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US Army Combat Capabilities Development Command Army Research Laboratory South Research Summaries: Open Campus Collaborations (2019–2020 Update)

by Heidi Maupin

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14. ABSTRACT

This report updates highlights of the collaborative research efforts resulting from the US Army Combat Capabilities Development Command (CCDC) Army Research Laboratory's (ARL's) Open Campus initiative. The ARL South research summarized in this report is integral to the CCDC ARL overarching research strategy; each project is a component of one or more of ARL's foundational research portfolios. While ARL's research primarily falls in the basic research arena with projected longer-term transitions, critical shorter-term outcomes will be recognized and exploited along the way.

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Open Campus, Army Foundational Research, Collaborative Research, Army Research Laboratory South, University and Industry Partners

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1. Introduction

In April 2017, the US Army Combat Capabilities Development Command Army Research Laboratory (CCDC ARL) extended its geographical presence to the southern region of the United States, centered in Austin, Texas. "ARL South," as it is colloquially called, grew from a nascent effort to a robust ecosystem addressing high-priority Army problems with a continually expanding base of new talent. Researchers within the ARL South community are embedded in universities primarily in the state of Texas, with member connections reaching out to New Mexico, Oklahoma, Alabama, and Pennsylvania. Through strategic collaborative efforts, ARL joined forces with the region's partners to identify areas of mutual technical interest resulting in an environment that fosters innovation, rapid development, and accelerated technology transitions.

Researchers working in the ARL South region summarized their projects in an ARL special report published in 2019. This document updates the research, including progress achieved in the past year. The ARL South research summarized in this document is integral to the ARL overarching research strategy.

This document highlights the collaborative research efforts resulting from ARL's Open Campus initiative. Not included in this document are many other excellent university research efforts funded by the ARL directorates and the ARL Army Research Office.

2. ARL South Research Summaries

2.1 Army Medical Department Center and School

Title: Resilience and Mindfulness

Modernization Priority: Soldier Lethality

Army Researcher: Valerie Rice and Gary Boykin (both on-site)

Directorate: Human Research and Engineering Directorate (HRED)

Summary of Research: Our investigations to improve performance have already shown that Soldiers participating in an effective mindfulness program will increase resilience, improve awareness, and decrease the effects of post-traumatic stress disorder and adult deficit hyperactivity disorder. We are currently wrapping up this research on resilience and mindfulness (outcome measures include self-report, cognitive testing, and physiological measures), which has spanned seven years and

five funded protocols. Our research has been focused on issues of interest to ARL and to the Army Medical Department Center and School and the Army Medical Command. Our efforts also included other interventions including peripheral neuromodulators, sound vibration, audiovisual entertainment, and mind/body meridian-based energy techniques.

2.2 Bell Innovation

Title: Autonomous Micro Unmanned Air Systems

Modernization Priority: Next Generation Combat Vehicle

Army Researcher: John Hrynuk

Directorate: Vehicle Technology Directorate (VTD)

Industry POC: Andrea Chavez

Summary of Research: ARL researchers are collaborating with Bell Innovation to develop and demonstrate a unique Soldier portable small unmanned aerial system (sUAS). This system will provide unprecedented range and endurance for sUAS platforms providing new intelligence, surveillance, and reconnaissance (ISR) capabilities for the Army. The effort is occurring as a result of a cooperative research and development agreement (CRADA) that we established in spring 2018. ARL provides expertise in aerodynamics and controls, while Bell leverages its expertise in design, development, hardware integration, and flight testing. In December 2019, the team successfully demonstrated a fully autonomous flight including vertical takeoff, landing, and maneuver to global positioning system (GPS) waypoints with a vehicle weighing roughly one pound. The target flight time of the system is 60+ minutes and 30+ km range. The vehicle has been accepted by Army Maneuver Center of Excellence as part of its 2021 Army Expeditionary Warrior Experiment.

2.3 Rice University

Title: Dynamic Optical Control via Metasurface Integrated Soft Robotic Skins

Modernization Priority: Next Generation Combat Vehicle

Army Researcher: Mark Griep

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POCs: Naomi Halas, Stephan Link, and Ben Cerjan

Summary of Research: The goal of this project is to produce a flexible color-changing surface that can be used as a "skin" on a given object and therefore be used as camouflage or a cloaking tool. Our challenge is to determine the complex quantum-physics phenomena and then use this knowledge to develop the manufacturing capabilities for scalable production of tailored structures on flexible substrates to enable dynamic optical responses. To do this, we are coupling the expertise at Rice and the University of New Mexico in design and fabrication of nanostructures and metasurfaces along with the knowledge and experience in nanoimprint lithography and roll-to-roll scale-up at ARL. Previous work at Rice has demonstrated two complementary approaches to this challenge: first, by designing a tailored array of nano-scale metal structures with finely tuned size and periodicity to produce the desired color and, second, by designing more complex individual structures that, due to the near-field interaction among different parts of the structure, produce a strong color. Either of these methodologies could work on its own as both are highly sensitive to the geometric distance among neighboring elements and so by placing them on a stretchable substrate, the color response can be directly tuned by mechanical deformation.

This work is funded through the Laboratory University Collaboration Initiative (LUCI).

