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Appendix D: Enhanced Electro-mechanical Powertrain Safety through Deterministic Online Model Assimilation

College of Charleston

Dr. Cassandra Runyon

Inside the Aeronautics Research Mission Directorate (ARMD), the Advanced Air Mobility Mission is pursuing safety in emerging aviation markets that will move people and cargo in nontraditional methods within local or regional sectors. A high probability of failure has been highlighted in the powertrains for Electried Vertical Takeoff and Landing (eVTOL) vehicles. To improve the powertrain safety of eVTOL vehicles, we propose the use of digital twin technologies to monitor the health and safety of these systems. The powertrain system, for this initial study, is the motor and inverter with a focus on the electromechanical interconnections between these two subsystems through the use of a digital twin. The advantages of this digital twin for powertrain safety are twofold. First, each aircraft has an individualized per-vehicle maintenance program and, thereby, less downtime. Second, the digital twin can enable a variety of intelligent control schemes that reduce wear on components, increase energy efficiency, and aid in noise abatement.

The deployment of digital twins on-board the aircraft rather than in the cloud will enable the future integration of digital twins into ight controllers and simplify maintenance. An accurate model of these components will enable extended run-time for powertrains while maintaining the high level of safety expected in the air transportation industry. Therefore, the digital twin will be updated in situ to ensure model accuracy as components degrade over time to ensure a balance between safety, maintenance, and run- time. The developed multi-physical digital twin has great potential to attract future research focused on system reliability, adaptive ight control, and design optimization.

Along with this research, a standardized powertrain digital twin will be created with plug-n-play capabilities. A modular design from the onset will enable further subsystems to be connected in the future and expand the digital twin to encompass the full eVTOL system. The standardization of information transfer at the input and output boundaries of the subsystem digital twin will be a key aspect of this research to enable coupling with multiple testbeds and integration with digital twins of other eVTOL subsystems.

This research will be integrated with NASA through a partnership with Dr. Timothy Krantz from the Glenn Research Center and its Advanced Recongurable Electried Aircraft Lab (AREAL), which is under development with an expected completion date of Summer 2022. The hands-on research experience gained by students interacting with this proposed research and NASA will contribute to South Carolinas workforce development effort and further increase technological expertise in the state as outlined in the SC Vision 2025 Strategic Plan. The students who are trained on this project will expand the human infrastructure of South Carolinas STEM workforce, and a personnel focus will be to create research opportunities for undergraduates who may enter graduate programs in the future. As the students are exposed to this research, they will increase the capabilities of South Carolina in the energy and transportation sectors. Ultimately, this will contribute to the economic development of South Carolina.

22-2022 R3-0007

Appendix I: Coupled CO2 Capture and Conversion at Ambient Conditions to Enable In-Space Propulsion

College of Charleston

Dr. Cassandra Runyon

In collaboration with NASA, we propose a demonstration of a one-stage electrocatalytic system that converts carbon dioxide (CO_2) captured from near Earth space station cabins into CH_4 fuel, which can be used for in-space propulsion (such as in CH_4 thrusters to maintain the space stations orbit). The proposed work will facilitate a robust and competitive U.S. low Earth orbit economy, particularly in Commercial Space Capabilities of materials and processes improvements for propulsion. The successful development of the technology is also extensible to sustainable propulsion to Mars and beyond in longer terms.

The state-of-the-art technology for converting CO2 into CH4 in space is a multi-stage and energy consuming process. This involves the water electrolysis to produce highly flammable H2 in the first stage. The H2 produced then react with the CO2 at elevated temperatures through a Sabatier reaction to generate CH4. In addition, the pre-capturing of CO2 usually requires a separate unit with energy intensive process to recover the CO2 as a concentrated gas fed reactant stream. These together bear significant energy loss, multi-step operational process and safety concerns.

The overarching goal of the proposed work is to develop a non-gaseous feed stream CO2 reduction electrocatalytic reaction system featuring the use of bipolar membranes (BPM) and single-atom alloy catalysts (SAA). Our proposed technology will have the following advantages when measuring against the benchmark: 1) a single-stage reaction system is needed to release and convert the captured CO2; 2) the entire process will take place at ambient temperature and pressure; 3) the production of highly flammable H2 gas intermediate is not required. To meet the needs of the vehicle-cabin applications where the CO2 concentration is less than 1% by volume per NASA Life-Support Baselines, the proposed reaction system will operate without the typical high-concentration gaseous CO2 feed stream. Instead, we will use [OH- CO32--HCO3-] type of electrolyte as an inexpensive and efficient chemical adsorbent to capture dilute CO2. Next, in our single-stage reaction system, the CO2 in its aqueous ionic carbonate and bicarbonate forms, which are mostly catalytically inert, can readily react with the in situ generated H+ from the BPM to generate CO2 molecules in affinity to the active SSA cathode catalysts to selectively produce CH4 without triggering the undesired hydrogen evolution reaction (HER).

Building upon our preliminary findings, this proposed work will begin with the chemistry and cost optimization of shape controlled (Pd, Pt, or Ni)1Cu SAA catalysts for active and selective CO2 reduction to CH4 while suppressing the HER. A concerted effort in the same timeframe will be made to the BPM and cathode compartment configuration validations, where a matched speed of CO2 and proton transfer to the SAA electrode can be gained to maximize reaction efficiency and avoid undue CO2 escape and HER initiation. Reaction pathways of the promising BPM+SAA configuration will be probed to better rationalize further system optimization. Next, long-hour reaction validation with typical gas contaminants such as CO and O2 to reflect NASA applications will be performed to interrogate the reliability of the chemistry. Lastly, zero-gravity and high-g force tests will be performed to examine the mechanical robustness of the most promising catalysts and the reactor configurations. To meet preliminary engineering needs, we plan to achieve ~80% Faradaic efficiency and current densities in the range of ~200 mA/cm2 for CO2 conversion into CH4 when completing the project.

The proposed work also aims to elevate studentseducation experience, particularly for those from underrepresented groups in South Carolina and the Southeast region of the nation, by igniting their research interests, career passion, and citizenship and aligning them with NASA missions.

22-2022 R3-0008

Appendix J: Impacts of Climate and Land-use Changes on the Carbon Cycle in Charleston Coastal Waters.

College of Charleston

Dr. Cassandra Runyon

Carbon cycle dynamics in coastal waters have global importance due to their ability to connect terrestrial and oceanic ecosystems. Coastal ecosystems such as tidal salt marshes, seagrass meadows and mangrove forests have been termed areas of blue carbondue to their high rates of C-sequestration compared to land. Models predict that climate change processes will lead to higher mean sea level (SL) and sea surface temperatures (SST) this century. Concurrently, land use-land cover changes (LULCC) are significantly impacting carbon and nutrient fluxes to coastal ecosystems. Loss of wetlands due to urbanization, LULCC and SL changes can have significant impacts on coastal erosion and result in enhanced nutrient runoff into coastal waters. In addition, nutrient inputs into coastal ecosystems from extreme weather events and SST changes may significantly alter the phytoplankton and bacterial community composition thereby significantly impacting carbon cycling. Observations from other coastal ecosystems have noted that these environmental changes can result in the proliferation of toxic microbes including harmful algal blooms. More importantly, it is unclear how these future environmental changes will impact not only the magnitude of carbon sequestration in tidal salt marsh ecosystems (e.g., blue carbon) but also whether these coastal ecosystems will remain a net carbon sink or even become a net source of carbon dioxide to the atmosphere. The project will focus on carbon cycling processes in coastal waters in relation to climate change and LULCC processes that will aid our understanding of the global carbon cycle.

Remote sensing techniques will be coupled with various carbon measurements collected from surrounding coastal waters and sediments in the Charleston, SC area. Coastal water samples will be collected for surface particulate and dissolved organic carbon (POC, DOC), dissolved inorganic carbon (DIC), chromophoric dissolved organic matter (CDOM), nutrient concentrations, bacterial abundances, chlorophyll a and phytoplankton pigments to determine community composition. Sediment organic carbon (SOC) will also be measured at a few selected sites from the 3 main rivers emptying into Charleston Harbor. We propose to leverage the field activities and sampling program of the Citizen Science group Charleston Waterkeeper (CWK) to enable us to collect weekly surface water samples from 15 local sites in rivers and salt marsh estuaries emptying into Charleston Harbor. This collaboration with CWK will also allow us to access ancillary datasets that they collect as well as use those data collected in the past. For example, we have collected and analyzed samples from the 2021 field season (April-October) for various parameters including CDOM, nutrients and phytoplankton biomass and community composition. Remote sensing and ground-truthing of CDOM, POC and phytoplankton biomass as well as observing LULCC changes will allow us to enhance our spatial coverage area to regions outside the CWK monitoring sites. These data will serve as an important baseline for determining how future climate and environmental changes will impact the carbon system in coastal waters surrounding the Charleston, SC region and will be instrumental in developing new models relating to blue carbon cycling in coastal waters. The project will also facilitate the validation or development of algorithms from the in-situ data that will expand inland water applications.

