2023 NASA EPSCOR Rapid Response Research (R3)

Proposal Abstracts

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23-2023 R3-0011

B-003: Dimensionless and Experimental Characterization of Thin Film Transition during Evaporation and Condensation of Two-Phase Flow in a Mini-Channel

University Of Alaska, Fairbanks

Dr. Denise Thorsen

As consumer electronics (mobile phones, tablets, etc.) are made more densely packed and functional, they consume more power and generate more heat. To effectively dissipate heat for the best performance, heat pipes of miniaturized size have been developed and widely used. These heat pipes have a similar functionality as in freezers and refrigerators, of circulating a coolant in a closed-loop pipe for cooling. Yet, the difference is that heat pipes that are miniaturized to accommodate the minute space in consumer electronics have no active components such as the compressor. Instead, they are smartly designed to work passively by just using the natural cycle of evaporation-condensation to move the coolant around in mini- (or micro-) channels. This is the principle of oscillating heat pipes (OHPs).

NASA is exploring the applications of OHPs to thermal management of electronics, batteries, and power systems in space missions. Since OHPs lack an active element to drive the coolant for heat dissipation, one major concern is that, when overheated, part of the interior wall in the OHP will completely dry-out. Any dryout in a minute pipe will naturally form an invisible barrier for coolant to move across, thus breaking the desired heat dissipation functionality. A thin film of liquid must remain on the wall to allow for continuous oscillating motion. Knowing how to design OHPs under working conditions while maintaining a thin film of liquid in the hot spot is critical to successful application of OHPs.

The proposed project will characterize the thin liquid film in the heating and cooling sections of an OHP, by developing dimensionless correlations based on dimensional analysis and by collecting sensible data to preliminarily substantiate the dimensionless correlations to quantify the thin film dynamics. The formulated dimensionless groups and correlations will characterize the transient state of the thin film thickness. This analytical approach will address how heat flux governs evaporation of the thin film and growth of the vapor plug in the channel, and relate how the cooling conditions in OHPs govern condensation of the vapor plug and growth of the thin film. To benchmark the dimensionless groups and relations obtained from the analytical characterization, an experimental setup will be constructed. The experimental apparatus will enable parametric experimentation that will allow us to easily vary tangible parameters to acquire data from as many different combinations of the heat exchange conditions as possible, to substantiate the relations of the dimensionless groups. The proposed work will fill the aforementioned gap with a fundamental understanding of liquid film formation, thinning by evaporation, and growth by condensation in OHP channels.

23-2023 R3-0044

A-005 - Polydicyclonentadiene (poly-DCPD) Aerogels as Light-Weight, Heat-Resistant Insulators

University Of Alabama, Huntsville

Dr. Lawrence Thomas

Proposed is the development of polydicyclopentadiene (poly-DCPD) aerogels for thermal, electrical and shock insulation purposes. The advantages of poly-DCPD are high thermal resistance coupled with excellent mechanical strength, high corrosion and oxidative stress resistance and last but not least, high commercial viability. Previous work established that poly-DCPD aerogels can be produced using Grubbs' second generation catalyst (GC2) polymerizing and crosslinking the monomer in acetone. The advantage of the technology is that the gel network separates from the solvent during the reaction via chemically induced phase separation (CIPS). Hence, the isolation of the aerogel is straightforward and the removal of the solvent will not cause a collapse of the aerogel network. While not quantified yet, this methodology causes little shrinkage in the mold and hence a low-density material can be isolated.

The proposed work will build on this technology. Three specific aims have been identified for the funding period. Specific Aim one targets to quantify the densities of the aerogels produced with this technology. Ideally, the measured densities are similar to the theoretical ones given by the volume of the solution and mass of monomer used. Ultimately, the goal is to make gel densities < 0.05 g/mL. Specific Aim 2 targets to map out reaction parameters in relation to the resulting material properties. Tunable reaction parameters are concentration, catalyst loading, reaction time and temperature which will influence the properties such as density (see above), mechanical strength and thermal stability. By establishing correlations between these parameters, we will be able to plan and modify future reaction designs based on desired properties. Specific Aim 3 targets to produce aerogels with various shapes and sizes by using three-dimensional, reusable molds.

The proposed work will also serve as a vehicle for the scientific education of science majors. The educational impact extends beyond the lab work as dissemination of the research findings will also be partial student responsibility. Furthermore, the proposed materials are projected to have an impact on NASA as well as the broader society due to the unique stability and strength of poly-DCPD which in the form of aerogels could find multiple applications as heat, shock and impact resistant materials.

23-2023 R3-0053

P-001 - New interface passivation process for stable SiC power MOSFETs at 500°C

University Of Alabama, Huntsville

Dr. Lawrence Thomas

In high power applications such as utility grid voltage conversion or electric motor controls, transistors made of 4H-SiC, a wide bandgap semiconductor, are preferred over traditional silicon. The ever more stringent requirements in energy efficiency is resulting in increased adoption of the new technology. The most common SiC devices are the Schottky barrier diode and the MOSFET transistors. Both are used in voltage converters to match renewable energy sources to the grid, in fast, arc free circuit breakers or for the sequential switching of the voltage at the poles of a motor such as those found in electric vehicles.

With a bandgap of 3.26 eV, SiC maintains its electronics properties at temperatures in excess of 700°C. Depending on doping, its thermal conductivity (280 to 347W/mK) is about or higher than that of Aluminum (237W/mK) used for most heatsinks. The low reactivity of the material makes it well adapted to harsh ambient conditions such as found on Venus.

Both applications and material properties are a good fit for robotic missions on a planet such as Venus. The SiC MOSFET device is therefore clearly of great interest in that context. However, our previous experiments have shown that voltage instability around and above 400°C may be the critical limitation for operation of current SiC MOSFETs at such temperatures. The problem is due to the activation of additional energetically deep interface traps at high temperature.

Recently, superior SiC/SiO2 Interfaces have been demonstrated using surface passivation with hydrogen etching and annealing, followed by deposition of the oxide instead of thermal growth, and finally terminated with state of the art Nitric Oxide passivation. Observed trap density is reduced, accompanied with an increase in charge mobility, meaning higher current transport capability for the device.

This project proposes the use of this recently developed interface, at temperatures reaching 500°C and its comparison to the traditional nitric Oxide passivation currently used in SiC commercial devices. Our previous study indicates that an improvement in trap reduction should translate into more stable devices at the targeted temperatures. Through the use of previously developed high temperature contacts and high temperature testing setup, the behavior of the new interface can be thoroughly tested at high temperature, detecting the presence, the density and the position in the bandgap of active traps. MOS capacitors studies at room temperature, 500°C and with UV on both reference and new interfaces will reveal the differences between the interfaces while the long term voltage stress at 500°C will evaluate the actual performance of the proposed solution.

The impact of this project goes beyond the development of power electronics for the Venus mission. The demonstration of the viability of SiC MOSFETs at such high temperatures will have high impact on the way they are used in military, consumer and utility applications. A high temperature transistor can be used with lighter heatsinks or can bear much higher power densities. Already the high frequency capability of the SiC devices results in smaller form factor for the passive electronics surrounding them, trend that will be pushed further.

The development of such project will consolidate Auburn University and through it, the state of Alabama as a Space technology related institution, attracting both interested STEM student and businesses.

23-2023 R3-0057

H-001 - A Portable Continuous Wave Diffuse Correlation Spectroscopy (pCW-DCS) for Better Monitor of Cerebral Blood Flow (CBF), a Biomarker for Microgravity-induced Neurocognitive Dysfunction

University Of Alabama, Huntsville

Dr. Lawrence Thomas

With the advances in human space exploration, early detection and intervention of changes in neurobiological and neurophysiological responses to microgravity and the stressful environment is critical to ensure the health and function of the space crews. Early evidence has shown that it is inevitable for astronauts to experience neurocognitive impairment after as a long-duration space mission due to the effect of both weightlessness and the stressful environment [1-5]. To further study the effects of microgravity alone in a controlled environment, head-down tilt bed rest (HDBR), a ground-based analog was often used [7]. Short-term and long-term duration HDBR in healthy individuals could cause an increase in intracranial pressure (ICP) [5, 8] whereas changes in ICP may affect cerebral blood flow (CBF) directly [9, 10]. More specifically, CBF remains constant when ICP level is less than 50 mm Hg, but increases when ICP is between 50-96 mm Hg (associated with systemic hypertension) while decreasing rapidly when ICP further increases [9]. In addition, strong evidence indicates that physiological stresses may alter CBF and its regulation, leading to cognitive impairment [11]. CBF has also been recognized as a novel biomarker of progressive cognitive decline such that a decrease in CBF often associates with a decline in neurocognitive function [12]. Therefore, routinely monitoring CBF of astronauts can help identifying neurocognitive issues caused by microgravity and stressful environment at early stages. However, accurate tools that allow quantitative and continuous monitor of CBF in space do not exist. Gold standard" modalities such as Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) are impractical for continuous monitoring in space. Although Transcranial Doppler (TCD) Ultrasound is the closest approach to a non-invasive CBF monitor and was used to study CBF changes during parabolic flights [13-15], TCD provides qualitative trend monitoring of blood velocity, not CBF. TCD measures velocity in large vessels (not microvascular flow), and can be position-dependent and challenging in many subjects [16]. In addition, velocity and flow (mean vessel speed times area) may diverge in cases of vasospasm [17], a phenomenon that can be evoked by gravity change [18]. On the other hand, near-infrared (NIR) photon light introduced via the scalp can penetrate the brain and interact with dynamic scatterers (red blood cells) before escaping at the surface. Because red blood cell dynamics are encoded in the fluctuations of the escaped light [19], a NIR optical instrument that quantifies these fluctuations may be able to monitor CBF non-invasively. While standard NIR technologies to measure CBF in adult humans face a unique challenge, diffuse correlation spectroscopy (DCS) is the current state-of-the-art optical blood flow monitor for traumatic brain injuries [20-22]. DCS achieves coherence with single or few mode detection [23, 24] (i.e. small core fibers), and detects weak light levels with single photon counting (i.e. a cumbersome detection strategy that registers each photon, or quantum unit, of light). The goal of this application in Year 1 is to develop a portable DCS (p-DCS) system to measure cerebral blood flow (CBF). The proposed research is well fit within NASA Translational Research Institute for Space Health, and NASA Human Research Program. The accomplishment of Phase 1 will be the solid first steps in expanding our knowledge on the functional significance of DCS technology in cognitive health in space. This proposal leverages Dr. Le's trainings as a radiation oncology physics resident at Juravinski Cancer Centre, and his research to develop portable optical spectroscopy methods to study CBF in traumatic brain injuries at UC Davis, to detect brain tumor margin at McMaster University, and mucosal cancer at the FDA [6, 25-29].

23-2023 R3-0059

C-004 - Study of Krypton Ion Erosion of Satellite Relevant Materials

University Of Alabama, Huntsville

Dr. Lawrence Thomas

The use of in-space electric propulsion (EP) has undergone substantial growth in the last decade for both commercial and space exploration missions. During this time, xenon has been the most studied EP propellant, while krypton has gained recent use due to its advantages in lower cost and higher specific impulse (Isp). The higher Isp of krypton allows a lower propellant mass for a given total impulse, which is desirable for small satellites where weight is of concern. But regardless of the type of propellant used, a fundamental issue of EP is the sputtering (i.e., erosion) of materials near the high energy ion beam. This can cause damage to critical components or contamination of the sputtered material onto spacecraft and instrument surfaces. While there has been characterization of xenon sputtering of materials, there is a need for similar characterizations of krypton sputtering which will be accomplished in this proposal through four specific tasks presented below.

Task 1 - Characterize the UAH miniature ion engine that will serve as the ion sputtering source. This engine uses a microwave surface plasma to produce the plasma and the accelerator grids extract and accelerate the ions. Acceleration voltages of 100-800 V have been tested with argon. The same thruster will be characterized with krypton for plume density, ion energy and distribution.