Title: Synthesis and Processing of High-Strength and High-Toughness 2-D Kevlar

Modernization Priority: Soldier Lethality

Army Researcher: Emil Sandoz-Rosado

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POC: Rafael Verduzco

Summary of Research: We are preparing new 2-D covalent organic frameworks (COFs) with hydrogen bonding between the 2-D layers to improve properties. Initial work focuses on chemistry and characterization to produce COFs with a high degree of regular order. Later work will focus on the mechanical properties of ideal COF chemistries. We have multiple universities collaborating with us on this effort with Rice, including Massachusetts Institute of Technology and the University of Texas (UT) at Dallas.

Title: Responsive Materials with Active Subunits

Modernization Priority: Future Vertical Lift, Next Generation Ground Vehicle

Army Researcher: Frank Gardea (on-site)

Directorate: Vehicle Technology Directorate (VTD)

Faculty POC: James Tour

Summary of Research: Our research will provide energy-efficient actuation to future Army vehicles by mimicking behavior found in nature. This research focuses on embedding active molecular units in polymer systems to achieve behavior similar to what is observed in biological muscle. These active subunits will be manipulated to achieve dynamically reconfigurable structures at the macroscale. This approach is expected to lead to highly multifunctional structures. These artificial muscle actuators could be embedded in morphing UAVs or ground robots.

Title: Seek and Treat UAV Technologies for Combat Casualty Care

Modernization Priority: Future Vertical Lift

Army Researcher: Thaddeus P Thomas

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POC: Paul Cherukuri

Summary of Research: The goal for this effort is to make Robotic and Autonomous Systems (RAS) more intelligent and capable in the medical treatment of military personnel. We are incorporating novel imaging technologies that measure physiology at range onto unmanned mobile platforms to support the remote identification and triage of battlefield casualties. This capability would enhance the speed and effectiveness of medical evacuation/triage crews, and improve the likelihood of patient survival. Biosensor advancement and assessment tasks are being conducted at Rice University, ARL, and the US Army Medical Research Institute of Chemical Defense. The University of Pittsburgh contributes medical expertise and Carnegie Mellon University is building robotic interventions and researching means for providing virtual help.

2.4 Texas A&M University

Title: Spanwise Extending Unmanned Aerial Systems

Modernization Priority: Future Vertical Lift, Next Generation Combat Vehicle

Army Researcher: Francis Phillips (on-site)

Directorate: Vehicle Technology Directorate (VTD)

Faculty POC: Darren Hartl

Summary of Research: Our research will advance capability of aerial systems and enable them to modify structure to respond to current situational needs. ARL is developing a spanwise extending sUAS. The concept sUAS will be able to actively change the span of the wings in response to mission profile, environmental conditions, and Soldier/vehicle command. Several prototypal wings have been developed and wind-tunnel tested for validation of the spanwise extending concept, with net positive lift achieved in December 2019. Additional optimization work is ongoing, leveraging Texas A&M University's (TAMU's) expertise in uncoupled fluid-structure interaction modeling and optimization capabilities.

Title: Modular Hybrid-Electric Analysis Tool (New Start)

Modernization Priority: Future Vertical Lift Army/Next Generation Combat Vehicle

ARL Researcher: Dino Mitsingas

Directorate: Vehicle Technology Directorate (VTD)

Faculty POC: Moble Benedict

Summary of Research: We are developing software that will enable us to predict the power needs of a power system throughout its operations. Our software will analyze hybrid-electric land, sea, and air vehicles that have become available due to the confluence of high power/weight ratio electronics, motors, and batteries. The primary focus will be on the propulsors (e.g., rotor and aerodynamics), energy source (e.g., battery) and power conversion (e.g., electric motor drive). The modules will consist of models that can predict each component's performance and losses at different operating conditions and size an optimal component for a given load, based on a mission profile. System models will track power losses among different components—including secondary loads such as power-hungry payloads

to predict the entire vehicle's performance throughout the mission, such as endurance of a hybrid ISR capability in a high/hot battlefield.

Title: Advanced Gas Bearings for Compact High-Speed Turbocharger

Modernization Priority: Future Vertical Lift/Next Generation Combat Vehicle

Army Researcher: Ryan McGowan

VICTOR PM: Mike Kweon

Directorate: Vehicle Technology Directorate (VTD)

Faculty POCs: Luis San Andres and Adolfo Delgado (TAMU)

Summary of Research: ARL and TAMU are collaborating on high-pressure compact turbochargers (TCs) to support ARL's multifuel-capable hybrid-electric propulsion program. The project aims to advance innovative gas bearing technologies enabling oil-free TCs for ultra-efficient internal combustion engines (ICEs) in unmanned aerial vehicles (UAVs). These oil-free TCs will improve the reliability, efficiency, and performance of ICEs for operation at increased power with more compact units free of mineral oil and other ancillary systems. Our success in achieving oil-free TCs will reduce weight and friction, extend maintenance intervals, and certify reliability and availability.