The project will also contribute to the development of the Nations STEM workforce by supporting the training of an undergraduate student who will work on the project from its inception as part of their Bachelor of Science Honors thesis research at the College of Charleston. By partnering with the CWK Citizen Science group the project will leverage their support in collecting water samples that will also facilitate and spark numerous outreach collaborations with the public.

22-2022 R3-0010

Appendix C: MRI Brain research on astronauts pre- and post-flight (renewal)

College of Charleston

Dr. Cassandra Runyon

We have previously shown that astronauts of long-duration missions aboard the International Space Station (ISS) experience an upward shift of the brain, compression of cortical veins, and crowding of eloquent brain tissue at the vertex along the superior sagittal sinus (SSS). We hypothesize these anatomical changes may impede venous outflow from the cranium resulting in decreased blood flow through the internal jugular veins (IJVs.) Supporting this hypothesis, there have been recent reports of astronauts experiencing abnormal venous outflow from the head and in at least one case, an astronaut was found to have asymptomatic IJV thrombosis.

In addition, increased intracranial pressure (ICP) and papilledema have also been documented in NASA astronauts following long-term missions aboard the ISS months to years after spaceflight which NASA has named the Spaceflight Associated Neuro-ocular Syndrome (SANS). Some researchers have hypothesized that venous outflow obstruction may play a role in the development of SANS.
Here, we aim to characterize the response of the intracranial venous system to spaceflight, evaluate for any evidence of venous congestion or brain edema post-flight, and correlate those findings to intracranial pressure at spinal tap in astronauts with and without SANS. The study will include a total of 12 astronauts: (1) six astronauts with documented signs of SANS, and (2) 6 astronauts without signs of SANS matched for gender, approximate age, and approximate mission duration to serve as controls. In addition, we aim to characterize the early post-flight time course of structural changes of the brain by obtaining brain MRI scans pre-flight and post-flight within 6 hours of landing in a group of 4 spaceflight participants on the SpaceX Polaris Dawn mission.

This proposed study directly addresses a significant health risk that was recently identified in ISS astronauts (abnormal venous blood flow and IJV thrombosis). This study will also provide evidence concerning the role intracranial venous physiology may play in the develop of SANS in susceptible astronauts.

22-2022 R3-0011

Appendix G: SMD Astrophysics: Proportional Counter for Absolute X-Ray Flux Calibration

Iowa State University - Iowa Space Grant Consortium

Dr. Tomas Gonzalez-Torres

The accuracy of fundamental cosmological constraints derived from X-ray observations of clusters of galaxies is limited by the accuracy of the flux calibration. We propose to build and demonstrate a proportional counter for absolute X-ray flux calibration in collaboration with NASA/GSFC. This work will support the active development of mission concepts for X-ray flux calibration by researchers at NASA/GSFC and lead to future partnerships on related research.

22-2022 R3-0015

Appendix K: Metalized Ceramic Nanoparticle Containment Filter Systems for Mars Missions (Nanofiber Filters)

Louisiana State University

Prof. Gregory Guzik

Our approach for microbial growth mitigation in spacecraft environments and on planetary surfaces focuses on the dual-threat of the entry of Martian pathogens and the release and spread of earth microbes into the Martian environment. We have developed a metalized nanofiber-based, and 3D printed air filtration unit and systems. Our filtration unit protects against the entry of pathogens and particulate material (dust/DNA/particulates). The porosity of our filter membrane (50 nanometers) prevents the entry of pathogens and uses embedded metal ions to enhance entrapment, containment, purging, and analysis of entrapped material.

Pilot studies have confirmed their containment potential for preventing microbial disease transmission and preventing bacterial colonization and biofilm formation. Furthermore, we believe this technology can enhance life support systems in crewed spacecraft and habitats.
Our technology can be employed in filtration systems throughout the spacecraft to prevent pathogen entry or exit, ensuring astronauts' safety in space. In addition, in airlock environments of future space habitats (Mars), there is a need to limit planetary dust, debris, and airborne pathogens into the living portions of the habitat. Furthermore, there is a coordinated need to prevent the escape of earth microbes/DNA and other material of terrestrial origin.

Metal-coated (Ag, Cu, and Zn) halloysite nanotubes (mHNTs) were developed to produce air-tight and interchangeable filters and filter housings. Our method offers a one-step and low-cost process with many other advantages. With solution blow spinning, the deposition of mHNTs or dual-coated mHNTs can be sprayed on a 3D printed framework as a fibrous membrane or film coating. On human-crewed space missions, our ventilation systems will protect against airborne pathogens by deactivating a virus, reducing or eliminating bacterial adhesion, preventing bacterial growth, eliminating airborne particulates. Our filter units can be further coated with materials that mitigate the entry of particles smaller than 50 nanometers on crewless spacecraft. Funding is requested for further prototype development, testing, and validating our air filtration capabilities and antimicrobial/viral potential. This project will require one year to accomplish proposal objectives.

22-2022 R3-0017

Appendix J: Improving Estimates of Land-to-Ocean Carbon Flux Through Characterization of Colloidal Inherent Optical Properties

Maine Space Grant Consortium

Dr. Terry Shehata

The retrieval of dissolved organic carbon (DOC) concentrations from ocean color remote sensing reflectance (Rrs) is a key step in the monitoring and prediction of carbon fluxes from land to ocean. However, its retrieval has traditionally been challenging in estuarine and coastal ocean systems, because at visible and near-ultraviolet wavelengths, colored dissolved organic matter (CDOM) absorption coefficients (ag) and DOC are often not well-correlated, and because sensors with high spatial and temporal resolution are required. Further complicating matters is the typical, operational partitioning of carbon and inherent optical properties (IOPs) by size, through filtration with size cutoffs ranging from 0.2-1 m. In the transition from land to ocean, this size range encompasses an important pool of colloidal material whose optical properties are not well-characterized. The estuaries that empty into the western Gulf of Maine will serve as the site for this research, because these watersheds generate a high dynamic range in CDOM sources, and because climate-driven changes in precipitation are expected to drive greater export of terrestrial organic carbon to the Gulf of Maine.

This proposal has three main objectives. The first is to adapt a generalized algorithm for the retrieval of CDOM optical properties and DOC concentration from ocean color for use in coastal Maine estuaries, and with imagery from the high resolution Landsat 8/9 and Sentinel 2a/b sensors. Our second objective is to determine the influence of colloidal matter (< 0.2 m) on the optical properties of DOC in transitional waters between the land and the ocean, and to conduct a sensitivity analysis of the DOC retrieval algorithm to natural variability in colloidal IOPs. The third objective is to estimate fluxes of DOC through coastal Maine estuaries to the Gulf of Maine using high resolution ocean color observations, as well as uncertainties in fluxes that arise from variable carbon-specific IOPs of DOC in the source waters.

We will use opportunistically-collected surface water samples from three contrasting estuaries (Penobscot, Damariscotta, and Sheepscot) to characterize sub-micron, colloidal optical properties. A flow-field flow fractionator coupled to a volume scattering sensor and offline long-path UV-visible absorption measurements will provide detailed information on the size dependence of colloidal IOPs, and how these covary with organic carbon (OC) concentration. We will then test the agreement of size-fractionated colloidal IOP and OC measurements with the assumptions of an existing, DOC algorithm developed for the northeast United States, and the sensitivity of calculated DOC fluxes to variations in the carbon-specific IOPs of source material in the region.

The application of high resolution ocean color imagery for retrieval of nearshore aquatic carbon fluxes is in its infancy. Here we would develop these methods for use in coastal Maine, which is a step towards providing new monitoring data for use in coastal carbon budgets and climate change assessments. This project will also provide new information about the IOPs of colloids smaller than 0.2 m, which is an unresolved issue in the field of ocean color remote sensing. The collected data will also broaden our understanding of ultraviolet optical properties as PACE data come online.