Task 2 - Conduct total sputter yield experiments on the primary materials of interest Kapton, anodized aluminum, cover glass, and boron nitride using a range of sputter parameters. The total sputter yield will be determined using the target weight loss method and change in surface topography method. For each target material, the test parameters of voltage, sputtering time, and incident angle will be varied as determined by a test matrix with a total of 15 operating conditions for each target material, resulting in a total of 60 samples produced for the primary materials of interest. This data will allow plots of, 1) voltage vs total yield at normal incidence and 2) angle of incidence vs total yield.

Task 3 Conduct differential yield experiments with varied test parameters of voltage, sputtering time, and incident angle defined within the test matrix of Task 2. The differential yield characterizes the spatial distribution of the sputtered material and is important to understand how the material sputtered from the target material can contaminate the surface of nearby devices and instruments. Measurements of the differential sputtering yield will be performed by collecting sputtered material on blank substrates positioned at intervals of specific polar angles (±) along a semicircular path above the target material and measuring their weight before and after sputtering.

Task 4: Material characterization - These characterizations include elemental composition of the target materials and sputter coated surfaces, mechanical damage (ex., spalling fracture and flaking), and optical/thermal measurements (ex., reflection, transmission, and/or absorption) relevant to the different target materials of interest. To better understand sputter yield and contamination of the sputtered material, the elemental composition of the sputtered material will be determined using laser induced breakdown spectroscopy (LIBS), or a similar method, on the target before and after sputtering as well as on adjacent substrates.

The information from these tasks and proposed research are beneficial to improve the performance, reliability, and lifetime of EP components and instruments. There is a growing need for such further characterizations to promote and meet the growing applications of krypton-based EP specifically in commercial applications.

23-2023 R3-0087

Quantifying effects of land cover change- climate interactions on ecosystem productivity over western North America

University of Arkansas, Little Rock

Dr. Mitchell Hudson

The Arctic and Boreal regions have experienced considerable warming, leading to tremendous changes in ecosystems. Meanwhile, it is undergoing rapid land cover changes with approximately 21% of areas experiencing changes. Such changes could influence regional climate through both biogeophysical (e.g., altering soil moisture) and biogeochemical (e.g., change CO_2) processes. However, how the resultant climate variabilities affected ecosystem productivity in the Arctic and Boreal regions is rarely explored. Let alone if they amplified or dimmished the effects of global warming. A quantitative assessment of the impacts of land cover change and its subsequent climate variability on ecosystem productivity is paramount for understanding the vulnerability and resilience of Arctic and Boreal ecosystems. As such, this project has three research objectives. (1) We will detect spatiotemporal trends, magnitudes, and transitions of all land cover types in western North America; (2) We will examine how the identified land cover changes influenced regional climate; and (3) We will quantify how the resultant climate variability impacted the ecosystem productivity in western North America. The theoretical, methodological, and contextual knowledge of land and atmosphere interactions from this project is expected to greatly benefit land management policymakers.

23-2023 R3-0022

P-001: High temperature GaN transistors using TiA1O for Venus long-duration surface electronic systems

University of Delaware

Prof. William Matthaeus

Long duration lander is needed to perform surface observations of seismic activity and atmospheric conditions on Venus (with the high surface temperature 460ºC) to explore how climate and geology work, and thus provide a better understanding of how these processes work in our earth. Previous Venus landers' data transmission at Venus lasted only for two hours[1]. It utilized silicon electronics (conventional silicon metal oxide field effect transistors-MOSFETs), which failed due to their invulnerability to high temperature despite of the use of cooling measures. Thus, transistors that can tolerate high temperature are required. GaN high electron mobility transistor (HEMT) is one of such potential candidates due to its 2-dimensional electron gas (2DEG) nature. However, its Schottky gate often induces high leakage current, which degrades the device performance. A gate insulator is thus needed to minimize the gate leakage. Here, we propose to employ high-k dielectrics (TiAlO), with its temperature robustness, to develop GaN high temperature transistors that can be used for Venus long-duration surface electronic system. The successful completion of this study will enable high performance and high efficiency electronics that can tolerate high temperature with improved size, weight, power and cost (SWaP-C) metrics for Venus applications.

23-2023 R3-0071

C-001: RMAF Softgoods Repair Lab

University of Delaware

Prof. William Matthaeus

Missions beyond LEO are challenging for traditional survivability paradigms such as redundancy management, reliability, sparing, orbital replacement, and mission aborts. Distances, transit durations, crew time limitations, onboard expertise, vehicle capabilities, and other factors significantly limit the ability of human spaceflight crews to respond to in-flight anomalies. There is a need for a Repair, Manufacturing, and Fabrication (RMAF) facility to increase the capability of the crew to recover from spacecraft component failures by combining aspects of machine shop, soft goods lab, and repair shop into an IVA capability for both microgravity and surface spacecraft. A RMAF is responsible for restoring damaged components to working order (repair), keeping components in service or properly functioning (maintenance), and creating new components from raw or scavenged materials (fabrication). This responsibility extends not only to the habitat, but to all other elements sharing the same destination environment (e.g., landers, rovers, robots, power systems, science instruments, etc.).

NASA is exploring space architectures that can serve as next steps to build upon the current Artemis program. The Common Habitat Architecture Study is based on a suite of common spacecraft elements that can be used for long-duration human spaceflight in multiple destinations, including the Moon, Mars, and deep space. Because most habitats intended for use beyond LEO do not return to Earth, yet may operate for decades, it can be assumed that even low probability failures will eventually occur and there must be a way to recover from them and continue the mission. Thus, the Common Habitat must include the RMAF capability. The RMAF speaks to an overarching gap of inability to mitigate spacecraft component failures. The RMAF goes beyond the replacement of failed components with spares and focuses on the capabilities to restore failed components to working order, making them effectively the new spare.

Because softgoods are used in many space exploration applications, and often do not have the longevity of metals or composites in use, the RMAF will require specific capabilities to work with softgoods elements. Softgoods components use several materials formats (coated fabrics, textiles, films, webbings, etc.) which are themselves comprised of a wide range of materials (polyurethane, polyethylene, polyester, polyimide, Nomex, Vectran, elastomers, etc.). The processes required to repair and rework softgoods typically include sewing, thermal welding, adhesive bonding, and taping. Of particular interest in this study is identifying processes and equipment that can adapt to a range of needs, have excellent process control, minimize crew burden, and eliminate the need for complex machines and multi-part adhesive systems used on earth in the manufacturing of the original softgoods components.

23-2023 R3-0060

A-004: High-fidelity Multidisciplinary Design Optimization of Heat Exchangers for eVTOL Aircraft Thermal Management

Iowa State University, Ames

Dr. Sara Nelson

The objective of this proposal is to develop the capability to rapidly design high-performance heat exchangers for electric vertical take-off and landing (eVTOL) aircraft thermal management, under NASA's OpenMDAO/MPhys framework. eVTOL aircraft is the next-generation aviation concept in NASA's Advanced Air Mobility Mission as it enables zero-emission, on-demand air taxis and is poised to transform how people live and connect. However, eVTOL aircraft do not have a natural way to dissipate the heat accumulated in their electric motors, which may cause the failure of other components, such as the battery. An urgent need is to design efficient heat exchangers to dissipate the heat with a minimal penalty to the aircraft's overall performance, i.e., minimal pumping power and weight.

In this project, we will extend the OpenMDAO/MPhys framework's capability for conjugate heat transfer optimization of various heat exchanger configurations. OpenMDAO is an open-source multidisciplinary design optimization (MDO) framework developed at NASA, with MPhys being one of its derivatives for high-fidelity optimization, e.g., computational fluid dynamics (CFD). MPhys currently has an aerothermal interface that can conduct conjugate heat transfer for simple geometries. However, it faces a main technical challenge when extending for complex geometries, such as ducted heat exchangers. This project will break this limit by creating a new MPhys aerothermal interface that can handle various complex geometries and working conditions.

To pursue the above objective, we will conduct three research tasks. (1) Develop the aerothermal data transfer functions to extract heat flux and temperature at the conjugate heat transfer boundary through DAFoam (a high-fidelity multiphysics solver being actively developed by the science investigator at Iowa State University). (2) Create a new MPhys aerothermal interface to use DAFoam for conjugate heat transfer optimization. (3) Conduct CFD-based conjugate heat transfer optimizations for a plate-fin heat exchanger. The objective is to minimize the pumping power and weight of the heat exchanger while dissipating a prescribed heat flux (constraint). We will perform multi-objective and multipoint optimizations to balance the performance between pumping power and weight at different heat flux (motor power) levels. The new MPhys aerothermal interface can also be used for optimizing other heat exchanger configurations using high-fidelity CFD. We will submit our new aerothermal code development to the MPhys repository as a pull request.

If successful, the new aerothermal interface will allow MPhys to rapidly design high-performance heat exchangers for maximizing the efficiency of eVTOL aircraft thermal management. Leveraging the flexibility of the OpenMDAO framework, the new aerothermal interface can also be integrated into power and thermal management system-level optimization and extended for more disciplines, such as aero-thermal-structural optimization. From the MPhys development standpoint, the proposed project will build a strong foundation for standardizing the patch-based multidisciplinary coupling and can be extended for other eVTOL vehicle components, such as coupled wing-propeller optimization.

The proposed research fits well with NASA Aeronautics Research Mission Directorate's (ARMD) strategic thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles" and aligns well with the NASA EPSCoR R3 program's objective to promote collaboration between the EPSCoR jurisdictions and NASA. In the past year, the science investigator has incorporated DAFoam into the OpenMDAO/MPhys framework for aerodynamic and aerostructural optimization. With the support of this EPSCoR R3 project, he will continue contributing to the MPhys development and research on the multidisciplinary analysis, design, and optimization of eVTOL aircraft.

23-2023 R3-0080

A006: Microscale-informed Calibration of Composite Material Post-Peak Behavior for the LS-DYNA MAT213 Model

Iowa State University, Ames

Dr. Sara Nelson

A university-NASA partnership is being developed to provide a microscale informed calibration for compressive response and post-peak characteristics of hybrid weave composite materials. Full experimental calibration, analysis of the incremental deformation fields and rigorous evaluation of the post-peak stress will assimilate the implementation of material constants and calibration of LS-DYNA MAT213 predictive material model.

Two objectives are targeted in this work. First, we will assess the role of different failure mechanisms (which are characteristics of the fiber, matrix and their interface) on setting the compressive strength of the laminate. A combination of unsupported short gauge and supported (anti-buckling) long gauge specimens will be used to screen the different failure modes. Full field digital image correlation (DIC) will be employed to monitor (i) precursors for microbuckling/kinking to set effective yield and strength limits, and (ii) incremental plastic strain field over the reduced Moher strain-plane to calibrate/verify the modeling framework. The incremental strain measurements will provide prospective and quantitative measures for assessing the assumed plastic flow potential, hardening evolution, separation angle between flow potential and assumed yield surface, thereby highlighting the material non-associative deformation characteristics.

Second, we will develop an intrinsic measure for peak-instability and post-peak response. The model is derived based on an equivalent crack model having a cohesive zone at its tip representing the compression induced damage zone (microbuckling, kinking and delamination). An edge-supported specimen containing central hole under compression is utilized to induce a stable propagation of a damage zone emanating from the hole edge. The fracture toughness, and intrinsic compressive strength are independently measured from cracked and uncracked panels, respectively. The proposed methodology is expected to overcome current limitations in the numerical framework of MAT213, by providing an experimentally calibrated intrinsic measure of the microbuckling/kink-band energy formation and the associated intrinsic post-peak stress.