Title: Tube Launched Attritable Unmanned Aerial Systems

Modernization Priority: Future Vertical Lift

Army Researcher: Hao Kang

Directorate: Vehicle Technology Directorate (VTD)

Faculty POC: Moble Benedict

Summary of Research: The goal of this project is to extend the overall range of operation of a hover-capable, micro air vehicle (MAV) by launching it from a 40-mm grenade launcher. In addition, this method could be used to propel the vehicle beyond line of sight or around other obstacles. The development of such aircraft requires the vehicle to be compact, maneuverable, and capable of transitioning from a projectile phase to hovering flight. ARL and TAMU research collaborators have reached substantial milestones of our tube-launched unmanned aerial system (UAS). We successfully developed novel and configurable rotary-wing aircraft capable of sustained hover. The aircraft can be launched from air or ground using a launch tube. This method of deployment will allow the vehicle to

reserve the entirety of the onboard battery for performing a desired mission such as ISR in a designated target area. The team designed the aircraft with a specialized counter rotating motor composed of two independently controlled motors. At the end of the launch phase, the rotor blades can be unfolded passively by using centrifugal force from spinning up. The aircraft will provide two assets at the company level. When launched from a 40-mm grenade launcher, the aircraft provides an organic asset at the company level with combined ISR. When launched as a projectile up to the point of operation, the aircraft can significantly improve the mission range for energy-constrained platforms. The aircraft can provide the Army with a vertical flight/hover capability that operates as a member of a team with other manned and unmanned platforms that can penetrate defense-in-depth, anti-access, and area-denial environments and disintegrate Integrated Air Defense Systems.

Title: Human-in-the-Loop Autonomy

Modernization Priority: Future Vertical Lift, Next Generation Combat Vehicle

Army Researchers: Vernon Lawhern, Nicholas Waytowich, and Greg Gremillion

Directorate: Human Research Engineering Directorate (HRED)

Faculty POC: John Valasek

Summary of Research: TAMU is collaborating with ARL on human-in-the-loop machine learning for autonomy with specific applications in real and simulated aerial platforms. By more tightly integrating a human operator into the learning process, autonomous agents learn faster and the learned behaviors can become tailored to the specific needs of the Warfighter.

Title: Monolithic Tungsten for Kinetic Energy Munitions

Modernization Priority: Soldier Lethality

Open Campus Army Research Collaborators: ARL/TAMU/Shearform

Army Researcher: Brady Butler and James Paramore (both on-site)

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POC: Ted Hartwig (Shearform)

Summary of Research: New processing technique by TAMU's spin-off company Shearform produces tungsten with properties that when used to manufacture medium and long-range penetrators will surpass the performance of current

penetrators, achieving oblique angle penetration. Additionally, we are collaborating with the CCDC Armaments Center to characterize and optimize properties of monolithic (single crystal) tungsten, which has exhibited remarkable properties.

Title: Hydrogen Assisted Processing of Ti-6Al-4V

Modernization Priorities: Soldier Lethality

Army Researchers: James Paramore and Brady Butler (both on-site)

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POC: Ankit Srivestava

Summary of Research: This project targets Next Generation Squad Weapon Technologies. We are currently optimizing the sintering process we developed with our partner University of Utah to transform low-grade titanium to an alloy exhibiting properties equivalent to conventionally manufactured high-grade titanium alloys, without the need of expensive mechanical working of the alloy. The process enables shape and size retention, making it amenable for additive manufacturing (AM) technologies. Titanium is a material of interest that could be used for replacement parts at the point of need; this process will be cost effective for point-of-need part production. The research is being combined with near-net-shaping and AM process technologies for prototyping titanium alloy components with exceptional mechanical properties. An AM company has started the process to license the technology.

Title: Adaptive Material Behavior

Modernization Priority: Future Vertical Lift, Next Generation Combat Vehicle

Army Researcher: Frank Gardea (onsite)

Directorate: Vehicle Technology Directorate (VTD)

Faculty POCs: Svetlana Sukhishvili

Summary of Research: Our advanced materials will contribute to a sophisticated vehicle system that will sense and adapt to current threats. We strive for on-demand tailoring of material properties (i.e., high strength, high stiffness, and high energy dissipation) and functionalities (e.g., self-healing, actuation, and wave manipulation) to achieve adaptive behavior in materials. We utilize advanced manufacturing methods, such as AM, to obtain properties that are unobtainable using conventional manufacturing.

Title: Compact, High Performance Electric Machines Using Magnetic Gears

Modernization Priorities: Future Vertical Lift, Sustainability, Next Generation Combat Vehicle

Army Researcher: Matthew Johnson (on-site)

Directorate: Sensors and Electron Devices Directorate (SEDD)

Faculty POC: Hamid Toliyat

Summary of Research: Our ultimate goal in this partnership is to provide the power performance that our newly modernized Army technology will demand. This research focuses on the design of compact, high-performance, and high-reliability electric machines and magnetic gears for Army platform drivetrains, including hybrid-electric aircraft and UAVs. We will reduce the size and weight of magnetic gears, while enabling them to achieve higher gear ratios and operating speeds without sacrificing high efficiencies. The noncontact operation offers numerous potential advantages over traditional mechanical gears, including inherent overload protection, reduced maintenance requirements, decreased acoustic noise, and physical isolation between the input and output shafts. Since the start of our collaboration, we have designed, fabricated, and tested a small-scale magnetic gear prototype with a gear ratio of 4.67:1, which achieved efficiencies of 99% or higher at some operating points. Our next step is to investigate higher gear-ratio magnetic gears using a physics-based simulation infrastructure on TAMU's high-performance research computing resources. Additionally, we will design, fabricate, and test a fault-tolerant multiphase electric motor used in conjunction with the magnetic gear to offer potential increased reliability benefits. Based on the lessons learned from the discrete combination of the multiphase electric motor and the magnetic gear, we will design, build, and evaluate an integrated magnetic gear and multiphase electric motor, which offers the potential for a smaller and lighter package for interfacing with high torque loads, as compared with the discrete combination of an electric motor and magnetic gear.