22-2022 R3-0022

Appendix D, D.1.1: A Series Hybrid Electric Propulsion for an eVTOL Using a Fault Tolerant 9-phase Generator

North Dakota Space Grant Consortium

Dr. Caitlin Milera

This project proposes a series hybrid electric propulsion (SHEP) for electric vertical takeoff and landing (eVTOL) aircraft. The proposed scheme consists of two energy sources: (i) A battery system that acts as a primary source providing peak power for the eVTOL powertrain, and (ii) An engine-driven 9-phase permanent magnet (PM) generator with a fixed speed that acts as an auxiliary source providing an average power for the eVTOP powertrain. The output of 9-phase generator is rectified using a voltage source converter (VSC) before connecting to DC-link. The series term refers to the combined peak and average power concurrently supplied by the battery and 9-phase generator, however, the DC output of the two sources are connected in parallel on the eVTOLs DC-link. The proposed scheme mechanically decouples the engine from the eVTOL powertrain. Generally, engines demonstrate low specific fuel consumption over a relatively small region of their power-speed characteristic. They also demonstrate particularly high fuel consumption and emissions during transient engine operation. Therefore, mechanically decoupling the engine from the powertrain and operating it at a fixed speed offers the potential for reduced engine size, fuel and emissions. A control scheme is proposed where the objective is to maintain a constant output power for the 9-phase generator at a fixed speed while minimizing speed variation via vector control of VSC. The control scheme matches the 9-phase generator rectified voltage to DC-link voltage variation as eVTOL accelerates/decelerates. The project investigates operability of the system under faults at the output of 9-phase generator; phase-to-ground, and phase-to-phase faults are considered. Compared to a conventional 3-phase machine a 9-phase generator results in improved quality of DC-link voltage and power, and increased fault tolerance; features that will be investigated in this project.

22-2022 R3-0024

Appendix D: Multi-Scale Experimental Characterization of Non-Associative Plasticity Flow Rule Coefficients and Mixed-Mode Traction-Separation Laws for the LS-DYNA MAT213 Model

The University of Mississippi

Dr. Nathan Murray

This project is focused on developing a novel experimental method for characterizing non-associative plasticity flow rule coefficients and post-peak stress degradation through coupon-scale tests for the LS-DYNA MAT213 model. The main objective is in characterizing these coefficients and stress degradation based on the multi-scale (i.e., both microscopic and macroscopic) full-field measurement of the evolution of strain and stress fields along fracture process zones in geometrically scaled composites under loading-unloading-reloading conditions. The deformation sub-model in the MAT213 model requires several material parameters as inputs to define the non-associative flow rules of composite materials. In the current methodology, however, complex material properties such as plastic Poissons ratios need to be measured to determine some of the key parameters. Furthermore, for simulations of post-peak stress degradation using the damage sub-model in the MAT213 model, the methodology requires correlation based on structural-level impact or crush tests, which are extremely challenging with respect to cost and resources. To address these issues, the first thrust of this project will be focused on characterizing the non-associative flow rule coefficients based on the full-field measurement of the evolution of plastic strain and stress fields along fracture process zones in front of crack tips. The main objective of this thrust is in developing a novel experimental method for in-situ characterization of the flow rules using the progressive digital image correlation (DIC) method, where plastic strain increments will be obtained by characterizing strain and displacement fields at every DIC image frame. In the second thrust, an experimental method for characterizing post-peak stress degradation in composites through coupon-scale tests will be proposed and investigated. The goal of this thrust is in determining traction-separation laws through coupon tests and capturing post-peak stress degradation based on the laws. Traction-separation laws for mixed-mode delamination will be characterized based on the multi-scale full-field measurement of the evolution of separation (i.e., damage progression) along fracture process zones in test coupons. Geometrically scaled coupons will be tested due to the size effect in the quasi-brittle fracture process in composites. Macroscopic 3D DIC data will be used to determine the fracture energy of the coupon material based on the Ba~ants type-II size effect law, while the curve shapes of the traction-separation laws will be characterized based on microscopic DIC data. The proposed methods will be validated by comparing the parameters obtained from these methods with the ones characterized by the current methodology. The experimental work will include tension and compression tests in the 1- and 2-directions, shear tests in the 12- and 21-directions, and 45-degree off-axis tension tests. These tests will provide data to find the parameters required for the current methodology (e.g., plastic Poissons ratios, etc.). For validation of the proposed methods, additional tests will be performed like the following: mode-I, mode-II and mixed modes-I/II interlaminar fracture tests. Three levels of geometrically scaled specimens will be tested in these fracture tests. Both 3D and microscopic DIC systems will be employed in all the tests listed here, while a minimum of three repeats for each test scenario will be conducted. The experimental capabilities dedicated to the proposed work include a

psylotech TS test frame with an Olympus BXFM microscope and a Basler Ace 12MP machine vision camera for the microscopic DIC tests, an Instron 8872 test frame with an ARAMIS DIC system for the 3D DIC tests, and VIC-2D and GOM software for DIC analysis. The proposed methods are expected to enhance the fidelity of material parameter inputs for the MAT213 model, while reducing cost and resources required to obtain the parameters.

22-2022 R3-0025

Appendix A: The Energy Cost of Producing Water and Chemical Feedstocks from Lunar Regolith

The University of Mississippi

Dr. Nathan Murray

In the presence of hydrogen, the creation of molecular water and metallic hydrides from corundum and periclase requires successive energy inputs in the range of only 30-40 kcal/mol or 700-900 nm photons. The proposed work will extend the previous production of water and metallic feedstocks from corundum, periclase, and brucite to the lunar-abundant pyroxene (specifically enstatite; $MgSiO_3$) and olivine (specifically forsterite; Mg_2SiO_4) minerals. The quantum chemical methods employed for the determination of these energy profiles the previous work and those to be used in the proposed work are among the most advanced developed to date: CCSD(T)-F12b/cc-pVTZ-F12 with harmonic zero-point vibrational energy corrections. The principle deliverable of this project will be the amount of energy (and corresponding photon wavelengths) necessary to progress these step-wise reactions to produce water and metallic hydrides from small molecules of lunar mineral composition. The minimum energy geometries for the reactants, products, and intermediates will be computed along with the transition states to produce the reaction profiles and the step-wise, accurate energy barriers needed to assess the viability of the macroscopic production of water from lunar regolith. The energy cost for the corundum, periclase, and brucite reaction back to water has an energy cost of <40 kcal/mol per each step. This energy is ~900 nm, in the range of standard Solar wavelengths (< 900 nm). If such energy barriers/wavelengths are consistent with enstatite and forsterite, IR lasers could be utilized to produce the needed energy, but the possibility exists that concentrated Solar photon exposure on the Lunar surface would be sufficient for allowing these processes to take place in a passive manner reducing cost and maintenance.

22-2022 R3-0027

Appendix G, SMD Astrophysics: Enhanced Detection of Cosmic Rays by Radio Probes

University of Delaware

Prof. William Mattheus

Cosmic-ray research is one of the traditional NASA areas targeting the fundamental understanding of our universe. NASA operates several space-based and balloon-borne instruments measuring cosmic rays and other high-energy particles from the Universe such as photons and neutrinos. These instruments typically create large datasets of millions to billions of detected events per mission. Among those instruments, the balloon-borne ANITA probe and its successor PUEO are the missions targeting the highest energies, otherwise only accessible by ground-based instrumentation. ANITA pioneered a novel technique for cosmic-ray detection observing the radio emission of atmospheric particle cascades, called air showers, with antennas on a balloon payload. It had four successful flights until now and, consequently, is succeeded by PUEO as follow-up mission with improved detection capabilities. During the last decade, digital radio detection emerged as an alternative to traditional optical techniques offering similar precision for the measurement of air showers without being restricted to clear nights. The big advantage of balloon-borne radio detectors over ground arrays is that a single detector can overlook a huge area and thus feature a much higher exposure per antenna than a ground-based array. During these flights massive data sets of time series are acquired by the radio antennas. The challenge is to find the signal events within this huge data set, in particular those events close to the detection threshold with low signal-to-noise ratio.

Building on promising prior work to identify and denoise cosmic-ray radio pulses with low signal-to-noise-ratio, this proposal will further investigate how the scientific merit of such radio measurements of cosmic particles can be enhanced by machine learning techniques, in particular, deep neural networks. Machine learning can improve the scientific outcome of future radio probes for cosmic rays and neutrinos in at least two ways: First, the classification of signal events against background will increase the purity of the sample, lower the detection threshold, and increase the total statistics of signal events. Second, the detected signal events can be reconstructed with higher accuracy. With the preliminary work, we have already shown that the first step is possible at the level of a single antenna, and we have demonstrated that, in the second step, the properties of the radio pulse can be measured more accurately, which are linked to the properties of the cosmic particle. In this proposal we will further improve the existing results and will investigate the realistic situation of antenna arrays with two polarization channels per antenna. Finally, we plan to study how the threshold and the measurement accuracy for the energy and type of the primary particle can be improved directly through the application of the neural networks. A direct experimental validation is possible by comparing the neural-network classification of radio data to traditional cosmic-ray detectors. As a result, the potential of the machine learning techniques for future flights can be assessed. Based on these findings, subsequent studies can investigate whether such neural networks should be incorporated directly in the data-acquisition running during a flight, or are better used to leverage the subsequent data analysis on the ground. Due to the general applicability of the expected outcomes (lower threshold, higher aperture, improved accuracy) and the increasing use of digital radio detectors for astroparticle physics, the proposed project is expected to create significant impact much beyond just the next NASA flight for radio detection of cosmic rays.