The EPSCoR-R3 funding will nourish the university-NASA Glenn and Langley partnership to develop the supporting experimental framework for further development of the composite material models and their implementation into computational frameworks. Dr. Bastawros, two aerospace engineering graduate students and an undergraduate student will execute the experimental testing and analysis plan to calibrate the model parameters for NASA-provided hybrid weave composite panels. The established partnership with NASA will enable the development of the future workforce through educating young engineers and scientists, with further global impact on reliability of transportation systems by ground, sea, air, and beyond, while influencing the environmental and industrial practices.

23-2023 R3-0079

INE 2023 R3 P-005: Detection and Characterization of Spore-Forming Anaerobic Bacteria in an Aerospace Clean Lab

University of Idaho

Dr. Matthew Bernards

Dormant bacterial endospores are one of the toughest biological structures on Earth designed for survival during unfavorable conditions. Contamination of spacecraft surfaces with endospores has been a long-standing concern related to planetary protection and many studies have been conducted in the past two decades to isolate spore-forming bacteria from surfaces within NASA aerospace facilities and test the survivability of endospores in conditions simulating space and extraterrestrial environments. Most of these studies used aerobic Bacilli as model organisms, likely because of well-defined cultivation strategies easy to optimize in and outside of laboratory. Furthermore, NASA's standard spore assay also only uses aerobic growth conditions for isolating spore-forming bacteria. Members of Clostridia, consisting of strictly anaerobic spore-forming bacteria many of which are extremophiles, however, have received much less attention regarding planetary protection. Endospores of Clostridia were recently shown to be transported via fluid migration and sediment burial and colonize pristine habitats within the Earth's subsurface. This project will partner with the Astromaterials Research and Exploration Science Division at NASA's Johnson Space Center to address two objectives 1) isolation and enrichment of anaerobic, spore-forming Clostridia from clean lab samples using anoxic cultivation assays using a combination of different media and incubation temperatures; and 2) physiological and molecular characterization of enrichment cultures / isolates using a combination of growth assays and high-throughput DNA sequencing. Our long-term goal is to help expand NASA's toolbox on identifying and eliminating endospores of metabolically diverse bacteria in aerospace facilities as potential terrestrial contaminants on Mars during future crewed missions.

23-2023 R3-0093

INE 2023 R3 B-006 Effects of Lunar and Martian Regolith Simulants on Growth, Survival, and Fitness of Vertebrates: Acute and Chronic Exposure Zebrafish Models

University of Idaho

Dr. Matthew Bernards

NASA Artemis missions aim to establish a long-term presence on the Moon, then send astronauts to Mars. However, the health effects of increased human exposure to potentially toxic regolith, fine particle dust covering the Moon and Mars, remains poorly understood and poses a fundamental challenge to the safety and success of NSAS's deep space explorations.

In response to the FY2023 NASA EPSCoR Rapid Response Research (R3) solicitation (NNH23ZHA002C) under Biological and Physical Sciences (BPS) Space Biology Program Research Focus Area B-006 Effects of Regolith Simulant on Growth, Survival, and Fitness of Animal Models", we hypothesize that zebrafish, an in vivo vertebrate animal model widely used in environmental toxin studies, will further the understanding of the health implications of regolith exposure, thanks to zebrafish's remarkable genetic similarity to human disease-associated genes and physiological conservation.

The project will examine four important types of lunar and Martian regolith simulants that have been sourced from Exolith Lab. Compared to non-exposed control zebrafish, the following effects of regolith will be determined: (1) The effect on animal growth will be determined by hatching success and time, embryonic development, and malformation; (2) The effect on animal survival will be determined by mortality rates during and post-exposure; and (3) The effect on animal fitness will be determined by changes in swimming behavior and stimulus response. Both are governed by the neuromuscular system thus the results will be particularly relevant to human performance in spaceflight. All experiments will be performed in a dose- and time-dependent manner.

Upon completion of the project, acute and long-term consequences of lunar and Martian regolith exposure will be characterized using in vivo zebrafish models. It is anticipated that results from this project will provide important biological insights into regolith toxicity and have broader impact on developing effective countermeasures to protect NASA crew during spaceflights.

23-2023 R3-0106

A-005: Manufacturing/Fabrication of Bi-Modal Capillary Wick Structures for Efficient and Compact Thermal Management Systems for EVTOL Propulsion Components using High Voltage Press-Sinter Method (PSM)

Wichita State University

Dr. Linda Kliment

The 21st century has seen both upstart and established aerospace companies compete to capture the emerging Urban Air Mobility (UAM) aviation market to revolutionize and provide safe, efficient, and accessible 'on-demand air mobility systems' for passengers and cargo within urban areas, taking the aviation industry's potential to its next level. The need to provide immediate and flexible high-speed transportation in metropolitan areas has resulted in the evolution of aircraft technologies, and as such various novel 'short take-off and landing aircraft' options are currently being explored like flying cars, air taxis, personal air vehicles which can be enabled by conventional take-off and landing vehicles (CTOL) or vertical take-off and landing (VTOL) vehicles. The basic objective of UAM is to provide a less congested means of transportation and zero emissions-based mobility using a new generation of aircraft relying on a very different propulsion system than a traditional aircraft, in a smaller airframe. Concurrently, there is a global focus on the reduction of CO2 emissions which is leading the transition from conventional combustion engine-based propulsion systems to the development of electric, turbo-electric and hybrid electric propulsion systems for space, automotive and aviation applications.

Meanwhile, it has been observed that thermal management is becoming increasingly complex as weight saving, higher efficiency, lesser emissions and cost saving have become key factors in designing and manufacturing optimal thermal management systems for eVTOLs where power requirements are reaching megawatt levels. Electric propulsion architectures vary depending upon their applications. A typical electric propulsion system architecture consists of batteries as a source of propulsion power driving the motor(s) coupled to propeller-rotor systems. Several thermal management strategies are being currently explored for cooling electric motors.

Of all the thermal management systems implemented in the electric motor, the predominantly used thermal management system is the 'heat pipe-based two-phase liquid-based' cooling system near evaporators/condensers where a heat source is placed on the outer surface of the evaporator section, with heat being transferred to the liquid through the wall. The working fluid subsequently heats up utilizing the latent heat and evaporates and travels through a porous structure called wick structures and condenses in the condenser section of the heat pipe, transferring the heat to the heat sink through the walls and the liquid then returns to the evaporator section, thus completing the cycle. This system having wick structures can achieve 100 times higher thermal conductivity than copper, enhancing heat conduction. With the increase in the electrical needs of the aircraft propulsion systems and onboard electricals it is imperative to seek innovative evaporator/condenser designs to substantially improve the thermal management performance. Through the development of advanced materials and innovative manufacturing technologies, we propose innovative evaporators and condensers using bimodal, capillary wick structures that enable a very high heat flux with an extremely low thermal resistance, micro/nano-engineered using the process of High Voltage Press Sinter Method , an additive manufacturing process allowing for greater complexity and customization in heat pipe designs and performance , and as well as elimination of any secondary wick manufacturing processes. The primary benefit of the proposed research is to provide a fast turnaround, rapid prototyping additive manufacturing process, creating thermally efficient wick structures having controlled porosity and permeability depending upon the geometry and functionality of the heat pipe, fabricated in one-tenth of the time required by any conventional processes and laser based additive manufacturing.

23-2023 R3-0063

NASA EPSCoR R3 (E-006): Modal Isolation of Porous Media Thermal Transport Properties

University of Kentucky

Prof. Alexandre Martin

The proposed research activity will be the development of thermal conductivity prediction models for porous insulation materials used in thermal protection system (TPS) for hypersonic and re-entry vehicles. An experimental facility and method for obtaining these measurements with the ability to isolate the modal contributions from solid conduction, gaseous conduction, and radiation has been developed at the University of Kentucky Paducah Campus. This facility will be used to analyze materials of interest to the NASA Entry, Landing, and Descent community.

Kentucky's NASA EPSCoR Program at the University of Kentucky solicited proposals from university-led research teams in Kentucky to address NASA research needs listed as topics for the FY2023 NASA EPSCoR Rapid Response Research (R3) announcement (NNH23ZHA002C). This proposal addresses topic E-006, E-006: Entry Systems Modeling - Thermal Conductivity Heat Transfer of Porous TPS Materials," with research led by the science team from the University of Kentucky Paducah campus.

23-2023 R3-0064

NASA EPSCoR R3 (E-007): Optical Transmissivity of Windows Coated by Laser-Ablation Products

University of Kentucky

Prof. Alexandre Martin

This project is for investigating the optical transmissivity of radiometer windows as pyrolysis and ablation products are deposited on their surfaces. NASA's space mission vehicles such as Mars 2020 carry radiometers as part of their instrumentation suite. Due to high-temperature and low-pressure conditions during entry, pyrolysis and ablation products such as phenolic-impregnated carbon ablator (PICA) can be deposited on the radiometer windows, resulting in significantly reduced transmissivity. The reduction in transmissivity can lower the signal level reaching the radiometer sensing element. Hence, it is imperative to systematically investigate how optical transmissivity is affected as pyrolysis and ablation products are deposited. For example, some pyrolysis and ablation products may affect only a limited range of spectral wavelengths of optical windows, whereas other products may deteriorate the overall transmissivity. Using a pulsed laser ablation technique, we will evaporate samples such as PICA and collect their ablation product on optical windows. Compared to large-scale ArcJet or Plasma torch experiments, our table-top experimental approach can economically create pyrolysis and ablation products in systematically controlled high-temperature and low-pressure conditions. The outcome of this project will also help find technical solutions to prevent or mitigate the deposition problem of pyrolysis and ablation products.

Kentucky's NASA EPSCoR Program at the University of Kentucky solicited proposals from university-led research teams in Kentucky to address NASA research needs listed as topics for the FY2023 NASA EPSCoR Rapid Response Research (R3) announcement (NNH23ZHA002C). This proposal addresses topic E-007, E-007 Entry Systems Modeling - Deposition of Ablation/Pyrolysis Products on Optical Windows," with research led by the science team from the University of Kentucky.

23-2023 R3-0003

Thermal property and microstructure measurements for additively manufactured parts with novel alloys (C-003 Thermal Properties)

Louisiana Board Of Regents

Prof. T. Gregory Guzik

The targeted research topic of this application is C-003: Materials and Processes Improvements for Chemical Propulsion State of Art (SoA). Chemical Propulsion Systems use chemical reactions to release energy and accelerate gases to generate thrust. There are three major components that make up chemical propulsion systems, including the Propellant Delivery/Feed System, the Thrust Chamber Assembly, and Thrust Vector Control systems. Both the Thrust Chamber Assembly and Thrust Vector Control systems operate at high temperature/high pressure, thus require careful thermal control and detailed material thermal property data for design optimization.

This team will evaluate the bulk thermal properties of novel materials made by additive manufacturing (AM). AM creates unique opportunities to fabricate parts with complex geometries, such as thrust chamber assembly for the chemical propulsion systems. Build on the established collaborations with NASA Marshall Space Flight Center (MSFC) Additive Manufacturing team (Paul R. Gradl), the Science-PI's team will characterize and test novel chemical propulsion components made by laser powder bed fusion (LPBF) based additive manufacturing (AM). Specifically, the Science PI's team will focus on thermal property measurements and microstructure evaluation of additively manufactured parts made of new NASA-developed oxide dispersion strengthened (ODS) alloys. The new alloys have shown high temperature capabilities and high strength at nearing 1100ºC. NASA scientists believe this new type of alloy is a critical and enabling material for high temperature capabilities for propulsion and would work well in chemical propulsion (C-003), such as liquid rocket engine propulsion systems, and even aviation engines. At the moment, there are no thermophysical property data for AM parts made with this new type of NASA alloys, thus limiting the design optimization for chemical propulsion components using the state of art AM manufacturing technology and novel alloys. The objective of this application is to fill the knowledge gaps by generating thermal diffusivity, thermal conductivity, specific heat, and density data, and by examining the microstructure evolution at high temperatures for the new alloy AM parts.