Title: Multi-Scale Mechanics of Lung during Blunt Trauma: Alveolar Sacs to/from Parenchyma

Modernization Priority: Soldier Lethality

Army Researcher: John D Clayton

Directorate: Weapons and Materials Research Directorate (WMRD)

University POC: Alan D Freed (Joint Faculty Appointment)

Summary of Research: Soldiers are placed at risk of incurring Behind Armor Blunt Trauma (BABT) on a field of battle whenever their personal protective equipment (PPE) suffers a ballistic impact from a weapon or blast wave from an explosion. The objective of this project is to provide design engineers a realistic tool to produce the next generation of PPE for our Soldiers. We will develop material models that will be capable of describing soft-tissue responses under ballistic impact conditions. Our multiscale models will predict lung-tissue damage that affects breathing from tissue stiffness and internal bleeding.

Current TRL Level: 1

2.5 Texas A&M Commerce

Title: Human Understanding of Complex Visualizations Using Virtual Reality

Army Researchers: Jonathan Bakdash (ARL South/UT Dallas), Laura Marusich-Cooper (ARL South/UT Arlington), and Michael Geuss and Shannon Moore (HRED/Aberdeen Proving Ground)

Directorate: HRED

Faculty POCs: Shulan Lu (Psychology and Special Education) and Derek Harter (Computer Science)

Summary of Research: We are conducting collaborative behavioral research on human understanding of complex visualizations using immersive virtual reality. Human understanding is quantified using the time and accuracy for drawing inferences about relationships and patterns among variables in graphs. We aim to predict and enhance human understanding of complex and uncertain information by investigating underlying perceptual factors that influence the utility of different visualization techniques.

2.6 Texas Tech University

Title: Machine Learning Technique Applications for Power Electronic Systems

Modernization Priority: Next Generation Combat Vehicle

Army Researcher: Argenis Bilbao (on-site)

Directorate: Sensors and Electron Devices Directorate (SEDD)

Faculty POC: Stephen Bayne

Summary of Research: ARL and Texas Tech University are investigating the currently available machine-learning techniques for implementation in power electronic converters. Our research is subdivided in multiple application levels: machine learning at the power distribution, power converter, and semiconductor module levels. The use of machine learning at the aforementioned levels will provide significant improvements in reliability and overall system capabilities.

Title: Wireless Power Transfer for Unmanned Aerial Vehicles

Modernization Priority: Future Vertical Lift

Army Researcher: Argenis Bilbao (on-site)

Directorate: Sensors and Electron Devices Directorate (SEDD)

Faculty POC: Stephen Bayne

Summary of Research: We are performing research on wireless power transfer to efficiently recharge UAVs. Wireless power transfer is the ideal and primary candidate to recharge battery powered UAVs due to the increased reliability, convenience, and reduced logistics burden that it provides over recharging through wires using metallic contacts. In August 2019, we successfully demonstrated wireless power transfer to a small UAV. In our demonstration, the UAV autonomously landed on a designated landing platform to wirelessly recharge its battery. Our next milestone is to successfully transfer power while both the UAV and the manned or unmanned land vehicle with the charging device are in motion. Our successful technology is first of its kind, relying on inductive-resonant wireless power transfer method that features “Maximum Power Point Tracking” to achieve higher recharge rates and/or increased efficiency under nonideal conditions.

2.7 University of Alabama, Huntsville

Title: Situation Awareness and Decision-making Enhancements with Digital Eyewear Modernization

Priority: Next Generation Combat Vehicle

Army Researcher: Jeff Hansberger (on-site)

Directorate: Human Research and Engineering Directorate (HRED)

Faculty POCs: Nathan Tenhundfeld (Professor, University of Alabama in Huntsville) and Chao Peng (Professor, Rochester Institute of Technology)

Summary of Research: ARL is partnering with the University of Alabama in Huntsville (UAH) to perform applied research on ways to enhance situation awareness and decision-making of Next Generation Combat Vehicle (NGCV) crew members. Human–computer-interaction research with UAH focuses on three areas: information visualization, multimodal interface input, and virtual reality/augmented reality/mixed reality (VR/AR/MR) interfaces. Guided by task analysis, our research into information visualization explores new ways to visualize information and data to users in order to make decisions faster and easier. Multimodal-input approaches allow us to explore new ways to interact with digital information that integrates natural modalities including eye gaze, speech, and hand gestures. These culminate in the development of virtual information dashboards and interfaces using digital eyewear technology (VR/AR/MR). NGCV role-specific visualizations and interfaces for digital eyewear are being developed for experimentation in collaboration with UAH and the Ground Vehicle Systems Center.

2.8 University of New Mexico

Title: Studying Human Agent Teaming Through Games

Modernization Priority: Next Generation Ground Combat

Army Researcher: Evan Carter (onsite)

Directorate: Human Research and Engineering Directorate (HRED)

Faculty POCs: Lydia Tapia and James Cavanagh

Summary of Research: The study of human agent teaming is complicated by the fact that there is immense variation both between and within individuals. As a result, it is difficult to design agents to be optimal teammates for any given user at any given time. Our goal is to develop adaptive agents based on large data sets

collected through mobile games that can be played by many people throughout their daily lives, thereby better accounting for between- and within-person variability.