22-2022 R3-0034

Appendix A: Biological and Physical Sciences: Exploiting Hydrodynamic Oscillations of Oscillating Heat Pipes for Thermomagnetic Power Generation from Low-Grade Waste Heat

Iowa State University - Iowa Space Grant Consortium

Dr. Tomas Gonzalez-Torres

Low-grade waste heat is abundant in many NASA platforms but challenging to leverage because the temperature of the waste heat (< 200 C) is too low to be effectively utilized with the existing technologies. Several technologies capable of utilizing low-grade waste heat (e.g., thermoelectric power generation) are available, but are not utilized because of various constraints (e.g., size, weight, cost). Thus, almost all the energy is dissipated as waste heat to deep space. Oscillating heat pipes (OHP), also known as pulsating heat pipes, are a widely used passive thermal management strategy. OHP rely on inherent two-phase hydrodynamic oscillations to transport heat, thus providing the rapid oscillations needed for thermomagnetic power generation (TMPG). However, the poor understanding of these two-phase flow oscillations limits the integration of OHP and TMPG into a viable low-grade heat recovery technology. Thus, there is an urgent need to improve our fundamental understanding of the hydrodynamic oscillations of an OHP to improve thermal transport and enable TMPG as a viable technology for power generation from low-grade waste heat. In the absence of such knowledge, the two-phase flow physics of OHP will remain relatively unknown, OHP thermal management strategies will underperform, and low-grade heat will continue to be under-utilized and wasted.

Our long-term goal is to enable an oscillating heat pipe-based thermomagnetic power generation (OHP-TMPG) technology to recover low-grade waste heat from various applications, including future NASA missions. The overall objective of this project, which is the next step toward attaining our long-term goal, is to characterize, manipulate, and exploit the inherent hydrodynamic oscillations of OHP for TMPG from low-grade waste heat. Our central hypothesis is that understanding the rapid hydrodynamic oscillations of OHP will enable selection, control, and integration with applicable magnetic materials for inducing rapid changes in the local magnetic field and generating electricity. The rationale for the proposed work is that once the OHP oscillations are well understood, traditional OHP can be made multi-functional, in that it will provide not only thermal transport, but also power generation when appropriately coupled with magnetic and electrical components.

Apart from having supportive preliminary data, we are particularly well prepared to undertake the proposed research based on: (i) prior experience performing two-phase microchannel flow studies focused on characterizing the oscillation magnitude and frequency of flow instabilities and (ii) experience with magnetic materials, shape memory alloys, and energy harvesting systems using smart

materials and structures. We plan to attain the overall objective for this project by pursuing the following objectives:

1. Characterize the hydrodynamic oscillations of the vapor/liquid slug flow in the OHP
2. Leverage the hydrodynamic oscillations of the OHP to vibrate small magnets contained within the OHP to create a time-varying magnetic flux

The proposed research is creative and original because it departs from the status quo of using OHP solely for thermal transport in favor of making OHP multi-functional such that they can also be utilized to directly generate electric power from low-grade waste heat. Upon completion of the proposed project, our expectation is that we will have: provided new fundamental understanding of the two-phase flow physics in OHP (objective 1) and utilized the hydrodynamics of the vapor/liquid slug flow in the OHP for TMPG (objective 2). Collectively, these would enable the development of an OHP-TMPG device capable of converting low-grade waste heat into usable electric power. These outcomes are expected to have a significant positive impact on future NASA missions by improving system efficiency and reducing system mass, two key goals for NASAs exploration missions.

22-2022 R3-0035

Appendix A: Appendix E: Marshall Space Flight Center (MSFC): Additive Manufacturing of Zirconium Carbide using Pressure-assisted Precursor-Binder Jet

Iowa State University - Iowa Space Grant Consortium

Dr. Tomas Gonzalez-Torres

The overall objective of this proposal is to establish a pressure-assisted precursor-binder jet (P-PBJ) process for additive manufacturing (AM) of complex, high-density zirconium carbide (ZrC) parts. The P-PBJ process, pioneered by Sc-I Songs group, is capable of printing ZrC parts with enhanced sinterability by utilizing in-situ uniaxial pressure and novel precursor binders. The P-PBJ process fabricates a ZrC component through layer-by-layer compaction of a powder bed and strategical deposition of a precursor binder in the compacted powder layers. The layerwise compaction can improve the green density of printed parts, while the precursor binder can be pyrolyzed to a ZrC1-x compound with controlled stoichiometry that then acts as a sintering aid to enhance atomic diffusion of the green parts under pressureless sintering.

Two specific research objectives are proposed as follows: (1) Quantify the effect of layerwise compaction pressure on the green density of printed ZrC parts; (2) Understand the effect of binder composition on the densification behavior of printed ZrC parts. Our hypotheses are that (1) the green density increases with an increasing compaction pressure until a powder rearrangement-to-deformation transition occurs; (2) the pressureless sintering density of printed ZrC products is determined by the stoichiometric ratio between Zr and C in pyrolyzed binders through combined effects of surface oxide reduction and carbon vacancy diffusion. To achieve the research objectives, three research tasks have been planned, including (1) formulate precursor binders with varying compositions; (2) construct green parts under varying pressures; (3) link microstructure/composition/properties of P-PBJ printed parts to binder composition and printing pressure.

If successful, the proposed research will overcome the long-term challenges of traditional ceramic AM processes in achieving high-density carbide-based materials. The proposed method is amendable to different carbide-based materials, including carbide-based fuel and structural ceramics, for various high performance applications including energy, defense, aerospace, and nuclear. The project will enable a powerful tool capable of producing next-generation carbide nuclear fuels for NASAs nuclear propulsion systems.
To build a strong partnership between NASA and Iowa, the Sc-I will closely work with researchers at MSFC on the proposed research activities. Specifically, the Sc-I plans to partner with NASA researchers to test the structural/compositional stability of P-PBJ ZrC parts in nuclear propulsion applications and explore the role of different heat-treatment techniques in further promoting the density of P-PBJ ZrC parts using MSFCs advanced sintering facilities.

22-2022 R3-0037

Appendix D: (Aeronautics Research Mission Directorate, ARMD): Deformation and Flow Characterization of Composite Materials for LS-DYNA MAT213 Model

Iowa State University - Iowa Space Grant Consortium

Dr. Tomas Gonzalez-Torres

A university-NASA partnership is being developed to provide an insight on the deformation, flow and post-peak characteristics of hybrid weave composite materials. Full experimental calibration and analysis of the incremental deformation fields will assimilate the implementation of material constants and calibration of LS-DYNA MAT213 predictive material model.

Three objectives are targeted in this work. First, we will explore the subtle differences associated with hybrid weave and textile composites arising from the additional microstructure periodicity to translate the macroscopically measured mechanical properties and the observed cell-level deformation mechanisms into constitutive input parameters for the deformation and flow characterization of MAT-213 for shell elements. We will employ full-field displacement measurements by digital image correlations (DIC) and global coordinate axial strains measurements by non-contact video extensometer.

Second, we propose to utilize the experimentally measured incremental plastic strain field on reduced Mohr strain plane to identify multiple unique details of the assumed plastic flow potential, including ratios of its 9-constants, isotropic and kinematic hardening evolution, separation angle between flow potential and assumed yield surface, and prospective dependence of plastic Poissons ratio on plastic strain increments. These measurements will provide a comprehensive model calibration and verifications for the examined hybrid weave composite.

Third, we will employ simple and well-characterized 2D cylindrical indentation, which is amenable to provide strain rates in the range of (10-3 to 10 /s) and offset double notched tension specimen. These configurations provide (i) a stable localized deformation path, and (ii) the ability to monitor and study

the evolution of the deformation field in the form of nucleation and propagation of individual deformation bands. We will try to identify the critical shear and plastic strain limits, leading to incipient formation and propagation of shear bands, and/or local cracks and delamination fronts. The proposed methodology is expected to overcome current limitation in the numerical framework of MAT213, by providing detailed mechanistic view of post-peak stress degradation response.
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 a NASA-provided hybrid weave composite panels. The established partnership with NASA will enable the development of the future workforce through educating young engineers and scientist, with further global impact on reliability of transportation systems by ground, sea, air, and beyond, while influencing the environmental and industrial practices.

22-2022 R3-0040

NASA EPSCoR FY22 R3 Appendix B (ARC): Wavelength-dependent micro and meso scale measurements of radiative properties

University of Kentucky

Prof. Alexandre Martin

Design and development of thermal protection systems (TPS) materials is an integral part of most NASA missions. Missions under development now include the degradation of the TPS material through in-depth radiative transfer (transport) as a design metric. New modeling tools to understand penetration of radiative signatures from the shock layer into the TPS material are being developed by researchers at NASA and the University of Kentucky, supported through prior support from NASA and NASA KY EPSCoR. In the proposed effort, complementary experiments will be performed to provide insights into the complicated photon paths through complex heterogenous structures of TPS materials and improve the understanding of radiative transport in TPS materials. Additionally, the data will help to rigorously validate the radiative modeling tools that are being developed, both at NASA and the University of Kentucky.