23-2023 R3-0012

A lab-on-a-chip platform for bacterial enrichment and single-step RNA purification for rapid screening of spacecraft microbiome (P-004 Lab on Chip)

Louisiana Board Of Regents

Prof. T. Gregory Guzik

Our approach for rapid detection and monitoring of microbial growth in spacecraft environments is focused on the mitigation of adverse pathogen contamination for both crewed Mars missions as well as robotic exploration. We have developed a Gene Sampling Tool for rapid, dry (without liquid), purification of nucleic acid for subsequent genotyping in microgravity. At the core of the gene sampler technology is a gold-plated stainless steel microscopic pin (130µm×3mm) functionalized with synthetic RNA capture sequences for selective purification of bacterial nucleic acid after at least 2 minutes of incubation in the biological specimen. The tool is designed to interface with the Cepheid cycles in orbit and the feasibility of the RNA extraction approach was successfully validated on the International Space Station (ISS) in February 2021 using a radish plant harvested from the APH-02. Building upon this feasibility study results we propose to integrate the Gene Sampling tool with a lab-on-a-chip platform for the selective, aptamer-mediated enrichment of bacterial species followed by on-chip nucleic acid extraction for subsequent genotyping. The microfluidic chip will elegantly interface with the Gene Sampling Tool for dry and selective purification of RNA for subsequent genotyping of the pathogens. In response to identified microbial and health monitoring gaps by the Committee for Space Research (COSTAR), this proposal aims to develop a tool for bacterial enrichment for rapid, selective, and sensitive detection of pathogens in the spacecraft microbiome. One of the crucial obstacles to both human and robotic space exploration is maintaining and monitoring the cleanliness of the spacecraft and instrumentation surfaces. Microgravity increases the risks of microbial proliferation and outbreaks emphasizing the need for rapid pathogen monitoring that eliminates the need for multistep bacterial plating and nucleic acid purification protocols.

Our method offers a one-step nucleic acid purification process that provides faster results and requires less crew time and reduced workspace area. One year of funding is requested to develop a portable platform that does not require large, equipment and eliminates the multistep protocol for additional pre-concentration steps of the bacterial specimen while enabling selective isolation of target bacteria species and genetic analysis. RNA purification and 16S-specific enrichment will be performed using the gene sampler tool for subsequent PCR genotyping experiments. The results of this study will also inform future efforts to integrate the platform with on-chip amplification and gene expression analysis.

23-2023 R3-0014

Quantifying thermophysical, mechanical, and transport properties of regolith-derived materials for in-space manufacturing (B-005 Regolith Materials)

Louisiana Board Of Regents

Prof. T. Gregory Guzik

This proposal is in response to Research Identifier B.005, and specific to the focus areas Studies of the extracted material to determine its properties&" and Investigations to determine manufacturing processes using regolith or materials extracted from regolith..." Of particular importance in the ultimate application of regolith for in-situ resource utilization is to understand fundamental material properties that are not readily available and difficult to measure. These properties are critical to enable hi-fidelity process modeling and development particular to the in-space processes currently in development.

Several methods of additive manufacturing (AM) are currently under investigation for application in micro- and reduced-gravity environments including bound metal deposition (BMD), wire+arc AM, and laser-based fusion methods, all of which include either the generation of a melt pool or surface wetting of the metal alloy feedstock to facilitate generation of the desired geometry. The evolution of the liquid phase, in-turn, is influenced heavily by the gravitational field, with samples undergoing distortion relative to the gravitational environment. An important aspect of the optimization of processes for ISM, independent of the method, is the development of robust models and simulation. ISM models must therefore utilize methods such as phase field that can incorporate field effects like gravity in the evolution of the as-built structure and properties, and capture effects of melting, formation of interfacial phases, and segregation.

This project will build upon recent in-space manufacturing advances by the proposing team to measure thermophysical, thermochemical, and structural properties of alloys derived from regolith simulant, namely Fe-xSi and Al-xSi alloys. Methods for quantifying material properties will include thermophysical properties (melting range, heat capacity, viscosity, density) via electrostatic levitation at MSFC, surface and interfacial energy through sessile drop contact angle measurements, phase evolution through in-situ high temperature XRD, and thermal and electrical transport properties as a function of temperature through PPMS measurements. Based on feedback with the ISM team, experiments will be repeated with optimized compositions and environmental conditions needed for model validation. This work will support the investigation into the applicability of these materials for in-space manufacturing processes, through the comprehensive characterization of feedstock properties, and will facilitate development of a sustainable collaboration conducting future studies directly impacting ISRU and ISM process and simulation improvements.

23-2023 R3-0068

Appendix B (B-004) Transcritical Spray Combustion Under Microgravity Conditions

University Of Mississippi

Dr. Nathan Murray

In launch vehicle rocket engines, the fuel-air mixing occurs under a transcritical state that involves extremely high ambient pressure and temperature. Numerical simulations are often used to design the fuel injection system of rocket systems, and they primarily rely on models derived from laboratory experiments. However, very little is known about the morphological evolution of microscopic droplets before, during, and after their transition from evaporation to diffusive mixing under transcritical conditions. This is because the generation of a thermodynamically controlled environment representing rocket engines in a laboratory setup is challenging. The innovative measurement techniques and experimental setup are essential for developing a fundamental understanding of transcritical spray physics and advancing the accuracy of the numerical models. The proposed research aims to develop phenomenological models to describe the morphology evolution of microscopic droplets under transcritical and zero-gravity conditions. To achieve these objectives, the proposed research will: (1) develop an experimental setup that can reproduce transcritical conditions in a constant volume combustion chamber (CVCC), inject three single-component fuels, and perform high-speed, high-resolution measurements to characterize the transition of fuel droplets from two-phase evaporation to single-phase diffusive mixing, (2) the entire experimental/measurement setup will be sent for drop tower to procure datasets in zero-gravity conditions (test will be performed at NASA Glenn Research Center) and (3) experimental data set will be used to evaluate and advance currently available transcritical fuel-air mixing sub-models using collaborative CFD simulations. The key outcome of this study is enhanced understanding and phenomenological models of the transcritical mixing process and validation datasets for future CFD simulations.

23-2023 R3-0069

Appendix C (C-010) Incremental Learning with Knowledge Distillation for Autonomous Rover Terrain Characterization

University Of Mississippi

Dr. Nathan Murray

Autonomous characterization of terrain is a key technology to enable missions such as the Mars Perseverance and the Lunar Endurance rovers to perform extended autonomous navigation and data collection in hazardous planetary terrain with minimal human intervention. Current state-of-the-art AI/ML models employed to estimate terrain traversability directly from image data are subject to significant power and compute constraints. In addition, ML-trained models frequently suffer from inductive bias due to domain shift when using the same model on data obtained from different time periods and different planetary sites. The objective of this study is to investigate an incremental self-supervised learning network paired with knowledge distillation to achieve efficient and adaptive learning of terrain characterization models. The technical contributions from this study include (i) creating an incremental formulation of contrastive learning to allow a terrain characterization model to adapt to different planetary sites while avoiding the need to completely retrain neural network models (ii) reducing the processing power and physical performance requirements using knowledge distillation techniques, and (iii) deploying a terrain characterization model on a resource-limited mobile platform. Incremental self-supervised learning enables model parameters to be continually updated using incoming unannotated data, while knowledge distillation enables the transfer of learned features from larger "teacher" model architectures to smaller, onboard-ready student" architectures. For algorithm development and validation, this research will make use of publicly available planetary surface image data from the Mars Curiosity and Perseverance rovers as well as the Lunar Yutu-2 rover. In particular, labeled datasets such as the MSL v2.1 classification dataset and the AI4Mars semantic segmentation dataset will be used to benchmark the predictive performance of developed neural network models. These contributions are expected to achieve broader impacts by expanding the paradigm of learning algorithms for autonomous space robotic systems and benefit the greater AI/ML scientific community. The outcomes of this study will include source code, Jupyter notebooks, documentation, datasets, and models for deployment to planetary science and robotics missions.

A pilot study, funded by JPL's Data Science Working Group, has found that contrastive learning schemes are effective at improving performance on downstream vision tasks for Mars rover images. We propose to extend this work by investigating different incremental learning and knowledge distillation techniques and also further benchmark the processing power capabilities & limitations of self-supervised models. We hope to integrate the research outcomes from this project into NASA missions such as the Mars sample return mission and future long-range Mars/Lunar missions through a close collaboration between Dr. Jingdao Chen from Mississippi State University (MSU) and Dr. Edwin Goh, a data scientist, and Deegan Atha, a robotics technologist, from NASA's Jet Propulsion Laboratory (JPL).

Educational impacts from this project include the integration of research outcomes into Dr. Chen's classes in Artificial Intelligence, AI Robotics and Advanced AI Robotics. As faculty advisor for MSU's State Space Robotics Club, Dr. Chen will lead student teams to participate in NASA's Centennial Challenges. NASA rover simulations will be used as demo examples to promote and foster greater participation in science and engineering among K-12 students through programs such as Engineering Discovery Day and Engineering Summer Camp at MSU.

23-2023 R3-0029

Focus area C-010 and C-014: Documenting Current and Projected Capabilities and Societal Ramifications of Autonomous Intelligent Systems

Montana State University, Bozeman

Dr. Angela Des Jardins

The 2023 NASA Rapid Response Research (R3) solicitation calls for exploratory research in ethical and societally aware artificial intelligence (AI) solutions. As noted by IBM, a tech-centric focus that solely revolves around improving the capabilities of an intelligent system doesn't sufficiently consider human needs" (https://www.ibm.com/design/ai/ethics/everyday-ethics/). However, little work has been done in compiling information regarding societal ramifications or ethical concerns of using autonomous decision-making systems. Likewise, the capabilities and limitations of state-of-the-art autonomous systems is not well documented. In this proposal, our multidisciplinary team will perform essential background research in ethical AI systems. Pursuant to the goals of CISTO as stated in the R3 solicitation, we will document our findings, identify key risks and possible mitigations, and propose possible next steps in two important areas. Our research goal for this 1-year R3 project is to prepare review paper manuscripts in two areas of focus: (1) current and projected autonomous performance capabilities and limitations, and (2) societal ramifications of ethical decision-making models.

The first focus area of this research will deal with the technical performance capabilities and limitations of AI systems. We will investigate both ground-based systems and space-based systems, as these types of systems vary greatly in their use cases and computational capabilities. Based on focus area C-010, we will consider autonomous systems' abilities with respect to situational awareness, context assessment, and design characterizations. We will research ethical and computational ramifications of providing autonomous systems with situational or context-based data. We will also document findings of current roles and responsibilities of autonomous systems, and how those roles might evolve. For example, as technology improves to allow for more frequent and accurate decisions, it may be more ethical to allow AI systems to operate completely autonomously rather than simply providing suggestions to human decision makers.

The second focus area of this research will deal with societal ramifications of ethical decision-making models. Based on the focus area C-014, we will consider current methods of including multi-cultural perspectives in algorithm development, as well as current practices (if any) involving the prioritization/ranking/tradeoff between lives and property. We will also consider the evolution of ethical problems that may face fully autonomous AI decision-making systems. As part of our research, we will propose possible next steps for incorporating ethical considerations in the development of artificial intelligence technology.

In summary, our team will draw on expertise in the two relevant fields of machine learning and ethics/philosophy in technology to perform important exploratory research in ethical AI. This research will culminate in the preparation of two literature review journal papers: one outlining current and projected capabilities for autonomous computing, and one outlining current and suggested practices in considering societal ramifications in autonomous computing development. Our combined expertise gives us the ability to effectively study the capabilities, limitations, and social ramifications of current and near-future AI technology. Our research will provide key information to NASA personnel as they work to solidify their framework for the ethical use of AI and develop formal ethics standards for highly automated and autonomous systems.