2.9 University of North Texas

Title: Design of Novel Metals, Ceramics, and Additively Manufactured Structures for Protection Applications

Modernization Priority: Next Generation Combat Vehicle

Army Researchers: Jeff Lloyd and Chris Cummins

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POC: Rajiv Mishra

Summary of Research: Quad City Manufacturing, ARL, and University of North Texas (UNT) researchers have demonstrated that small-scale prototypes produced using AM techniques are representative of the full-scale vehicle structure. Using our validated results that reduce assessment time from years to weeks will rapidly provide new solutions for blast-resistant structures and reduce research and development costs by 98%. Furthermore, our small-scale experimentation enables an indoor laboratory environment, eliminating scheduling risks arising from weather constraints and significantly reducing the risk of damage to sensitive instrumentation. We are supporting a West Point senior design team that has used computational tools to design blast-mitigating structures. We are producing novel materials (e.g., high entropy alloys and ceramics) having lighter and/or ultrahigh toughness to enhance vehicle protection and efficiency. In addition to our materials research, we are designing additively manufactured structures that will dramatically increase vehicle protection and durability.

Title: Modulate Mechanical Properties under Applied Magnetic Fields

Modernization Priority: Next Generation Combat Vehicle

Army Researcher: Heather Murdoch

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POC: Rajiv Mishra

Summary of Research: This advanced materials research will result in greatly improved lightweight vehicle and Soldier protection. We will identify changes in mechanical behavior under applied magnetic fields, particularly relating to deformation processing of lightweight (paramagnetic) metals (e.g., aluminum and

magnesium alloys) and novel steels (such as TRIP HEAs). We have observed shifts in yield under low fields in aluminum, magnesium, and titanium alloys and thus have developed a robust testing frame incorporating variations in magnetic field strength to investigate tension, compression, and fatigue. We will identify magnetic property characterization of Army-relevant alloys for use in magnetic processing model development.

Title: Tribological Materials Science for Low Viscosity Fuel Lubrication

Modernization Priority: Future Vertical Lift Army/Next Generation Combat Vehicle

ARL Researcher: Stephen Berkebile

VICTOR PM: Mike Kweon

Directorate: Vehicle Technology Directorate (VTD)

Faculty POC: Diana Berman

Summary of Research: High-pressure fuel systems used to pressurize and deliver fuel for ICEs in medium-sized vehicles such as UAVs fail prematurely when operated with fuels of low viscosity and lubricity. This limitation both results in loss of aircraft with poor field-fuel quality and inhibits the true tactical-unit independence that could be achieved with multifuel engines. This project addresses the shortcomings of current materials found in the component pumps and injectors through collaborative research with UNT. By exploring the behavior of several different types of materials and coatings in low-viscosity fuels, we plan to find and improve ways to provide adequate resistance to wear and scuffing in the mechanical interfaces found within these high-pressure fuel systems. We will evaluate cutting-edge ultrahard commercial coatings under relevant conditions for their ability to resist material damage in fuel-lubricated interfaces, while also developing several higher-risk materials that have shown self-lubricating behavior under certain conditions through catalytic formation of protective amorphous carbon films from lubricating hydrocarbon fluids.

Title: Combustion Coating Material Technologies

Modernization Priority: Future Vertical Lift/Next Generation Combat Vehicle

Army Researcher: Jon-Erik Mogonye

Directorate: Vehicle Technology Directorate (VTD)

Faculty POC: Samir Aouadi

Summary of Research: ICEs that operate on heavy fuels at high-altitude conditions, such as those experienced by UAVs, experience thermomechanical-stress states that differ drastically from ground vehicle applications and cause premature material failure. These failures primarily occur in current coating materials applied to combustion-chamber alloys and can lead to higher sensitivity to fuel properties, reduced power and mission capability, and loss of the asset. Our project is focused on understanding the current material-failure mechanisms and evaluating new coating materials and processing methods to improve material performance. Primarily, the material failures of greatest concern have been located at the interface between coating and engine alloy. The collaborators will jointly develop an experimental schedule to evaluate new materials and coating technologies that improve the adhesive strength through diffusional and mechanical methods and optimize their processing conditions to achieve the multiple material requirements of the dynamic combustion-chamber interface.

Title: Magnetic Freeze Casting of Ceramic Structures

Modernization Priority: Next Generation Combat Vehicle

Army Researcher: Raymond Brennan

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POCs: Marcus Young, Samir Aouadi, and Diana Berman

Summary of Research: We are pursuing an advanced ceramic material that will provide lightweight armor protection for vehicles. ARL is collaborating on a two-step task for generating porous ceramic structures via magnetic freeze casting, followed by secondary phase/material infiltration to form dense bulk composites capable of sustaining high strain rates.

2.10 University of Texas at Arlington

Title: Human Dynamics of Cyber Security

Modernization Priority: Soldier Lethality

Army Researchers: Laura Marusich (on-site), Jonathan Bakdash (ARL South/UT Dallas), and Katherine Gamble Cox, Michael Geuss, and Erin Zaroukian (HRED/Aberdeen Proving Ground)

Directorate: Human Research and Engineering Directorate (HRED)

Faculty POCs: Paul Paulus and Jared Kenworthy (Psychology), Gautam Das and Chengkai Li (Computer Science and Engineering), Kay-Yut Chen and Jingguo Wang (Information Systems and Operations Management)

Summary of Research: We are engaged in several lines of research focused on teaming and decision-making as well as building a credible open-knowledge network. One line of research focuses on effective team formation and collaboration, particularly the influence of top performers on the performance of other team members. Another project takes a behavioral game-theory perspective combined with agent-based modeling to explore human decision-making. The open-knowledge network project is National Science Foundation (NSF) funded (C-Accel pilot, Principal Investigator: Chengkai Li) and aims to build easy-to-use tools and technology for transparent access to large-scale real-world knowledge. This project has potential applications for intelligence analysis, particularly Open Source Intelligence. In other work, we are evaluating the magnitude and variability in the widely theorized relationships among situation awareness (i.e., knowing what is going on) and human decision-making.