Wavelength-dependent radiative properties and functions will be obtained both at the microscopic and mesoscopic length scales in the range of 200-700 nm using a continuous light source, which covers most of the shock layer emissions relevant to planetary entry, including reentry back to Earth. Additionally, fixed wavelength near-IR source will be used for CO and CO_2 emissions to cover wavelength emissions for entry into Mars. The refractive index and absorptivity on a single fiber will be quantified at the microscale, and the reflection and transmission functions for the bulk TPS material will be quantified at the mesoscale. The ability to measure wavelength-dependent properties in the range of 200-700 nm is crucial because all previous measurements have only been performed in the near-IR region. Finally, the two sets of measurements will minimize any uncertainty in model inputs, allowing a direct comparison between the experiments and simulations, making this validation effort a one-of-a-kind effort in the TPS mesoscale modeling paradigm.

The proposed work is in response to FY2022 NASA EPSCoR Rapid Response Research (R3) announcement (NNH22ZHA004C) Appendix B: Ames Research Center and the topic of B.1.2: Measurements for Characterizing In-Depth Spectral Radiative Properties of TPS Materials..

22-2022 R3-0043

Appendix E: Advanced Manufacturing Dense Nuclear Fuels with Complex Geometries

University of Idaho

Dr. Matthew Bernards

Recent advances in performance and accessibility of additive manufacturing (AM) technologies have facilitated cost effective and rapid prototyping, resulting in rapid developments of new solutions and technologies. AM of polymers and metals is a relatively mature process; however, ceramic AM is not. Ceramics have proven difficult to AM due to their high hardness and melting temperatures which results in viscous inks and porous structures [1]. Nevertheless, AM technologies have great potential to decrease the development cycle of ceramic based products and reduce cost, as near net shape parts will no longer require the extensive use of expensive post-processing.

Currently, NASA is developing technologies for AM of nuclear fuels and materials, which has been demonstrated in the AM of Zr3Si2 (as a surrogate for uranium silicide) as well as SiC [2] [3]. A material which AM can be of particular use to NASA programs is zirconium carbide (ZrC). ZrC has a multitude of uses in nuclear reactors due to its high temperature stability, high strength, radiation tolerance, low neutron absorption cross section, and thermal properties such as its impressive thermal conductivity (>30 W/m K at 2000 K) [4]. In addition, ZrC has been identified as a surrogate to carbide fuels, (U,Zr)C. Accordingly, we propose to use AM to print complex ZrC structures for next generation nuclear reactor fuels, particularly in space propulsion. The complex geometries for these reactors are difficult, if not impossible, to obtain from traditional manufacturing methods. Accordingly, new fuel geometries may be realized to improve efficiency and reliability. UC has been identified and implemented in space reactors for many decades due to its high thermal conductivity and uranium density, fission product stability, and inertness in air [5]. AM of ZrC presents great opportunity as there is limited, if any, literature on direct writing of ZrC. Therefore, the initial phase of this project will be the optimization of ink development, print parameters, and sintering parameters in the AM of ZrC structures with greater than 80% theoretical density. NASA-MSFC is interested to test these samples for hydrogen compatibility at 2200 C.

Ink will be developed in a similar fashion to other oxide-based ceramic AM processes [1]. A direct write (DW) nScrypt 150-3Dn-HP (housed in the Idaho Microfabrication Laboratory at BSU) will be used to print samples. All post-process thermal treatments, sample preparations, and light element characterization will occur in Prof. Jaques Advanced Materials Laboratory. In addition, microstructural and phase characterization will be performed in the Boise State Center for Materials Characterization. It is anticipated that the primary challenge for achieving fully consolidated structures will be the ink loading capacity; ZrCs hard hardness and melting temperature will likely result in higher viscosities than conventional ceramic AM materials. We will investigate the effects of various parameters such as ink type, particle size, and AM parameters have on the structure and performance of the consolidated samples. All samples will be characterized for density, composition, microstructure, and processing requirements, and will be compared to conventionally manufactured ZrC. Promising samples will be sent to NASA for hot hydrogen testing. The goal of this study will be to identify the particular challenges in the AM of carbide-based ceramics in order to optimize the process and implemented in the AM of UC without the exposure and costs associated with handling to radioactive materials. This project will also develop property correlations related to AM processing conditions that may be exploited for enhanced structures and performance. The results of the project will be documented through a peer reviewed publication and it is our hope that this will stimulate the community to further invest in AM of ceramic materials for NASA applications..

22-2022 R3-0044

Appendix H: Advanced Flip-Chip and TSV Based High-Temperature 3-D SiC IC Packaging for Venus Surface Exploration

University of Idaho

Dr. Matthew Bernards

The objective of this project is to continue and expand the research in three-dimensional (3-D) packaging of silicon carbide (SiC) integrated circuits (ICs) and sensors for high temperatures of 500 C and high pressure of 9.6MPa Venussurface explorations. Specifically, it is to explore the advanced flip-chip and through-substrate-via (TSV) based 3-D SiC IC packaging with higher interconnect speed, denser input/output (I/O), more compact package size, and lower stress over the active area.

SiC IC chips have been demonstrated to be able to operate stably in the simulated Venussurface extreme environment of 500 C temperature and 9.4MPa air pressure for a year. For the SiC IC microsystems to be integrated into the Venus landers, compatible electronic packaging systems for long-term high-temperature operations must also be developed. The NASA Glenn Research Center has explored basic two-dimensional alumina ceramic substrate-based packaging systems for SiC ICs to operate at 500 C. On the other hand, recent SiC IC chips tested in simulated Venus surface environment have only about 200 transistors, and the research for SiC chips with thousands of transistors is in progress. To integrate many more transistors into the limited footprint of the ceramic printed circuit board (PCB), a 3-D packaging system is essential. Currently, most research on 3-D packaging is for room temperature applications. The technology cannot be directly used for the packaging of SiC ICs for long-duration high temperature applications.

The Science Investigator (Sci-I)s research group at the University of Idaho has been working on wire bonding-based high-temperature 3-D SiC IC packaging since August 2021, and the research is expected to be completed by August 2022. Compared to wirebonding-based packaging, the flip-chip and through-substrate-via based 3-D electronic packaging systems are more advanced and can make the package system faster, more compact, more function-effective, and more reliable. The proposed research, beginning in August 2022, is to explore the advanced flip-chip and TSV based 3-D SiC IC packaging for high temperature and high pressure long-duration operations at Venussurface. The developed advanced flip-chip and TSV 3-D SiC IC packaging will be subject to the simulated extreme Venussurface acidic atmospheric environment of high temperature and high pressure to ensure the packaging system's electrical, mechanical, thermal, and structural integrity for long term (months) operations.

22-2022 R3-0047

NASA EPSCoR FY22 R3 Appendix J (SMD/ESD): Assessment of the Effects of Algal Blooms and Storms on Mangrove forests: Implications for carbon fluxes across the land-ocean interface

University of Kentucky

Prof. Alexandre Martin

Mangrove forests are considered as blue carbon sinks and store more carbon per unit area than any other ecosystems on Earth, provide critical habitats for wildlife, and provide essential ecosystem services to many plant and animal species including humans living in the coastal areas. In the last decade, extreme weather events have occurred more frequently than before due to the climate change. Hurricanes inundate low-lying coastal areas including wetlands and drylands, erode shorelines, and increase the flow of salt water into estuaries and nearby groundwater aquifers. Moreover, high winds associated with storms generally damage and destroy mature forests, such as mangroves. Furthermore, the high rate of runoff during storms increases the amount of nutrients in the environment and promotes the rapid growth of algae and may cause algal blooms when favorable environmental conditions exist.

The main goal of this proposed project is to assess the current distribution of mangroves and effects of algal blooms and storms on mangrove forests. We plan to utilize multi-temporal satellite remotely sensed data including Hyperion, Landsat 5, 7, 8, and 9, Sentinel 2 and 3, MODIS and Planet.com imagery, and time series of LCLU and NDVI to examine the behavior of algal blooms and their effect on mangrove forests. Storms also negatively affect such forests and ecosystems. We will examine the relationships among storm events, algal blooms, and the ecological function and services of mangrove forests using imagery and LiDAR/DEM/DTM data collected before and after such events. We will also use the high-resolution data collected by NASA Goddards LiDAR, Hyperspectral, and Thermal (G-LiHT) airborne imager program for our project.