23-2023 R3-0045

Evaluating climate-wildfire feedbacks and impacts on Arctic-boreal ecosystem dynamics across the ABoVE domain to address NASA EPSCoR Rapid Response Research Earth Science focus areas E-002 & E-004

Montana State University, Bozeman

Dr. Angela Des Jardins

Climate-driven increases in the frequency and extent of wildfire are rapidly altering ecosystems across the Arctic and Boreal Zone (ABZ). Although fire can immediately trigger vegetation mortality and carbon emissions in the ABZ, less clear are the longer-term implications of wildfire for permafrost thaw, vegetation cover, and ecohydrology across this region. We especially lack an understanding of how the trajectory of post-wildfire recovery of these conditions and processes interact with post-wildfire climate and, specifically, climate change. Better understanding these climate-wildfire feedbacks can provide a mechanistic basis for understanding the vulnerability and future persistence of the ABZ terrestrial carbon sink. The goals of this NASA EPSCoR Rapid Research grant are to 1) evaluate the extent, severity, and frequency of fire across the ABoVE domain and 2) determine how fire and post-fire climate control land surface processes (thaw and vegetation reestablishment) following fire. To achieve this goal, we propose to first integrate remote sensing data products to assess 1) climate and landscape (e.g., vegetation and topography) drivers of wildfire extent and severity and 2) quantify the trajectory of post-fire landscape and vegetation recovery or change across the ABZ of western North America. In doing so we will test the hypothesis that the size, severity, and location of fire will interact with climate variables to govern post-fire land surface evolution. We will then develop a hydrological connectivity model to assess how wildfire in the study region influences stream and river function by evaluating how burned landscapes hydrologically connect to aquatic ecosystems. This project will lay the foundation for the development of a larger grant proposal to NASA and will support the training of a postdoctoral researcher. The research addresses the priorities of R3's Earth Science Research focus area by 1) combing multiple data streams to develop insight into climate-vegetation interactions in the face of increasing wildfire in the ABoVE domain and 2) providing data-driven models to test hypotheses and guide future research on coupled terrestrial-aquatic ecosystems in a changing Arctic. Overall, this research will provide an understanding of the vulnerability of the ABZ to climate-driven increases in wildfire.

23-2023 R3-0107

H-007: Miniature Robotic Teleoperation Technology Demonstration during Orbital Spaceflight

University Of Nebraska, Omaha

Dr. Scott Tarry

This proposal outlines a plan to meaningfully enhance a future robotic technology demonstration occurring in-flight aboard the International Space Station (ISS). This project would be part of a larger body of work for an awarded NASA ESPCoR Grant, (NOFO# NNH22ZHA003C). As part of this grant, a new miniaturized robot and camera will be used to execute tasks on Earth under one-g and in space in zero-g for comparison. This robot has been developed with years of NASA support and is now part of a startup company that is in an FDA-approved clinical trial for use in terrestrial applications.

Given exceedingly expensive transportation and use costs, robots for spaceflight must be lightweight, simple, and enabling. This proposal advocates for expanding the scope of the research being conducted during the future ISS flight by including a new key functionality: remote teleoperation. This would allow for non-ideal tasks currently performed by astronauts, for example those in hard-to-access places, to be completed in a robotic manner. For this study, an Earth-based user would control the robot in executing such tasks, including mating cables/connectors, pressing buttons, and flipping toggle switches. This will help determine how robot precision and dexterity is impacted by zero-gravity. The inclusion of teleoperation will allow characterization of the latency involved in near-Earth orbital teleoperation and its impacts to user.

Data collection will be conducted on Earth as well as on the ISS using identical equipment. Finally, key metrics for each environment will be quantified and compared using the data recorded during each experiment, so the impact of zero-gravity can be determined. The system is designed to require little crew time, only installation and removal. The experiment will fit inside an Express Rack Locker and use an ISS Laptop to establish a ground data link to Johnson Space Center (JSC). This demonstration will be the culmination of a years of NASA sponsored projects including terrestrial testing, Zero-G flight testing, and teleoperation between a NASA astronaut at JSC and the University of Nebraska.

23-2023 R3-0030

Research ID: P-003 Development of eutectic electrolyte for low temperature multivalent batteries in support of future NASA planetary science missions

New Mexico State University

Dr. Paulo Oemig

Multivalent metal-ion batteries, specifically aluminum (Al)-ion batteries, offer significant advantages over the state-of-art Li-ion batteries in terms of energy density, safety and manufacturability. Most importantly, multivalent metal-ion batteries are capable of sustaining extreme environment conditions when coupled with appropriate electrodes and electrolytes. The objective of this project is to develop a eutectic electrolyte with substantially reduced freezing point for multivalent Al-ion batteries to enhance the scope and ambition of future NASA planetary science missions. Batteries, which are needed to power aerobot, must be able to operate under extreme temperature and pressure. Our research efforts seek to develop new battery concepts for space applications by combining a high-energy-density Al metal anode with a ternary phase eutectic electrolytes that exhibits significantly larger temperature windows and lower vapor pressures compared to conventional organic liquid electrolytes. Eutectic electrolytes are molten salt ionic liquids (IL) with melting points below 100 °C, exhibiting significantly larger temperature and electrochemical stability windows. We propose a ternary phase eutectic electrolyte to further reduce the melting point to room temperature (25 °C). The proposed electrolyte is composed of binary phase eutectic compositions of two different imidazolium chlorides ([ImCl]s), followed by the addition of a Lewis Acid i.e. AlCl3. The strategy is to form a binary eutectic phase between the two [ImCl]s at first, to achieve significantly lower freezing point (Tf d 40 °C) and low vapor pressure (at T d 125 °C) than the conventional IL-based electrolytes. The presence of two intermolecular interactions (Van der Waals and Lewis acid-base interactions) renders lower Tf, offering a wider liquid range for faster diffusion of chloroaluminate-ions across the electrodes at sub-zero temperatures. Given the high chemical stability of IL at high temperature, it is apparent that the ternary eutectic electrolytes accompany with a faster kinetics, and meanwhile, maintain a stable solid-electrolyte interface. We will collaborate with Dr. James J. Wu and bring Al-ion coin-cells optimized at 25 °C in our lab to NASA Glenn Research Center to evaluate the performance at the extreme environment conditions.

Our goal is to develop new multivalent battery concepts tailored specifically to NASA mission objectives based on a multivalent metal anode i.e. Al, coupled with a graphite cathode and the proposed ternary phase eutectic electrolyte. The proposed eutectic electrolyte is environmentally benign, yielding high ionic conductivity capable of retaining liquid phase in a wider liquid temperature range (-40 °C d T d 120 °C). Al metal anode is anticipated to yield longevity at high temperature of 120 °C, which appropriately suits for the mission of extreme environment aerobot. Graphite cathode, withstands intercalation/de-intercalation of ions at wide temperature ranges, being an asset to the extreme environmental energy storage devices. Through identification of key structure-composition-property relationships of the ternary phase, eutectic electrolytes appropriate for the extreme environment expected in space will be developed. The electrochemical behavior of relevant Al-ion batteries will be studied in ternary eutectic electrolytes, providing fundamental insights for the application of the electrolytes in novel batteries that can power aerobot at extreme environment conditions. Successful completion of the proposed research will not only advance our understanding of developing novel electrolyte for all climate Al-ion batteries, but also offer an important strategy for powering aerobot for future NASA Venus exploration mission.

23-2023 R3-0034

Research ID A-007: Optimization of SQUID array amplifiers for liteBIRD

New Mexico State University

Dr. Paulo Oemig

We propose to develop Superconducting Quantum Interference Device (SQUID) Array Amplifiers meeting the requirements of the JAXA LiteBIRD space mission. This project is responsive to NASA's identified Tier-4 2022 Astrophysics Strategic Technology Gap Advanced Millimeter-Wave Focal-Plane Arrays for CMB Polarimetry," which specifically mentions LiteBIRD.

LiteBIRD will measure B-mode polarization of the Cosmic Microwave Background (CMB) from its planned location at the Sun-Earth L2 Lagrange point. B-mode polarimetry of the CMB is of high importance as 1) detection of B-mode polarization in the CMB and hence a gravitational wave background would reveal the energy scale of inflation, 2) stringent upper limits on B-modes would strongly reduce the allowed variety of models of inflation, and 3) excellent measurements of B-modes due to lensing would afford unique determination of neutrino masses.

SQUID Array Amplifiers (SAAs) are a key component of the Digital Frequency Multiplexing used to read out LiteBIRD's superconducting detectors. For optimal performance the SAAs must be located on LiteBIRD's 100 mK focal plane stage, as close as possible to the detectors. This novel location creates an unusual and stringent set of requirements for the SAAs, and at present there is no available or planned SAA meeting all requirements for LiteBIRD.

This 1-year NASA project proposes to develop SAA designs meeting LiteBIRD requirements through a program of analysis, modeling, and simulation. The project will also participate in the testing and evaluation of the developed SAAs, which will be micro-fabricated by a separate project under JAXA funding. The project goal is to demonstrate an SAA design at TRL 4 that meets all LiteBIRD requirements.

23-2023 R3-0035

Research ID A-007: Characterization and mechanical testing of segmented and bonded monocrystalline Si optics for the next generation x-ray space telescopes

New Mexico State University

Dr. Paulo Oemig

The detection of cosmic X-rays fills a crucial piece in the full exploration of the Universe. To extend science frontiers, future X-ray space observatories need to push for higher performance in all areas including high angular resolution, large field of view and large effective area.[1] For instance, Lynx, a flagship mission funded for study by NASA under consideration for the 2020 Astrophysics Decadal Survey, consists of a large number (~42,700 pieces) of densely-packed, grazing-incidence, thin-shell mirrors (~0.5-4mm thickness) to achieve the ~30x larger collecting area while maintaining the same 0.5 arcsecond HPD resolution as its predecessor the Chandra Xray telescope.[2, 3] This challenge require expansion of technical capabilities by orders of magnitude beyond the current state-of-the-art, especially in the key technologies for X-ray mirrors.

One promising mirror technology to meet the requirements is the Silicon Metashell Optics Technology" [4~6], which is a lightweight, high resolution, low-cost X-ray optics made of single crystal silicon. The fabrication of such optics involves grinding and polishing monocrystalline silicon blocks with precision machining tools and chemicals, followed by cutting and ion-beam polishing to obtain the sub-millimeter-thick Si mirror substrates. The individual mirror segments are then aligned and bonded at four locations by layering on top of one another to create a module. This technology is currently developed by a research team at NASA Goddard Spaceflight Center (GSFC). This is a challenging task and one of the unresolved problems is whether the mechanical strength (static and kinematic) of the segmented and bonded monocrystalline Si optics, as well as the structural integrity, can survive the vibrations during flight launch and meet the spaceflight environment requirements over the designed life of span. Some strength testing has been done on single piece flat Si wafers [7] and bonding adhesives separately, but no similar work has been conducted on curved Si optics. In addition, the robustness and bonding strength of the two-pair modules remains in question.

If the resolution requirement, along with the strength, reliability, and robustness of the silicon metashell optics can be established, this technology can greatly enable future explorer missions, not just limited to large missions like Lynx but also to other smaller and mid-sized missions, such as STAR-X (Survey and Time-domain Astrophysical Research eXplorer), a NASA MIDEX Explorers Program mission funded for detailed study in 2021. STAR-X will cover simultaneous X-ray and UV survey to complement optical, infrared, and gravitational wave facilities to rapidly respond to transient events, and it is planning to utilize the silicon metashell optics technology for X-ray observations as well. [8]

To enable the silicon metashell optics that is crucial to the future mission success, this research project proposes to conduct a systematic mechanical testing and numerical simulations to measure the mechanical properties and characterize the reliability of the monocrystalline silicon optics both the segmented mirrors and two-pair modules (two mirrors bonded to each other). We hope to answer the question about whether the mechanical strength of the monocrystalline silicon optics, as well as the structural integrity of the modules, can survive the flight launch environment and meet the spaceflight requirements over the designed life span.