2.11 University of Texas at Austin

Title: ARL/UT Austin/Uber Stacked Co-axial Rotor for Quieter Vertical Lift Air Vehicles

Modernization Priority: Future Vertical Lift

Army Researcher: Rajneesh Singh

Collaborators: Uber/UT Austin/ARL

Directorate: Vehicle Technology Directorate (VTD)

Faculty POC: Jayant Sirohi

Summary of Research: ARL and UT Austin are investigating an innovative rotor concept to enable quieter operations of vertical lift and have a better flight-control capability. We are conducting experiments to measure aeromechanics performance and noise characteristics of the stacked coaxial rotor to evaluate feasibility of using it for UAVs and manned air-taxi operations. ARL, UT Austin, and Uber have completed the aeromechanics performance investigation of the stacked rotor. Key lessons from the last year's collaborative experimental and analytical efforts have led to improvement in the methods for modeling of aerodynamic interactions between the rotor blades. This knowledge has been transitioned into the computational rotorcraft-aeromechanics analysis software, Rotorcraft Comprehensive Analysis System, used by the vertical-flight S&T community, and

is being used to support the Future Vertical Lift's Future Attack and Reconnaissance (FARA). Acoustics evaluation of the stacked rotor is underway. This effort is part of our ARL/Uber CRADA and part of the research at UT Austin is funded by Uber.

Title: Human-in-the-Loop Autonomy

Modernization Priority: Next Generation Combat Vehicle

Army Researchers: Garrett Warnell (on-site)

Directorate: Computational and Information Sciences Directorate (CISD)

Faculty POC: Peter Stone (Professor, UT Austin)

Summary of Research: By studying and developing methods that can more tightly integrate human operators into autonomous systems, future artificial agents can be more effective and exhibit faster adaptation to new environments. ARL is partnering with UT Austin to perform basic research on human-in-the-loop autonomy for a variety of simulated (early-stage research) and physical (mid- to late-stage research) autonomous systems. Multiple modalities of human input—including passive (e.g., video) and explicit (e.g., teleop) demonstration and feedback—are being studied for the purposes of enhancing human control of robotic systems, increasing the efficacy of autonomous behaviors, and increasing the speed of autonomous-behavior acquisition. New methods for sharing control of platforms between humans and artificial agents in teleop-like control scenarios are being developed and validated, and new machine-learning algorithms that seek to allow nonexpert humans to teach new behaviors to artificial agents are also being developed and validated. One project seeks to extend classical imitation learning methods such that future autonomous agents can learn new behaviors directly from video demonstrations (e.g., YouTube videos).

Title: Pareto Optimal Streaming Unsupervised Classification for Human–Autonomy Interaction for Intelligent Squad Weapons (HAI2SW)

Modernization Priorities: Soldier Lethality

Army Researcher: Brent Lance and Steven Gutstein

Directorate: Human Research and Engineering Directorate (HRED)

Faculty POCs: Sanjay Shakkotai and Soumya Basu

Summary of Research: We will advance the ability of autonomous classification of data gathered to accurately identify and respond to detected objects through improved theoretical optimal limits on throughput and accuracy for an unsupervised ensemble of machine-learning classifiers. By applying these resulting adaptive training methods to label training sets obtained through opportunistically collected data generated as a result of Soldier actions, we will provide dismounted Soldiers with advanced target-acquisition capabilities.

Title: Synthetic Biology

Modernization Priority: Soldier Lethality

Army Researchers: Jimmy Gollihar (on-site) and Randy Hughes (on-site)

Directorate: Sensors and Electron Devices Directorate (SEDD)

Faculty POCs: Andrew Ellington, George Georgiou, Edward Marcotte, and Bryan Davies

Summary of Research: ARL and our partners are collaborating to realize our vision to achieve next-generation biological sensor platforms and rapid-response biological countermeasures for Soldier protection through sophisticated synthetic biological approaches. We are building a biological foundry at UT Austin with synthesis and automation pipelines for facile engineering of biological systems and components. By building an advanced biomanufacturing capability, we will be able to synthesize and assemble a wide variety of biological constructs that will be of utility across the Army and the Department of Defense. The Army biological foundry leads ARL's research efforts toward molecular tools and chassis organism development. The multidomain capabilities we aim to achieve include agile organism engineering, biomaterial development, advanced sense and respond capabilities, bioremediation and reclamation of resources, and rapid-response biological countermeasures. Examples of intended outcomes are advanced optical materials, production of novel adaptive biomaterials, and synthetic circuits for metabolic regulation.

Title: Large-Scale Multiphysics Modeling and Simulation for Advanced Electronic and Electromechanical Systems

Modernization Priority: Next Generation Combat Vehicle

Army Collaborator: Bruce Geil

Directorate: Sensors and Electron Devices Directorate (SEDD)

Faculty POCs: Shannon Strank (Joint Faculty Appointment), Vaibhav Bahadur, and Hamid Ouroua

Summary of Research: Technological advancements discovered through this project will revolutionize power capabilities. The final electronics package will include advanced materials robust enough to withstand extreme conditions, including electrical frequencies, and thermal and mechanical cycles. Critical to our success is a multiphysics model that will predict behavior of the designed package and will be used to evaluate innovative material selection for the power package. We will maximize performance gains garnered by emerging dielectric materials, new packaging techniques (including 3-D printing), and various power packaging applications.