We will establish a baseline, the year 2003, for our oldest mapping of the study areas in Florida. Detailed mangrove forest classification maps of the areas will be created using remotely sensed data for the following years to be used in a time series analysis. We will extract 19 bioclimatic variables from the BIOCLIM dataset version 2 to perform a principal component analysis on the bioclimatic data to eliminate the inter-correlation and to extract independent climatic gradients and employ a comparative

approach by using four different species distribution models to predict the potential ranges of mangrove species at regional scales.

We will modify the TG model to estimate gross primary production (GPP) and compare the modeled GPP to eddy covariance flux tower site data at the Everglades National Park (FCE LTER SRS-6). In this task, we aim to modify the TG model to improve the accuracy and prediction of satellite-based GPP for Mangrove forests. We expect to produce GPP data for the proposed study sites and document any improvements compared to the GPP estimated from the original TG model.

The proposed work is in response to NASA EPSCoR FY22 R3 Appendix J: NASA SMD Earth Science Division (ESD) and the topic of J.1.1: Improve understanding of carbon fluxes across the land-ocean interface.Our study should provide valuable information to current studies on the spatial distribution of mangroves at regional scales. The resulting time series maps should provide critical baseline information for resource managers to develop conservation and mitigation strategies. The study will also assess how environmental factors affect the occurrence and productivity of this critical wetland species. This proposed study should provide a unique opportunity to initiate a strong collaboration with researchers at NASA GSFC. In addition, the Sci-Is plan to visit NASA GSFC to give seminars to promote the research within the state of Kentucky and to forge sustained collaborations with NASA. Moreover, the results of this research will be presented at professional conferences and published in peer-reviewed journals.

22-2022 R3-0048

Appendix B: Characterization of Thermal Transport Modes in Porous Materials

University of Idaho

Dr. Matthew Bernards

NASA currently utilizes ablative materials for their thermal protection system (TPS). However the ablative materials undergo porosity changes during a launch cycle and these have a significant effect on the heat transfer in the TPS. Thermal transport in a porous material is inherently complex because of the simultaneous contributions of solid conduction, gas conduction, and radiation to an overall effective thermal conductivity. To fully understand the effective thermal conductivity of porous materials separating the contribution of each effect is critical. This is even more critical for NASA applications where gas conduction is minimal. Here, we plan to experimentally measure the contribution of each mode through a combination of techniques for measuring thermal conductivity (transient plane source, and modulated photothermal radiometery) under various gas pressures and across a wide range of temperatures. We currently have demonstrated expertise in the measurement of thermal conductivity of porous materials at similar conditions (up to 800 C) for packed beds of particles for concentrating solar thermal power that can be leveraged here. Establishing the role of gas conduction is relatively straight forward as the samples can be run at various levels of gas pressure (or under vacuum) to separate this effect and completely remove if desired. The role of radiative transfer is more difficult to isolate from solid conduction as both modes will always be present with the exception of testing at absolute zero. In this project we plan to conduct experiments on porous TPS materials to determine the effective thermal conductivity in a manner that allows for separation and understanding of the contribution from the 3 major components. First, we will utilize our experimental techniques for effective thermal conductivity at various levels of reduced gas pressure through the use of a vacuum pump to separate the role of gas conduction in the voids of the TPS media. Second, we will combine these experiments with testing across a wide range of temperatures (room temperature up to 1000 C) will allow for the separation of the radiative component from the solid conduction components. While this approach doesnt directly separate the radiative effect, it will allow for the characterization of the non-linear dependence associated with the radiative component, and establishing the baseline solid conduction contribution. Using a Rosseland diffusion radiation model it will then be possible to fit a Rosseland extinction coefficient for predicting the radiative component without the role of solid conduction. Additionally, we can leverage our expertise in thermal conductivity of packed bed materials to utilize them as model systems to quickly validate the proposed approach. The study will include the use of multiple novel techniques for thermal conductivity characterization that allow for the study of TPS materials (such as rigid carbon prefroms, carbon felts, rayon felts, and other phenolic materials) that have defectsin the forms of voids that are difficult to characterize with conventional techniques as the defects highly influence the local thermal conductivity measurement. This data will ultimately be useful for future modeling studies of porous TPS materials, as well as relevant for other applications of porous media thermal conductivity such as high temperature packed bed thermal energy storage.

22-2022 R3-0050

Appendix K: Development of Biofilm Resistant Coatings and Evaluation in Simulated Microgravity

University of Idaho

Dr. Matthew Bernards

Novel biofilm mitigation strategies for incorporation into spacecraft systems are desired by NASA, to mitigate microbial growth in space exploration settings. One approach for preventing biofilms is to eliminate the adhesion of bacteria to surfaces via nonfouling polymers, which have demonstrated bacteria resistance in Earth-based investigations. Our hypothesis is nonfouling thin film polymer coatings will demonstrate enhanced resistance to bacteria adhesion and biofilm formation on metallic surfaces under microgravity conditions. This hypothesis will be directly assessed in this investigation for stainless steel (SS) substrates using Ralstonia pickettii bacteria strains.

Recent studies by the PI and others have demonstrated that zwitterionic and mixed charge polyampholyte polymer coatings resist bacteria adhesion. In the most recent comparison, completed using citizen scientists, it was demonstrated that polyampholyte copolymers composed of equimolar mixtures of [2-(acryloyloxy)ethyl] trimethylammonium chloride (TMA) and 2-carboxyethyl acrylate (CAA) monomers (TMA/CAA) demonstrate the broadest resistance to bacteria adhesion and growth upon their exposure to common high contact household surfaces. Further, the performance of these materials can be improved through the incorporation of a novel zwitterionic cross-linker. Therefore, this study looks to develop and assess thin film TMA/CAA polyampholyte hydrogels for incorporation on future spacecraft surfaces to reduce bacteria transmission and growth.

The first research objective is the development of thin film TMA/CAA polyampholyte hydrogel coatings on SS with a range of coating thicknesses. This thin film coating will incorporate a novel chemical cross-linker species that will enhance the nonfouling performance of these hydrogels over existing chemistries. The ability of these thin film coatings to prevent bacteria adhesion from Ralstonia will first be assessed using 24- and 48-hour adhesion experiments under the influence of gravity. Gravity is expected to enhance bacteria adhesion, so only those coatings that prevent adhesion will advance to the final stage. The final objective is the long-term evaluation of bacteria adhesion and biofilm formation on thin film coated substrates under simulated microgravity. A clinostat will be used to create the microgravity environment. Uncoated SS controls will be used to determine the growth period necessary for biofilm formation, and then coated SS substrates will be evaluated using an identical timepoint.

The successful demonstration of the bacteria resistance of nonfouling thin film polymer coatings has the potential to be a transformative approach for reducing bacteria transmission for both space and Earth-based applications.

22-2022 R3-0051

Appendix K: Pathway-level, Consensus Analysis of Microbiome Profiling Data

Nevada System of Higher Education

Dr. Lynn Fenstermaker

The capability to detect and mitigate the adverse effects of microbiome communities exposed to Martian environments is critical to crewed missions to and from the red planet. Particularly for crewed environments, it is crucial to understand the baseline microbial communities and to detect changes or anomalies to those environments. This requires functional interpretation and comprehensive analysis of available microbiome studies that go far beyond differential abundance analyses. In this approach, we propose to develop a novel bioinformatics method, named Consensus Microbe Set Analysis (CMSA), that will allow researchers to: i) perform functional analysis to capture changes of commensal microbial communities at the systems-level, ii) perform meta-analysis of multiple related microbiome datasets, and iii) interactively and simultaneously explore the results obtained from multiple analyses, the impacted pathways, and the relationship between pathways and genes. The project has been discussed with NASA contact Dr. J Nick Benardini at Office of Planetary Protection, NASA Headquarters. Dr. Benardini has expressed his enthusiasm and approval of the proposed work. This work will be performed by Science PI Dr. Tin Nguyen and his Ph.D. student, in collaboration with NASA GeneLab Microbiome Analysis Working Group and Office of Safety and Mission Assurance. At the end of the project period, we will deliver a web-based platform implementing the proposed method.

The project fits into Emphasis 1: Microbial and Human Health Monitoring of Appendix K:

Office of Safety & Mission Assurance. Indeed, the proposed work would be the first steps on path to develop -omics based approaches (including downstream bioinformatic analyses) for planetary protection decision making with a particular emphasis on assessing perturbations in the spacecraft microbiome.Our long-term goal is to continue working with NASA to implement an automatic pipeline for microbial and human health monitoring that is capable of: i) determining the composition of microbial communities, ii) identifying the presence of unknown species of Martian origin, iii) assessing perturbation in spacecraft microbiome, and iv) predict their effect on crew and spacecraft health.