23-2023 R3-0077

P-005: Demonstrating Desert Lichens' Extreme Resistance to UVC

Nevada System of Higher Education

Dr. Eric Wilcox

Colonial cyanobacteria, cyanolichens, and algal lichens thrive in extreme deserts despite exposure to UVA and UVB. All three organisms possess aromatic, broad-spectrum UV-screening pigments in the surface of their thallus that dissipates the energy from absorbed UV photons while suppressing the photochemical formation of reactive oxygen species such as singlet. A recently funded Habitable Worlds project, now in its final year, showed that desert cyanobacteria and lichens that grow on top of soils are also resistant to UVC. They can be irradiated by a germicidal 254 nm UVC lamp ten times the UVC flux on Mars for weeks without losing viability. This RRR proposal will take advantage of the developed methods/approaches, the know-how, and the team to extend the observation to rock-inhabiting crustose lichens. Specifically, three cyanolichens and three algal lichens will be irradiated for various durations and assessed for ability to restore photosynthetic activity using the non-contact non-destructive pulse-amplitude-amplified chlorophyll fluorometry and assessed for photobiont viability by culturing. The studied lichens will be identified by sequencing of 16S or 18 rRNA genes in photobionts and mycobionts. The proposed research will identify two groups of microorganisms (lichens are symbiotic associations of two microorganisms, a fungus and a cyanobacterium or microalga) that have the capacity to grow on Mars, if inadvertently brought there by a spacecraft, a possibility which, as far as we know, is unknown to NASA.

23-2023 R3-0032

Certification, Validation, and Safe Integration of Turboelectric Aircraft Distributed Power and Propulsion Systems

Oklahoma State University

Dr. Andrew Arena

The proposed research directly supports standards development that NASA researchers are taking part in under the on-going Revolutionary Vertical Lift Technology (RVLT) Project. Aircraft concepts studied under the RVLT project feature distributed electric propulsion systems. Energy density limitations of current battery technology requires a hybrid power system to enable practical use of these emerging Urban Air Mobility (UAM) vehicles for much of the proposed mission sets. The aerospace community is working to create standards for safe and reliable permanent magnet driven electric engines and the associated power quality requirements from the source/rectifier.

Higher duty cycle operations on UAM powertrains, in comparison to ground-based generator applications, has motivated NASA researchers to develop experimental test rigs to study the high-voltage electrical dynamics and power quality between a generator and electric motor to support aerospace standards development. The NASA Glenn test stand utilizes an emulated source and inverter for the present experiments. The proposed work herein aims to support the on-going testing at NASA Glenn by utilizing the Oklahoma State University (OSU) turbo-electric test asset. The OSU ground test asset features a 180kW PBS Aerospace TP100 turboprop mounted on a Cessna 172 frame via a custom engine mount. Electrical power is extracted by a generator driven off of the low-pressure spool of the turbine, sent through an inverter, and passed to electric motors spinning fixed pitch propellers on the wing.

To directly support the NASA Glenn investigations, this program outfits the turbo-electric Cessna with a nearly identical generator and electric motor arrangement. Rather than using emulated source power, we will extract power from our turbine to enable end-to-end electrical dynamics testing. The results will be complementary to the NASA test rig and add value from the standpoint of generating similar results with a full set of hardware packaged into an airframe to force airframe integration considerations.

23-2023 R3-0054

NASA EPSCoR Rapid Response Research: Graph Based Deep Learning Architecture for Modeling Ecosystem Dynamics Integrating Hyperspectral and Remote Sensing Data Over the Alaskan Boreal Region

University Of Puerto Rico, San Juan

Dr. Gerardo Morell

The goal of this proposal is to characterize the ecosystem dynamics in the Tundra and Boreal from hyperspectral images, field observations, and remote sensing data using deep learning models for endmember extraction, and unmixing. Warming temperatures due to climate change has impacted this region more than any other resulting in ecosystem level responses, such as shift in vegetation, decreases in sea ice and thawing of permafrost, changing the landscape at a rapid pace. While plenty of remote sensing data, maps, and field observations are available for this region, artificial intelligence tools are yet to be explored for integrating multidimensional climate indicators from different sources in a unified manner for assessment of impact of warming temperatures on ecosystem and land cover. In this project, we will develop an unsupervised autoencoder deep learning architecture for estimating fractional abundances of land covers per pixel in the hyperspectral images, and a semi-supervised land cover labeling method for generating land cover labels, which will be transferred to multispectral images for generating land cover change maps, followed by a graph based deep learning neural network to model ecosystem dynamics.

The objectives for this NASA Rapid Response project are:

1) Perform spectral unmixing and land cover labeling of AVIRIS-NG hyperspectral images collected over the Alaska boreal and tundra region using deep learning networks; Fractional abundance mapping will be transferred to multispectral Sentinel datasets for land cover change estimation.

2) Integrate remote sensing data derived climate indicators, and land cover change maps using graph representations for graph neural network-based prediction of biophysical effects of land cover change in the boreal and tundra regions of Alaska.

Hyperspectral images (HSI) from AVIRIS-NG will be resolution enhanced and combined with field data for estimation of fractional endmember abundances, which will be input to a semi-supervised deep learning architecture for land cover label assignment. The HSI based label assignment will be transferred to multispectral Sentinel images. A data driven graph representation will be developed from multi-source remote sensing derived climate indicators: land surface temperature, albedo, evapotranspiration, gross primary product, and Land Use Land Cover Change (LULCC) maps for training a Graph Neural Network (GNN). The GNN will be trained with attention learning and used for predicting temperature. Thus, this project will combine three power tools of remote sensing, graphs, and deep learning to extract and integrate information from the extensive remote sensing data available over the Arctic tundra and boreal region for knowledge discovery on the biophysical effects of land cover change. This project is conducted in a Hispanic minority serving institution with 99% Hispanic students who will gain knowledge in the fields of satellite remote sensing, multispectral and hyperspectral image processing and Python tool development. This project will directly support two graduate students in Earth science research, and involve many undergraduate students through course work and workshops.

The PI will use the material from this project in the remote sensing, machine learning, and image processing courses taught at ECE, UPRM. The students will be exposed to NASA Earth science related research. This project will also enable Hispanic minority students to take up internships with NASA, and add to the workforce development for future NASA missions. It will enable future opportunities for internships between UPRM and UTEP which is also a predominantly Hispanic minority university.

23-2023 R3-0055

NASA EPSCoR Rapid Response Research: Improvements on low-density parity-check (LDPC) codes and high-performance neuromorphic engineering for communication systems

University Of Puerto Rico, San Juan

Dr. Gerardo Morell

Overview: This one-year proposal plan is a research, educational and outreach plan between the Mathematics and Physics faculties at the University of Puerto Rico-Cayey (UPR-Cayey), in collaboration with other UPR campuses (Humacao and Ponce). This plan proposes collaboration research in NASA-related issues (This project is aligned with NASA strategic goals appendix F: GSFC Computational and Information Sciences and Technology Office; a) Artificial Intelligence and Machine Learning and b) High Performance Computing) and the implementation of several science, computational and experimental activities for courses such as Discrete Mathematics, Coding Theory, Cryptography (Mathematics) and Electronics, Materials Science and Quantum Mechanics (Physics).

The main objectives are:

1. Enrich the existing mathematics research line in Communication Systems (Coding Theory, Cryptography) and physics research in ferroelectric tunnel junction devices (resistive random-access memory) at the UPR-Cayey, as well as initiate new collaborations with other small UPR campuses (Humacao and Ponce).

2. Implement theoretical-computational-experimental activities for courses in mathematics and physics of the Mathematics and Physics department of UPR-Cayey.

3. Incorporate undergraduate students to gain experience in these research topics.

The goals of this proposal are:

4. Establish the basis of this research on software/hardware results on NASA-related communication systems as the first step for future research, future collaborations, and new proposals.

5. Implement a novel educational plan in mathematics and physics about digital communication systems (theoretical, computational and experimental) with the purpose of motivating, exposing and involving undergraduate students of PR in the study of mathematics, physics and other STEM careers.

Intellectual merit: In this theoretical, computational, and experimental project, we propose to analyze and test new tools that improve the encoding or decoding algorithms of LDPC codes, the most important codes relevant to NASA. These includes algebraic, geometric, and combinatorial tools that will imply improvements on these codes, or the constructions of new LDPC codes. We also propose to study the effect of tunnel electroresistance and magnetoresistance in ferroelectric tunnels and multiferroic junctions respectively. In such tunnel junctions, the quantum tunneling mechanism occurs, which can generate zeros and ones to achieve a neuromorphic computer.

Broader impacts: This research will contribute to one of the crucial challenges of NASA, the improvement of current communication systems, in software and hardware, for deep space exploration and other NASA missions. This project will have great impact on the society by maintaining scientific progress towards multifunctionality and miniaturization of devices in communications technology and will consolidate interdisciplinary collaboration research on math, physics, computer science, and probably others discipline in more UPR campuses on behalf of the faculty, the students and NASA itself. Women and underrepresented undergraduate students will gain a broad-spectrum of experience with nanotechnology issues, tools, and trends while learning advanced thin film physics techniques, so that they can apply their versatile skills in the real world. The educational plan will involve science/experimental techniques through current research and interdisciplinary courses on topics related to this project to show up a new attractive relevance of STEM careers.

23-2023 R3-0075

C-005: Improving Space Solar Specific Power through Tailored Photon-Concentrating Devices

Brown University

Dr. Ralph Milliken

Space Solar Power Station (SSPS) is a grand idea to build a large solar power station on Earth's orbit and transmit electricity to the surface ground wirelessly. It has proven to be a new way of utilization of solar energy harvested from space. Generally, the ideal energy capacity of the SSPS is around 1-10 GW. To construct the proposed SSPS, creating effective photon- panels for large-scale construction in space is one of the significant challenges that need to be overcome. For this consideration, specific power -- defined as the power produced per mass of the solar harvesting system is a key term for the space proposed solar harvesting system. Recently, the thin film photovoltaic (PV) system for space applications could reach the highest specific power of around 3 kW/kg. However, by applying solar concentration techniques, there is still a great potential to further enhance the specific power of the solar harvesting system. In this context, luminescent solar concentrators (LSCs) have already shown their potential application with theoretical predicted specific power reach beyond 80kW/kg for the single junction case. LSC, a photo wave-guiding device that can efficiently collect, guide, and concentrate the solar light energy to the targeted areas. An LSC consists of a slab of transparent materials, for example, ultralight polymer materials, embedded with highly emissive fluorophores. Following absorbing solar light taking advantage of the large surface area of the LSC, the embedded fluorophores emit photons at a lower energy, then guided by total internal reflection and concentrated to the LSC device edges, where the photons are collected by attached PVs to produce on-site power. The coupled PV-LSC system can significantly reduce the total utilization of PV panels, minimize the weight of the overall construct (thus, increase specific power), and simplify the design and fabrication of large-scale solar harvesting devices. Currently, two major events dramatically decrease the solar light concentrating efficiency: (1) Photon loss due to the escape cone defined by Snell's law; (2) Re-absorption loss induced by overlap of absorption and emission profiles of the fluorophores. In this proposed project, we will overcome these two limiting factors by designing a new generation of quantum emitter-based LSCs with no/minimal photon loss, which are suitable for large-scale LSC-PV integrations for SSPS with the goal of improving the space solar specific power beyond the state-of-the-art. Specifically, I will achieve the following two aims through both experimental studies and theoretical calculations/simulations during this grant period: (1) design and fabrication of LSCs with Bragg reflectors to minimize the escape cone photon loss; (2) optimization and fabrication of LSCs using Stokes-shift-engineered quantum-emitters to eliminate re-absorption energy loss.