Title: Aerosol Deposition of Metal and Ceramic Powders

Modernization Priority: Long Range Precision Fires

Army Researcher: Michael Gammage (on-site)

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POC: Desi Kovar

Summary of Research: We are developing a new technique to complement current additive-manufactured electronics technologies. With this technique we can print electronics into structural parts and antennae on conformal surfaces to save space and weight. These electronics need to be designed to sustain the high g-forces of munitions launch.

Title: Aluminum-Based Nanogalvanic Powder Materials for Hydrogen Fuel

Modernization Priority: Next Generation Combat Vehicle

Army Researcher: Anit Giri

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POC: Michael Lewis

Summary of Research: Our low-cost material (US patent publication #20190024216A1/January 24, 2019) promises to deliver a safe and reliable mechanism for storing and provisioning hydrogen to a fuel-cell power system. This type of solution can be helpful in multiple mission scenarios where hydrogen is scarce. The powder has been shown to react with even the smallest amount of liquid to form hydrogen. The first case will consider cannibalizing a part of the vehicle

for immediate limp-home power. The second case will consider strategic power plants fueled by this powder dropped near any body of water for refueling of drones.

2.12 University of Texas at Dallas

Title: Adversarial Machine Learning

Modernization Priority: Cyber Security/Army Network (Network Command, Control, Communications and Intelligence).

Army Researchers: Jonathan Bakdash (on-site) and Laura Marusich (at UT Arlington)

Directorate: Human Research Engineering Directorate (HRED)

Faculty POCs: Murat Kantarcioglu and Yan Zhao (Computer Science), Yulia Gel (Mathematical Sciences), and Daniel Krawczyk (Brain and Behavioral Sciences)

Summary of Research: We are investigating the use of artificial intelligence (AI) for human decision-making. Specifically, we will determine if and when eXplainable AI (XAI) can improve, or even impair, human decision-making. We will also examine representing uncertainty in XAI and conditions when adversarial attacks on XAI may deceive human decision-makers. In addition, we are conducting research to augment detection of deception using multiple approaches, which include AI detection of deception and time-limited presentation of deceptive materials in behavioral experiments (paradoxically, detection of deception for people may be better with less information). In other research, we are evaluating the widely theorized relationships among situation awareness and decision-making.

Title: Fermenting Vegetation for Efficiently Running Artificial Muscle

Modernization Priority: Next Generation Combat Vehicle

Army Researcher: David Mackie (Adelphi/SEDD) and Frank Gracea (ARL South/TAMU)

Directorate: Sensors and Electron Devices Directorate (SEDD)

Faculty POCs: Ray Baughman (UT Dallas) and Oomman Varghese (University of Houston)

Summary of Research: Our desired outcome is to power artificial muscles using direct conversion of energetic chemicals. This capability will contribute to our overarching goal of an efficiently powered autonomous robotic mule. To date, we have demonstrated chemically powered artificial muscles with excellent

performance. Our challenge is to scale up the size by several orders of magnitude in order to achieve chemically powered artificial muscles suitable for the legs of robotic mules. In the first year, we have shown that fuel cells work in an alternating current (AC) mode, and AC fuel cells will be fast enough for our applications. We have shown that we can make affordable chemically powered artificial muscles that are scalable and work well, with speed being the key challenge to overcome.

Title: Mechanically Robust, Hydrogen Bond Stabilized Covalent Organic Frameworks

Modernization Priority: Soldier Lethality

Army Researcher: Robert Lambeth

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POC: Ronald Smaldone

University Partners: Rice University and Massachusetts Institute of Technology

Summary of Research: We are preparing new 2-D covalent organic frameworks (COFs) with hydrogen bonding between 2-D layers to improve properties. Initial work focuses on chemistry and characterization to produce COFs with a high degree of regular order. Later work will focus on the mechanical properties of ideal COF chemistries. To date, we have been able to synthesize layers of 2-D material that interact strongly with each other, which we expect will result in superior mechanical properties. These materials are currently being characterized by ARL for mechanical evaluation. In our collaboration, in addition to characterizing material properties, ARL provides computational design to UT Dallas, which synthesizes the materials. This effort is also being supported by additional collaborations between ARL and scientists at Rice and MIT.

2.13 University of Texas at El Paso

Title: Autonomous Active Cybersecurity Defense

Modernization Priorities: Network/C3I, Sustainability

Army Researcher: Jaime C Acosta (on-site)

Directorate: Computational and Information Sciences Directorate (CISD)

Faculty POC: Salamah Salamah

Summary of Research: ARL and UTEP are collaborating through several vehicles including coursework and the leveraging of NSF/Department of Homeland Security-designated scholarship for service students as part of ARL South's Cybersecurity Rapid Innovation Group, consisting of cybersecurity professionals, faculty, and students. The collaboration has yielded research, software and hardware infrastructures, and rapid workflows that fuel technologies that enable rapid experimentation, data collection, and analysis for empirically based autonomous active cyber defense. This work is already being used to develop cybersecurity scenarios, data, and models for automated network analysis, communication, and defense in next-generation, heterogeneous, network configurations.