22-2022 R3-0057

Appendix F: A Neural-Symbolic Aurora Model Driven by Aurorasaurus Data in Citizen Science

Wichita State University

Dr. Leonard Miller

The scientific objective of this proposal is to accurately predict visual aurora by designing a neural-symbolic model that incorporates the Aurorasaurus citizen science data. The other objective is to broaden the participation of underrepresented audiences by involving them in Artificial Intelligence (AI) and heliophysics research, and to establish a long-term collaboration for research and education. At present, the aurora prediction is primarily based on model fitting methods. These methods are reliable and efficient under restricted conditions, but they are sensitive to geomagnetic disturbances and inaccurate in boundary prediction. Leveraging the Aurorasaurus project, this project plans to design a neural-symbolic model that fuses formal logic representation and neural modeling. The proposed hybrid model inherently incorporates citizen science knowledge in the structure, and it can learn the coupling function between solar wind, magnetosphere, and ionosphere from big sensing data through parameter optimization. This novel model can therefore efficiently utilize all types of citizen science reports (verified/positive/negative). The transformative approach is also applicable to other use cases in Heliophysics Citizen Science that include high-level knowledge and big data. The project could assist in NASAs space scientific discovery efforts, establish a long-term collaboration strategy for the team, and have a significant impact on the economic and scientific development of Kansas.

22-2022 R3-0059

Appendix D.1.3: Aeronautics Research Mission Directorate (ARMD) - DEVELOPMENT OF TEST METHODS FOR QUANTIFYING FLOW RULE PARAMETERS AND POST PEAK RESPONSES OF COMPOSITE MATERIALS

Wichita State University

Dr. Leonard Miller

The performance of laminated composite structural parts subjected to transient loadings arising due to events such as localized impacts, vehicle crashes, etc., are typically evaluated using a combination of experiments and numerical simulations using a finite element code such as LS-Dyna. The simulations provide a less expensive, quicker, and more insightful option for design iterations, and augment the certification process, which consists primarily of testing full-scale test articles. The simulations necessitate the use of advanced material models such as MAT 213 developed by NASA Glenn, which are intended to capture the complex deformation and progressive damage that occurs under dynamic loading. In addition to the traditional orthotropic elastic properties, the material model requires specialized test data to capture the damage-induced softening and permanent deformations, and eventual fracturing of the material. The model uses a non-associative flow rule to capture the permanent deformations, which set in due to accumulation of damage in the plies. The flow rule parameters are obtained using a least squares fit of the model to test data from off-axis testing. The post-peak stress softening of the orthotropic material along principal material directions and under combined loading states is a fundamental aspect of the model required to capture the progressive damage and eventual fracture without inducing non-physical failure modes. The softening behavior at the ply level is hitherto identified using a trial and error process based on structural level tests.

In the proposed work, a new experimental methodology based on Bazants crack-band model will be developed to measure the ply level post-peak softening response along the principal material directions and loading modes using Over-height Compact Tension and Compression specimens. A methodology to extract the non-associative flow rule parameters from both standardized testing and limited off-axis tests will be developed and implemented for two material systems, identified by NASA. In addition, the basic orthotropic material properties required for using MAT 213 with shell elements will be experimentally characterized for the two material systems. Digital image correlation will be used for all the tests to record the displacements and strain fields. The deliverables for this project include (1) a new proposed approach for characterizing the non-associative flow rule parameters, (2) a new proposed approach for characterizing the post peak softening responses and (3) fully tabulated test data in electronic format along with the digital image correlation data for all the tests.

22-2022 R3-0062

Evolving the North Dakota Dual Aurora Camera Project: Data Analysis and the Creation of an Accessible and Engaging Citizen Science Platform - Appendix F

Dr. Caitlin Milera

North Dakota Space Grant Consortium

The University of North Dakota has an existing program to view and analyze Northern Lights in real time called NoDDAC, North Dakota Dual Aurora Camera. It was developed by a student at UND, a commercial entity (Live Arora Network), and NASA scientists. We are proposing to expand the project by creating a citizen science platform in which the public can partake in categorizing auroral features. The aurora database will be open source and can be used by the public as well as space weather scientists. In addition, we plan to create a new aurora camera site in the Fort Berthold Indian Reservation at the tribal college, Nueta Hidatsa Sahnish College. The project will benefit both scientifically and culturally from our newly formed collaboration between UND, NHSC, LAN, and NASA. The tribal college aurora camera with be outfitted with quality camera instruments and could be operational within a couple months of the grant start date. As well, the UND NoDDAC site will be upgraded with the same quality cameras. Currently the NoDDAC camera set up consists of two cameras, a north-facing video camera that livestreams aurora, and an all-sky stills camera. These two views provide unique data that are both beneficial to scientists as well as the public. The north-facing video camera records relatively high-framerate video that will contribute to our understanding of rare mid-latitude auroral phenomena such as STEVEs (Strong Thermal Emission Velocity Enhancement) and SAR (Stable Red Aurora) arcs. The wider field of view of the all-sky camera can also be used to track larger auroral displays. Over the last year the partnership with Aurorasaurus allowed NoDDAC to supply aurora chasers with access to ground-truth visual data which can help in gauging aurora activity during geomagnetic storms. After one year in service, NoDDAC has had an enormous community impact, with hundreds of thousands of livestream viewers from around the world, and the cameras have recorded aurora on over 20 occasions, including STEVE, SAR arcs, and other rare phenomena.

We plan to build a workforce by training one graduate student and three undergraduates from UND and three undergraduates at NHSC. These students, with the help of Aurorasaurus and NASA, will enable us to build a high-profile data site that can be accessed by an ever-growing public presence. With two cameras sites at similar latitudes but at opposite ends of the state of North Dakota, we can monitor aurora activity with extensive land coverage and correlate specific auroral phenomenon. The students will use image and video data from both sites to study rare auroral and making the data accessible to everyone. Our workforce team will clean the image and video data and upload to Zenodo, a general-purpose open-access repository (CERN) for scientist and interested citizen scientists. To further the citizen scientistscontributions, we propose to create a Zooniverse site that will enable a plethora of auroral features to be identified in the image and video data.

The Live Aurora Network, which has provided in-kind support and collaboration with NoDDAC in the past, has agreed to help bring a new camera site online. In conjunction with LAN we plan to create a dedicated NoDDAC website with live image feeds as well as a robust raw data archive that can be easily accessed by the public as well as scientists.

The goals of this project will drive science results, further community impacts, and empower citizen science.

22-2022 R3-0063

Appendix A: Machine learning of Bose-Einstein condensates in microgravity

University of Vermont

Prof. Bernard Cole

This proposed project is an extension of an ongoing collaboration between Science PI Herdman and David Aveline of NASAs Jet Propulsion Laboratory, who is Co-Investigator and the Science Module Manager of NASA's Cold Atom Laboratory (CAL). The proposed new directions of this theoretical project involve developing machine learning (ML) methods to further the characterization and development of the CAL experimental system. The ML tools developed through this project will have broader applicability to other ultracold atom experiments as well as related experimental quantum many-body systems.

The CAL instrument facilitates fundamental physics experiments that cannot be performed in terrestrial experimental systems. Based on compact atom-chip technology, CAL can be used to create and manipulate degenerate ultracold gases in an apparatus that can be deployed on the International Space Station. Experiments on CAL have produced a Bose-Einstein condensate (BEC), a fundamental quantum phase of matter, in the microgravity environment of Earths orbit. Such BEC experiments can probe fundamental physics and have potential applications to emergent quantum technologies. CAL experiments could create BECs with novel topologies and reach temperature and density regimes that are inaccessible on Earths surface; these temperature and density regimes may allow for matter-wave interferometry with higher sensitivity than can be achieved on Earths surface. Future experiments using CAL (and/or subsequent space-based systems) could include high precision tests of fundamental physics such as searches for dark energy, tests of Einsteins equivalence principle, and gravitational wave detectors.

However, experiments using CAL face particular challenges due to the compact design and remote operation of the CAL instrument. For example, precisely characterizing the trapping potential of the atom-chip based trap is difficult. The compact apparatus and proximity of the atom cloud to the atom-chip surface introduce stray magnetic field gradients and localized features in the field; these undesired magnetic field features lead to perturbations in the trapping potential and present experimental challenges that limit the capabilities of the CAL instrument. These potential challenges include fragmentation of the BEC, phase separation of dual-species gases, and difficulty estimating the temperature of the atom cloud or the number of atoms in the condensate.

To address these challenges, we propose to develop ML techniques to analyze and interpret CAL experimental data. The ML algorithms will focus several areas including: (1) characterizing the trapping potential, (2) identifying phase transitions (including the formation of the BEC and phase separation in mixtures), (3) thermometry of the atom cloud, (4) determining the number of atoms in the BEC, and (5) identifying fragmentation of the condensate.