The proposed project aligns with the research focus area of Improvements to Space Solar Power State of Art (SoA)" (Research Identifier: C-005). In addition, the proposed study demonstrates direct relevance to multiple priorities identified by the NASA Mission Directorates. Through the advances in information of this project, it is possible to create flexible nano-polymer composites allowing for stretching and flexibility, while giving the material a suitable optical and optoelectronic properties, which can be used for powering or engineering soft robotics. This area is directly beneficial to HEOMD) and SMD. Moreover, the knowledge gained for the engineering of fluorescent quantum emitters and photon management of the nano-assemblies can result in the next generation LSCs integrable in various settings beyond space/satellite uses. This study is also directly in line with the goals of ARMD for reducing aircraft fuel consumption and emission, and creating safer, greener and more effective travel.

23-2023 R3-0076

B-001: Multiphoton entangled state and plasmonic mediation

Brown University

Dr. Ralph Milliken

The project explores the feasibility of multiphoton entangled state mediated by plasmon quanta. The study of interaction of multiple pairs of photons with quanta of surface plasmon polariton (SPP) builds on a novel high efficiency source of entangled photons that is currently being developed in our laboratory. It is based on the spontaneous parametric down-conversion (SPDC) effect in an organic nonlinear optic material 4-N, N-dimethylamino-4'-N'-methyl-stilbazolium tosylate (DAST). It is well known for its exceptionally strong optical nonlinearity over a broad band from THz to the near infrared range. Our recent findings suggest that the SPDC process could be further enhanced in strained thin film. The proposed research extends the investigation to a system combining DAST with a plasmonic metasurface made of a gold film perforated with an array of subwavelength holes. The excitation of SPP resonances in the gold film by the incident laser light (pump) gives rise to intensified field thereby the enhancement of the SPDC yield. At the same time, the metasurface acts as a diffraction grating, enabling a more efficient generation and collection of the generated infrared entangled photons, their separation from the pump light, and helps heat removal in the nonlinear optical material that may lead to its bleaching and degradation.

Besides maximizing the entangled photon yield, this composite nonlinear optical system will provide us with a novel toolkit with which we can explore the fundamental nature of multiphoton entanglement. It enables explorations of new degrees of freedom that have been probed very little in the context of generation of multi entangled photon pairs and their coupling to plasmon quanta, reradiation, and entanglement. Especially when the critical features of the metasurface (i.e., hole diameter, periodicity, thickness, and separation between the film and DAST) are reduced to subwavelength, the system enters the regime of extraordinary optical transmission (EOT). In this regime, either the incident pump photons, or the generated entangled photon pairs couple resonantly to the SPP excitations in the gold film and then reradiate in the free space on the opposite side of the metal. EOT effect is well-known to produce a greatly enhanced transmission via collective excitation of the SPP mode distributed over the front surface and coupling to that on the back surface via the subwavelength holes. At the level of single quanta, prior studies have shown that the entanglement of the transmitted photons can be retained via entangled plasmons.

Interesting new questions can arise in such a system, especially in the EOT regime. We propose to pursue these questions in two of the possible experimental configurations that we plan to study. With pump light incident on the EOT mask first, entangled photon pairs are generated in the DAST crystal, but the path information is destroyed. However, the reverse configuration is also possible, where pump light is first incident on the crystal and the resulting entangled photon pairs pass through the EOT mask. In this configuration, the fascinating plasmon relay" mechanism comes into play, whereby entanglement generated before the mask may be preserved by the SPP waves generated on the mask, and then reradiated into free space.

If successful, the study will help improve the efficiency and the yield of the entangled photon source, provide new insight on the photon plasmon quantum interaction and on the mechanisms that induce, destroy, or preserve their entanglement. It may become possible to create the entanglement between a larger number of photons and plasmons.

23-2023 R3-0016

"A-006 Characterization of Composite Material Properties for the LS-DYNA MAT213 Model"

College of Charleston

Dr. Cassandra Runyon

Carbon fiber reinforced polymer matrix composite materials are widely used in aerospace structural applications such as fuselage and engine containment systems where impact resistance is important. MAT213 is a combined plasticity and damage material model developed by NASA to simulate the impact response of composites. The MAT213 model requires several key parameters as input that are difficult to obtain via standard testing techniques. To address this issue, the investigators propose development of a digital image correlation (DIC)-based experimental methodology to accurately characterize composite material parameters for MAT213. Specifically, the proposed approach will be used to characterize the plasticity flow rule coefficients and the post-peak stress degradation response of composite materials for implementation LS-DYNA MAT213. Since the flow rule coefficients in MAT213 are expressed as a function of the plastic Poisson's ratios (PPRs), these properties will be quantified by performing a series of quasi-static experiments in different loading directions (1-, 2- and 12/21-shear directions) using composite materials supplied by NASA. To determine the PPRs, the evolution of full-field total strains during these experiments will be measured via stereo DIC (StereoDIC) and combined with known fundamental elastic properties in different directions to determine the plastic strains via additive decomposition of the strain tensor and compute the PPRs. The PPR values then will be used to calculate the flow rule coefficients for MAT213. To characterize the post-peak stress degradation response under dynamic loading conditions, a series of dynamic compression experiments with ultrahigh-speed cameras/StereoDIC will be performed along the in-plane and through-thickness directions with a split Hopkinson compression bar. The average stress at each time will be measured via strain gage signals and the full-field total strain at each time will be measured via StereoDIC to obtain the stress-strain and post-peak stress degradation response.

23-2023 R3-0017

C-013: Construction of Ethical Artificial Intelligence Systems

College of Charleston

Dr. Cassandra Runyon

Requirement engineering is an important phase in software development lifecycle. In the development of artificial intelligence (AI) systems, requirements engineering is not clearly defined. The requirements phase for construction of AI systems depends on data, data models, model calibration. data analysis and feature extraction. In this work, we propose a novel methodology for evaluating requirements for the construction of ethical AI System. We will create a formalism that leverages on formal verification of requirement specifications that represents decisions of AI systems and incorporates uncertainty in the decision-making process. A prototype will be created to evaluate the correctness of the ethical properties of an AI system. The goal is the evaluate ethical decision making by an AI system.

AI systems are becoming ubiquitous. Construction of ethical AI systems requires the capabilities, and the roles of human-system interaction requires fulfilment of the ethical guidelines. The decision-making processes under the certain complex situations, dilemmas are very complex because often the definitions are not clear regards to the preferences of selecting an action from a set of actions. The situations are also uncertain. Therefore, there is a need to incorporate uncertainty in modeling of decision-making process and represent them using a probabilistic model. Quantification of error in the decision-making process is critical in estimation of the actions that should not be executed by the AI system. One of the formal verification techniques, model checking has been used in the software verification of avionics and chip design system. In the evaluation of the decision-making process for an ethical AI system, model checking can identify the actions that are permissible or non-permissible.

The abstraction of an AI system is constructed and called a model, M. The specification expected to be valid in the model, M is represented in the form of temporal logic formula, Õ. The formula is then posed as a query to the model, M for verification. In this work, probabilistic temporal logic formula. If the formula is true in the model with a probability, the model fulfils the specification. The feedback from model checking is useful to the developer to make changes for fulfillment of the ethical properties.

The aims of this work are

1. Construct of model abstraction for responsible action by an ethical AI system.

2. Evaluate the results through counterexamples during verification and provide the feedback to the developer the changes needed to make in the construction of the AI systems. In particular, the process in which ethical dilemmas are addressed by AI systems.

3. Evaluate the proposed formalism on a prototype of unmanned aerial vehicles under uncertain environments.

The work will provide enriching research experience to two undergraduate students from underrepresented communities in computing. The students will tour with the investigator in NASA Langley and hopefully, envision a career in NASA. The recruitment of computing major from underrepresented community aligns with the mission of South Carolina Epscor program. The project will be carried out with active collaborations from personnel from NASA Langley, in artificial intelligence and ethics. The research is expected to contribute cutting-edge technologies in computing and creating a pathway from theory to practice of AI systems.

23-2023 R3-0019

"H-003: Development of Screening Methodologies to Quantify Radioprotection of DNA from HZE Ion Damage"

College of Charleston

Dr. Cassandra Runyon

Since spacecraft shielding is inadequate for protection against irradiation from solar wind and galactic cosmic rays (GCRs), early and sustained effort is required to enable extended-duration astronaut radioprotection in high-Earth orbit and beyond. Attempts to quantify GCR damage typically focus on cell death to predict short-term impacts on cognitive and musculo¬skeletal functioning. Extreme DNA damage is responsible for cell death, but moderate DNA damage may better predict long-term health effects such as carcinogenesis. Therefore, we propose to develop a moderate-throughput technique for quantifying DNA damage from HZE Si and Fe ions. We will then use this methodology to screen known and potential radioprotectants and antioxidants for 1) their reactivity upon irradiation with HZE ions and 2) their ability to prevent HZE-ion-mediated DNA damage. Because hydroxyl radical is the primary DNA-damaging species for HZE ion irradiation, we will then correlate radioprotectant/antioxidant ability to prevent HZE-ion-mediated DNA damage with their ability to prevent DNA damage from Fe(II)/hydrogen peroxide, a non-radiative method for generating damaging hydroxyl radical. Results from both DNA damaging methods will then be compared to validate this screening methodology for known and potential radioprotectants. This work will provide the foundation for high-throughput assessment of radioprotectant/antioxidant compound libraries as well as for rational development of novel radioprotectants.
This proposed work is relevant to NASA research objectives, since developing methods to identify promising radioprotectants that prevent DNA damage from GCR components will accelerate their development and approval for astronaut radiation protection, a necessary accomplishment to enable long-duration spaceflight. In addition, the proposed project will help build a robust research pipeline to the superior but less-accessible facilities at the NASA Space Radiation Laboratory. Beyond space travel, GCR exposure is a health risk for military and commercial aviation that impacts thousands of crew members annually, especially in increasingly trafficked polar areas. Highly charged ions, as proton- and carbon-beam therapies, are on the cutting edge of cancer treatment. Improved understanding of their potential for killing cancer cells and development of radioprotectants to minimize radiation damage to healthy tissues would potentially impact millions of cancer patients annually.

23-2023 R3-0049

Commercial Space Capabilities, Research Focus Area: In-Space Welding (Research Identifier C-002)

South Dakota School Of Mines & Technology

Dr. Edward Duke

The development of advanced in-space welding technologies is becoming increasingly important to support the Commercial Low Earth Orbit Development Program of NASA's Space Operations Mission Directorate. The South Dakota School of Mines and Technology proposes to conduct research that advances the state-of-the-art and increases knowledge to support in-space welding to revolutionize how orbiting platforms are designed, manufactured, and assembled. When applied to in-space welding, traditional fusion-based welding processes often suffer from challenges associated with melting, solidification, and control of the melt pool in microgravity. Moreover, fusion welding of aerospace-grade aluminum, in particular, is difficult due to the material's high thermal conductivity, substantial laser reflectivity (for laser welding), and problems associated with molten droplet control and separation in microgravity.

To overcome these challenges, the proposed work aims to study the feasibility of solid-state laser-assisted friction stir welding (LFSW) of aluminum using self-reacting tools (SRT) for in-space welding. A Nd-YAG laser will be used to preheat the workpiece ahead of the FSW tool to reduce the torque needed to plasticize the material from frictional heating alone. Thus, LFSW is hypothesized to substantially lower forging loads and torque compared to the conventional FSW. Similarly, the use of a self-reacting tool (SRT) will eliminate the need for anvil support, while simultaneously reducing required process loads, limiting defects (e.g., root defects and lack of penetration), and improving mechanical properties. The overarching objective is to develop FSW processing conditions that are suitable for the production of portable, robotically actuated, FSW systems that can be used for in-space welding. An experimental plan has been designed to optimize processing parameters and to reduce forging loads (vertical axial force of 0 N, traverse force of 100 N, lateral force of 300 N and torques of 10 Nm) for aluminum alloys. Ultimately, the relationship between laser preheating, in combination with the use of SRTs, and the microstructure and mechanical behavior of aerospace-grade aluminum FSW will be established. The results from this study will be critical for future development of suitable FSW systems for in-space welding and repair applications. The technology would have the potential to (i) fabricate very large structures in space, which are too bulky or heavy to bring to space in one piece, or (ii) repair damaged components where shipping a new component may be too costly or time-consuming.