Title: Additive Manufacturing Development and Analysis

Modernization Priority: Sustainability

Army Researchers: Marc Pepi, Brandon McWilliams, and Jian Yu

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POC: Raymond Rumpf and Francisco Medina

Summary of Research: Our research will accelerate and advance manufacturing readiness of metal AM technology. In addition to UTEP's well-equipped manufacturing facility, we will rely on its modeling and design expertise to develop tools to print 3-D electronics. UTEP is at the leading edge when it comes to multimaterial prints for electronic applications. UTEP has world-renowned expertise in redesigning 2-D electronics in the 3-D space while matching performance. We at ARL bring to the collaboration our characterization expertise and facilities to optimize performance of the new designs. We focus on rapid AM alloy development, new AM strategies for repair using electron beam melting (EBM) technology, and AM process qualification and verification using powder bed monitoring technology. Through our partnership, we designed and produced a one-of-a-kind antenna with UTEP's nScrypt 3-D printer that is currently being Micro-Computer Tomography-inspected at ARL to ensure internal integrity. The antenna is a 3-D conical spiral antenna for high-frequency wide-band communication. The antenna is very difficult to make using conventional manufacturing methods. We successfully printed the device using UTEP's multimaterials preprocesser algorithm with UTEP's sophisticated nScrypt 3-D additive machine. Using our successfully demonstrated process algorithm, we plan to improve the functionality of the antenna by adjusting certain parameters.

Title: Additive Manufacturing of Alloys

Modernization Priority: Sustainability/Soldier Lethality

Army Researchers: Brandon McWilliams

Directorate: Weapons and Materials Research Directorate (WMRD)

Faculty POC: Cesar Terrazas

We have several projects underway with UTEP to advance AM processes for metals.

Generative Adversarial Network Framework: Army and UTEP researchers collaboratively developed a Generative Adversarial Network machine framework to predict and validate thermal histories during a laser powder-bed fusion build. This capability enables real-time certification and qualification.

Onsite Repair Applications: Our collaborations have resulted in demonstrating for the first time a process for repair applications, which will aid Soldiers in the field. We developed a novel 3-D printed fixture and process for repairing Abrams AGT1500 turbine engine blades using electron beam powder-bed fusion.

Tungsten for munitions: With UTEP and Lockheed Martin Missiles and Fires Controls (which is cost- sharing the project), we are currently developing binder jet and electron beam powder-bed fusion processes for tungsten and tungsten-heavy alloys. These alloys are being developed specifically for Long Range Precision Fire applications. We have achieved near fully dense material with tungsten heavy alloy infiltrated with Invar and are close to achieving pure tungsten in EBM Powder Bed Fusion (e-PBF). We have augmented funding for this work through the OSD ARAP-EEE program for further development of e-PBF tungsten and we plan to transition to our Arcam machine, a machine that uses electron beam as a heat source, at ARL.

Low-cost feedstock: We just started a low-cost feedstock project for FY20 to examine alternate feedstocks for binder jet, laser powder-bed fusion, and electron beam powder-bed fusion. We are working with UTEP, and our industrial partner in Austin, Ametek and Cumberland Industries.

2.14 University of Texas at San Antonio

Title: Modeling, Analyzing and Predicting Cyber Attacks

Modernization Priority: Network/C3I

Army Researcher: Ray Bateman (CISD) and Kristin Schweitzer (HRED)

Directorate: Computational and Information Sciences Directorate (CISD)

Faculty POC: Shouhuai Xu (UTSA Computer Science)

Summary of Research: We are developing a unified cybersecurity-management framework. The framework will enhance active, autonomous defense of Army networks through the development of algorithms for automated, end-to-end network security. The goal is to prioritize automated defensive efforts by leveraging threat intelligence, vulnerabilities, and data analytics for retrospective, real-time, and predictive system management.

3. Conclusion

Progress continues in our research areas at a quick pace, and we will publish updates regularly. Collaboration through ARL Open Campus is an essential component in the Army's strategy to maintain global cutting-edge technical dominance.

List of Symbols, Abbreviations, and Acronyms

2-D	2-dimensional
3-D	3-dimensional
AC	alternating current
AI	artificial intelligence
AM	additive manufacturing
AR	augmented reality
ARL	Army Research Laboratory
BABT	Behind Armor Blunt Trauma
CCDC	US Army Combat Capabilities Development Command
CISD	Computational and Information Sciences Directorate
COF	covalent organic framework
CRADA	cooperative research and development agreement
DE	Directed Energy
EBM	electron beam melting
e-PBF	EBM Powder Bed Fusion
GPS	global positioning system
HRED	Human Research and Engineering Directorate
ICE	internal combustion engine
ISR	intelligence, surveillance, and reconnaissance
MR	mixed reality
NGCV	Next Generation Combat Vehicle
NSF	National Science Foundation
POC	point of contact
PPE	personal protective equipment
RAS	Robotic and Autonomous Systems

SEDD	Sensors and Electron Devices Directorate
sUAS	small unmanned aerial system
TAMU	Texas A&M University
TC	turbocharger
TRL	technical readiness level
UAH	University of Alabama in Huntsville
UAV	unmanned aerial vehicle
UNT	University of North Texas
UT	University of Texas
UTEP	University of Texas at El Paso
VR	virtual reality
VTD	Vehicle Technology Directorate
WMRD	Weapons and Materials Research Directorate
XAI	eXplainable artificial intelligence

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