses

Following the catastrophic loss in combat of a CH-47 Chinook helicopter in the Wardak Province of Afghanistan, the Army's Aircraft Shoot-Down Assessment Team (ASDAT) sought ARL's analytical expertise for their investigation. ARL confirmed the ultimate cause of the crash by replicating the forensic evidence recovered from the crash site and by performing six ballistic vulnerability tests with two threats against CH-47 main rotor blades. Because of ARL's extensive experience with rotor blade vulnerability, and with both static and dynamic testing of helicopter rotor blades comparable to the CH-47's, ARL quickly and accurately recreated the damage witnessed in the combat incident. The ASDAT received a summary report and materials from the ballistic test for forensic comparison. The ASDAT included the results in their official incident report presented in theater, and the two organizations jointly presented details of the incident reconstruction at the November 2011 National Defense Industrial Association Aircraft Survivability Symposium. Reconstructing the incident will reduce combat losses in the future because of operational changes and potential improvements to helicopter design resulting from the accident analysis.

A helicopter main rotor blade being prepared for ballistic testing.

Ballistic vulnerability test of a static helicopter main rotor blade.

Analysis of Alternatives Leads to Potential Improvements in Ground Combat Systems Performance

The Program Executive Officer Ground Combat Systems requested that ARL conduct an Analysis of Alternatives (AoA) for technologies being considered for various Ground Combat Systems (GCS). The primary goal of applying these technologies is to improve the performance of GCS and enable the Army's current ground combat systems to operate alongside the Ground Combat Vehicle. ARL analyzed the vulnerability of Bradley non-infantry fighting vehicle variants, Stryker variants, and Armored Multi-Purpose Vehicle (AMPV) variants to numerous ballistic threats, and also delivered underbody blast estimates for all Stryker and AMPV variants. ARL's analytical

Bradley Fire Support Vehicle analyzed for the Bradley AoA study.

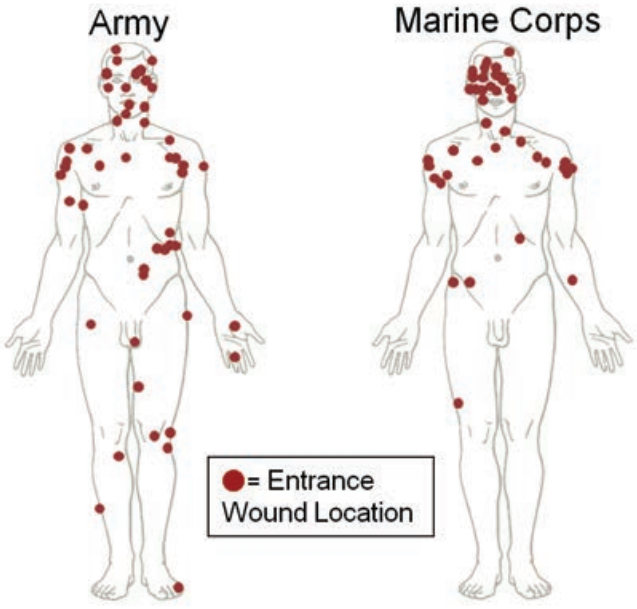
results were crucial inputs to the U.S. Army Training and Doctrine Command Analysis Center's force-on-force modeling and the U.S. Army Materiel Systems Analysis Activity's performance analyses, which are informing the acquisition and modernization decisions for the four GCS AoA — Stryker, Bradley, Abrams and the M113 replacement program, AMPV.

M113A3 analyzed for the Armored Multi-Purpose Vehicle (AMPV) AoA study.

M1126 Stryker Infantry Carrier Vehicle (ICV) analyzed for the Stryker and Armored Multi-Purpose Vehicle (AMPV) AoA studies.

Combat Injury Analysis Leads to Safer Personal Protective Equipment for the Warfighter

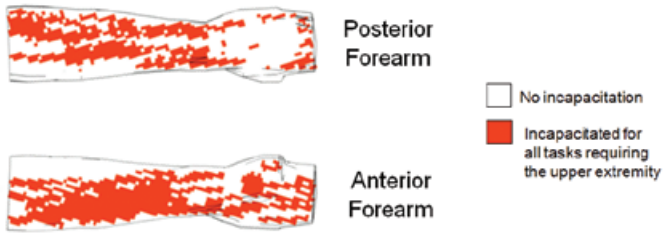
In 2012, ARL analyzed injuries, physical evidence and operational intelligence from the current conflicts in Iraq and Afghanistan to develop recommendations and influence enhancements to personal protective equipment (PPE). This work was performed as part of the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) partnership. The JTAPIC partnership links the medical, intelligence, operational and materiel communities and enables these organizations to collaborate and share medical, operational and materiel data. ARL's unique role in the



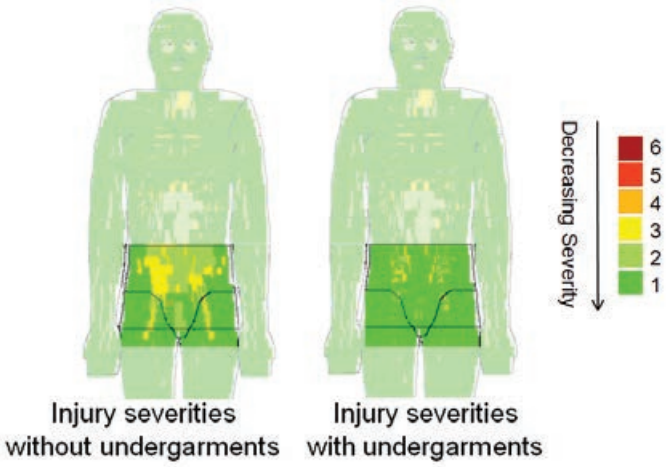
Mapping of gunshot-wound entrance locations used to identify trends.

partnership is to leverage expertise and experience in analysis; model and simulate vehicles and personnel; and experiment to produce products for JTAPIC. ARL performed three analyses that examined trends in gunshot-wound entrance locations, evaluated the benefits of adding forearm protection and determined the mitigation potential of ballistic undergarments. These analyses enable the development of safer PPE for the Soldier and influence future research strategies as well as fielding and design decisions.

ARL's Operational Requirement-based Casualty Assessment (ORCA) model output showing forearm incapacitation due to fragment penetration.



ARL's Operational Requirement-based Casualty Assessment (ORCA) model output quantifying the potential of ballistic undergarments to mitigate urogenital injuries.



Improved Stryker Infantry Carrier Vehicle, one of the seven DVH configurations analyzed.

Fielding of Improved Strykers Protects Soldiers from Improvised Explosive Devices

To inform the production decisions for Stryker variants with a double-V hull (DVH), ARL measured and analyzed vehicle damage and crew incapacitation from live-fire experiments for seven DVH variants of the Stryker Infantry Carrier Vehicle. ARL provided these data — along with post-shot engineering analyses of vehicle damage, assessments of vehicle robustness and options to improve survivability — to the U.S. Army Evaluation Center, the Project Management Office of the Stryker Brigade Combat Team and the Office of the Secretary of Defense Director of Operational Test and Evaluation. These organizations will use the results in their evaluation of the Stryker DVH variants and subsequent production decisions.

Improved Stryker Infantry Carrier Vehicle, one of the seven DVH configurations analyzed.

Soldiers are better protected against improvised explosive devices (IEDs) in the new Stryker DVH.

U.S. Army Research Laboratory

2800 Powder Mill Road
Adelphi, MD 20783-1197

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