23-2023 R3-0021

P-003: OrBNaV - Orbiter-assisted Balloon Navigation for Venus Exploration

West Virginia University

Dr. Melanie Page

Scientific exploration of Earth-like planetary bodies such as Venus, provides data critical to understanding fundamental knowledge about Earth's formation and habitability change over time. To accurately geotag instrumentation data with respect to a known global reference frame and enable an autonomous robotic exploration on Venus, new localization and guidance, navigation, and control (GN&C) algorithms need to be developed. This research proposal responds to this critical need and proposes a new GN&C concept, called Orbiter-assisted Balloon Navigation (OrBNaV), for Venus's exploration involving two heterogeneous agents: a variable-altitude balloon and an orbiter. The localization of the balloon will be based on an onboard radar altimeter for terrain matching, assisted by periodic ranging measurements between the balloon and the spacecraft orbiting the planet. The latitude control of the balloon will rely on tracking, using sensors mounted on the vehicle and previous models obtained by science probes, the strong winds of the planet by changing its altitude. Furthermore, we will develop an integrated motion planning and localization tradespace analysis framework based on Monte Carlo simulation and multi-objective optimization methods to design feasible and balanced OrBNaV architectures. Sensitivity analyses will be conducted to identify a set of key OrBNaV parameters and characterize uncertainties associated with the developed models and algorithms.

23-2023 R3-0040

B-007: Studying plant-microbe interactions using the cyanobacteria Arthrospira Platensis: the effects of growth in low gravity, simulated Lunar/Martian regolith, and high CO2 concentration environments

West Virginia University

Dr. Melanie Page

Our study will evaluate the efficacy of the use of Arthrospira Platensis, or Hawaiian Spirulina®, a blue-green cyanobacteria, to enhance the growth of microgreens using simulated Lunar and Martian regolith from Exolith Labs. We will analyze growth rates over a range of five regolith-soil mixtures using four different concentrations of Spirulina. We will evaluate growth in environments with increased levels of CO2 by performing the study using the Inflatable Lunar/Mars Analog Habitat (ILMAH) and the San Francisco Plant Laboratory (SFPL), and in low gravity using a 3D clinostat. This study will support NASA long term objectives for in-situ resource utilization (ISRU) in space exploration and applies directly in the area of Biological and Physical Sciences (BPS), under the research focus area: Effects of Space-Associated Stressors on Plant and Microbial Interactions (research identifier B-007).

ISRU is key for the success of long-term space exploration and settlement. Growth substrates are necessary to promote healthy plant growth using in-situ regolith, which is not nutritive, in the high CO2 environments of confined space habitats and the low gravity of the Moon/Mars. Bio-regeneration using algae is a promising avenue for supporting plant growth with ISRU as it can potentially mitigate the lack of nutrients, alkalinity, heavy-metal contamination, poor water-carrying capacity, and presence of perchlorates in regolith as well as increase plant growth at high levels of atmospheric CO2. The cyanobacteria Arthrospira Platensis, or Hawaiian Spirulina®, is an exceptional candidate for ISRU space environments due to its temperature and radiation resistance, nutritional properties, pharmaceutical applications, and ability to reclaim wastewater. It is a promising bio-fertilizer which has been shown to improve plant growth and nutritional levels even in heavy metal contaminated, highly alkaline terrestrial soils.

This study will measure the growth of Raphanus sativus (Organic Daikon radish) microgreens for both lunar/Martian regolith-soil mixtures of 0/100, 20/80, 50/50, 80/20, and 100/0 percent by mass. The different mixtures will be tested with/without additions of 1 g, 5 g, 10 g, and 25 g of Spirulina, each per 500 ml of lab grade DI water. Each study will be performed at both atmospheric levels of CO2 and high (3 mm Hg) levels of CO2; the high CO2 mixtures will be tested at ILMAH. Both high and low atmospheric CO2 studies as well as a 1/3rd gravity study will be performed at SFPL. Ten trials will be performed for each mixture. In each case, growth rates will be measured as a function of time and plant/root health will be evaluated by measuring plant height, color, chlorophyll content, leaf count, root length, fresh and dry weight, and root nodule/cap development. The plants will also be monitored continuously by video. Temperature, CO2, soil moisture, soil pH, light duration, and humidity will be recorded daily. Adjustable LED grow lights will be used, and wavelength and intensity recorded. Samples from select groups grown in regolith will be sent to Test America for analysis of iron oxide (FeO) uptake.

Use of the ILMAH facility is critical because it closely mimics the closed environments in space exploration, allowing evaluation of plant growth in an authentic, high CO2 environment. It provides a 1g baseline for future studies with non-terrestrial gravity as well as development of protocols for plant growth incorporating bioremediation techniques. The SFPL studies allow for direct comparison between growth in a controlled laboratory and an enclosed analog habitat. The SFPL also allows comparison with growth at non-terrestrial gravity using a 3D RPM clinostat.

Based on our previous pilot study, we anticipate the experimental groups will demonstrate growth similar to the controls, indicating the use of Hawaiian Spirulina® can effectively remediate space stressors and support healthy plant growth.

23-2023 R3-0038

7.6 NASA SMD Computational and Information Sciences and Technology Office (CISTO) C-010: Lyapunov Assured Trustworthy Multi-agent Reinforcement Learning for Large-scale UAV Decision-making Against Cyberattacks

University Of Wyoming

Dr. Shawna McBride

Background: The Unmanned Aerial Vehicles (UAV) have played a major role in searching and rescuing human on the terrain that is hard for human access. For larger and more complicated areas, the cooperation of a team of UAVs rather than a single agent is often required. The emerging of multi-agent reinforcement learning and game theory provide an elegant solution for solving the optimal group policies. However, this AI approach has brought in new legal challenges caused by cyber vulnerability in its complicated training process. The security concerns have become the key ethical limitations in the UAVs' decision-making problems especially for missions that have strong interaction with human directly, e.g., the search and rescue mission.

Proposed research: In a regular multi-agent UAV system, the agents are coordinated by decision-making algorithms such as the multi-agent reinforcement learning algorithm. However, the learning and execution process is vulnerable to cyber attacks coming from spy agents. A spy agent acts like a regular agent participating in the learning process and affects the learned policy. When the attack is called by an opponent, the spy agency will perform the attacking actions based on the corrupted joint policy. Such an attack will have a higher success rate since the spy agency has already injected its intention into the joint policy during learning. In the proposed project, the investigator will analyze this type of attack in three aspects, 1) Develop a spy agent detection algorithm according to the human-centric AI regulations; 2) Develop a trustworthy multi-agent reinforcement learning algorithm to generate robust optimal group decisions that will counter the effect of the spy agent; 3) Analysis the stability and convergence of the developed multi-agent reinforcement learning using Lyapunov methods to ensure the trustworthiness. Furthermore, the developed trustworthy multi-agent reinforcement learning algorithm will be tested on a fleet of UAVs. The PI has extensive experience in multi-agent decision-making, game theory, UAVs, and general robotics.

Summary of the potential impact of the proposed research on this field of study: The proposed multi-agent reinforcement learning algorithm against spy agents will lead to a new research area regarding the scientific and technical robustness as well as the ethics and safety of AI for large-scale UAV teams. This proposal will also contribute to the scientific community in the long term by bridging the gap between multi-agent decision-making theory and real-world applications that rely heavily on interconnected complex systems such as power systems, robotics, etc. The limitations and physical performance of the multi-agent team is also evaluated in a novel aspect, i.e., the spy agent attack.

All data and algorithms in the proposed research will be released for public use in the form of open-source software. The proposed project will provide opportunities to train undergraduate and graduate students at University of Wyoming and University of Nevada. Living in the least populated states in the US, Wyoming and Nevada residents need more exposure to cutting-edge AI technologies, and this project will serve that purpose. Special attention will be given to the minorities in the Wyoming and Colorado area through the CO-WY Alliance for Minority Participation, and the University of Nevada Reno First Generation Minority STEM Program. The PI will also participate in outreach activities to help promote public knowledge of AI techniques in the state of Wyoming and Nevada.

23-2023 R3-0061

E-002/E-004: Combining ICESat-2 photons with high resolution multispectral data for the monitoring of thermokarst lake dynamics in the North American Arctic

University Of Wyoming

Dr. Shawna McBride

This proposal is in response to Appendix 7.7: Earth Science - NASA SMD Earth Science Division (ESD) within the FY2023 NASA EPSCoR Rapid Response Research (R3) Notice of Funding Opportunity (NOFO). In particular, this work falls under Research Focus Area E-002: "Research that contributes to furthering our understanding of climate change impacts in high-latitude drainage basins, including coastal zones, and advance humanity's understanding of the potential feedback(s) of naturally- or anthropogenically-driven change in such zones." It is well known that ongoing climatic changes are altering complicated natural systems and causing notable environmental change across the globe. These changes have been more than apparent in the Arctic-Boreal Zone (ABZ) of North America. However, it is less understood how this "Arctic amplification" affects the vulnerable natural ecosystems within the ABZ. This is particularly true for the periglacial regions of the ABZ where there is a complex and delicate relationship between surface water hydrology and permafrost dynamics.

This proposed work seeks to address Research Focus Area E-002 by deriving a novel technique to quantify total water volume and total volumetric change for thermokarst lakes within the Alaskan North Slope (ANS). Most previous remote sensing-based studies focus on relative water volume and/or water level change as bathymetric data is required to derive total water volume or total level changes and is not available for the majority of lakes in the ABZ of North America (as well as globally). The quantification of lake bathymetry, surface water volume, and total hydrologic change within the domain of NASA's Arctic Boreal Vulnerability Experiment (ABoVE) will help to further our understanding of how ongoing climatic (e.g., increased Arctic warming) and environmental (e.g., permafrost, lake ice, and snow cover dynamics) changes in the western North American Arctic are impacting the hydrologic regime of thermokarst lakes within these high-latitude drainage basins, and vice versa. Moreover, large scale fluxes in Arctic surface water extent and volume have notable implications for the quantification of freshwater carbon (e.g., methane) emissions and the knowledge of total thermokarst lake volume change will help better our understanding of the ongoing changes in the western North American Arctic hydrologic cycle.

This work will utilize novel computational data processing techniques and make significant use of previously acquired remote sensing products from NASA (e.g., ICESat-2 and Landsat-8/9) and NASA's Commercial SmallSat Data Acquisition Program (CSDAP) (e.g., Planet and Maxar). Further, we will employ other remotely sensed datasets (e.g., Sentinel-1a/b, Sentinel-2, ICEYE) along with previously collected in situ bathymetric and lake level data (e.g., from the ABoVE campaign) to extend our lake volume time series and to help calibrate/validate our ICESat-2 (IS-2) bathymetric/water level outputs, respectively. These remotely sensed observations are the primary datasets we will utilize to accomplish our overarching goal of furthering the understanding of ongoing climatic and environmental changes in the western North American Arctic as they relate to surface water dynamics.

One of the main novelties of this proposed research lies in the utilization of NASA's IS-2 platform to create bathymetric products and subsequent total water volume (not simply volumetric change) for thermokarst lakes within the ANS. To our knowledge, IS-2 data has not been utilized for the derivation of thermokarst lake bathymetry and the outputs of this proposed research should prove to be the first of their kind. Lastly, this work will seek to prove the usefulness of IS-2 data for thermokarst bathymetric change monitoring at the individual lake scale, which would be an unprecedented use-case for IS-2 data.