Prior work has demonstrated that Monte Carlo simulations can be used to train ML algorithms, which then can subsequently applied to experimental data. The ML techniques proposed here will be developed and trained using path integral Monte Carlo simulations of the CAL system; Science PI Herdman is currently developing these simulations in an ongoing collaboration with the CAL experimental team. Subsequently, the proposed ML algorithms will be applied CAL experimental data with the aim to further the characterization, understanding, and development of fundamental physics experiments based on CAL. In addition to being useful for characterizing the CAL instrument and other ultracold atom experimental systems, the ML techniques that will be developed by this project will have applications to other theoretical and experimental studies of quantum many-body systems.

22-2022 R3-0064

Appendix H: Assessing Seismic Network Operation in the Venus Environment Using Terrestrial Analog Data

University of Alaska Fairbanks

Dr. Denise Thorsen

Understanding the interior structure of Venus and its current level of geologic activity, particularly the nature and frequency of tectonic and volcanic events, are high priority goals of NASAs planetary exploration program. Seismology is a particularly effective method of achieving these goals, but observation times of at least days, and preferably months, are required to return scientifically useful data, far in excess of the 1-2 hour lifetimes of previous Venusian landers in the extreme surface temperature and atmospheric pressure. NASA Glenn Research Center (GRC) has been engaged in a long-term effort to bring to fruition a seismometer that can operate in the ambient Venus surface environment. The Geophysical Institute (GI) at the University of Alaska Fairbanks has expertise in both Venus geoscience and seismology, and we partnered with GRC on a successful previous Rapid Response Research (RRR) grant. In that previous work we conducted a series of case studies using seismic records from a central Alaska seismic station in order to develop strategies and operational procedures for a seismometer operating under the projected restrictions of limited battery power and no more than a few bytes of computer memory. A few-month COVID-caused delay in starting work made it unfeasible to propose a second year of funding in 2021, and the proposal here builds upon work from the 2020 grant. We propose building upon that previous work, focusing on generalizing our initial results and extending them to consider operations with a small network of three seismic stations. We propose to : 1) generalize our first RRR grant results by considering different places and times beyond our initial set of test seismic records; 2) begin evaluating the effects of Venus surface-atmosphere coupling by comparing records from terrestrial surface and ocean-bottom seismometers in a Venus context; 3) develop a strategy to optimize station separation for a small Venusian seismic network; and 4) develop operational strategies for a small network that can receive transmission on-off commands from an orbiter that has an on-board computer capable of rapid autonomous data processing and evaluation. The proposing team includes a PI who is a Venus geoscience expert, and a Co-I and Collaborator from the GIs Alaska Earthquake Center. Using appropriate terrestrial seismic records as Venus analogs, a postdoctoral fellow will conduct much of the work, and the tasks will be conducted sequentially over the course of a year. The proposed work is relevant to the Planetary Science Divisions portion of the RRR call to address instrument design for extreme environments, especially the Venus surface. The work will have applicability to seismology studies and instrument design efforts for other planetary bodies, including Earth, where power conservation and the ability to withstand extreme environmental conditions are important.

22-2022 R3-0071

"NASA EPSCoR Rapid Response Research: Research and Education on TLEs: Artificial Intelligence / Machine

University of Puerto Rico

Dr. Gerardo Morell

The goal of this proposal is to apply Machine Learning (ML) and Artificial Intelligence (AI) methods for verification and categorization of images and videos of sprites and other Transient Luminous Events (TLEs) captured by citizen scientists and shared through the Spritacular project. This project will also involve development of education modules on TLEs for the public and perform outreach through workshops for the recruitment of talented storm chasers. Images of TLEs are captured by people worldwide, with different camera settings, lighting, acquisition parameters, which will be addressed by image processing and ML/AI methods to identify TLE events and to classify them by types. Some of the images captured do not have enough information to identify the event. Hence, the software tool that will be later integrated with the Spritacular project needs to address the issues of (a) noise in the images/videos, (b) reliable feature extraction for training an ML or Deep Learning (DL) model, (c) sufficient images for training and validation of the prediction model. To address these issues, we will develop a deep learner model that can be trained by the sprite image features. The objectives for this NASA Rapid Response Project are:

1) Preprocess the sprite and TLE images/videos to remove noise and extract spatial, spectral, and morphological features and compute feature embeddings.

2) Develop a DL GCN architecture to be trained on the extracted features, which will be used to label the images/videos with the event and its type.

3) Education and training of the public on upper atmospheric electrical phenomena and recruitment of talented sprite/storm chasers.

Sprites have features such as tendrils, beads, spots, and glows and can be classified into five morphological classes. Currently, these images are visually inspected and classified by human intervention. These features will be extracted by implementing spatial filters along with spectral and morphological filters to train a DL Graph Convolutional Network (GCN) algorithm that will then be used to automatically classify the TLEs. The duration of the sprites is an important feature that will be obtained from video images and used for training of DL algorithm. The DL method will then be implemented in Java for a web-based application to be integrated with the Spritacular project. We will be collaborating with Dr. Burcu Kosar, the lead in the Spritacular citizen science project. Our collaboration will enable the implementation of the web-based TLE identification and categorization tool, as well as coordination of education and training activities for recruiting citizen scientists in Puerto Rico. Mr. Frankie Lucena, an active member of the International Observers of Upper-Atmospheric Electric Phenomena, will be collaborating in this project as an ambassador for Spritacular. He has extensive knowledge of sprites, and he will assist in the preparation of education modules for the public and recruitment activities. The PI teaches Digital Image Processing Couse (INEL 5327). The images from this project will be used in class projects and engage UPRM students in citizen science related research. The ML method will be tested and validated using detection and Receiver Operating Characteristic (ROC) curves. We will host virtual workshops and activities to engage the public in Puerto Rico to disseminate knowledge in heliophysics and upper atmospheric transient luminous events. This project will be directed towards the education and training of underrepresented minority students to gain expertise in learning image processing methods, ML and AI methods for detection, and applying them to NASA datasets. UPR is a Hispanic minority-serving institution with 99% Hispanic students who will gain knowledge in the fields of image processing, developing ML ad AI tools for web-based applications, and knowledge of TLEs.

22-2022 R3-0078

Appendix E: Investigation of the Functional Properties of Ceramic Composite Materials, Fabricated Using Pneumatic Micro-Extrusion Additive Manufacturing Process

West Virginia University

Dr. Melanie Page

The goal of the proposed research project is to establish an intelligent, physics-guided platform for high-fidelity additive fabrication of defect-free, dimensionally accurate, and mechanically robust ceramic fuel structures in support of NASAs manufacturing infrastructure as well as the MSFC plan to advance additive manufacturing of ceramic nuclear fuels. In pursuit of this goal, the objectives of the project are: (i) to investigate the influence of ceramic material factors (e.g., suspension viscosity, ceramic content, particle size, binder and additive type, and moisture con-tent), fuel design factors (e.g., layer thickness, infill density, and porosity), as well as manufacturing process parameters (e.g., deposition temperature, fluid flow regime, solidification rate, translation speed, and nozzle diameter) on the functional properties (e.g., elasticity modules, yield strength, shrinkage, surface roughness, dimensional accuracy, permeability, and reactivity) of ceramic fuel structures, fabricated using pneumatic micro-extrusion additive manufacturing (AM) process; (ii) to establish an artificial intelligence (AI) model on the basis of the experimentally-observed relationships (from Objective #1) as well as observations from computational physical models. Once established, the AI-driven model allows for rapid, accurate, and in-situ prediction of the functional characteristics of ceramic nuclear fuels as a function of consequential ceramic materials, fuel designs, and AM processparameters.

Implied from a review of literature, there is a wide spectrum of material, fuel design, and additive manufacturing process parameters that significantly influence the functional properties of fabricated ceramic fuel structures. While additive manufacturing has emerged as a high-resolution and robust method for the fabrication of ceramic con-structs, what remains unknown is how and what physical- and material-related factors (as well as factor interactions) influence the complex dynamics of the ceramic fuel fabrication process. In the absence of such critical knowledge, NASAs MSFC engineers will be unable to efficiently, optimally, and swiftly fabricate ceramic fuels in the presence of intrinsic constraints such as viscosity, phase change, non-Newtonian material deposition, etc. This gap is addressed in this research project via multi-dimensional (i.e., integrated experimental as well as computation-al) characterization of the ceramic fuel fabrication dynamics, supported with an intelligent model aiding in additive fabrication of ceramic fuels with tunable critical properties.

In addition to the aforementioned technical and scientific outcomes of the project in support of NASAs (and potentially the U.S. Armys) manufacturing infrastructure, paving the way for additive fabrication of ceramic nuclear fuels, the proposed project will have impactful educational and societal outcomes. This project will lead to several graduate-level theses in the areas of Mechanical and Manufacturing Engineering. Furthermore, this project not only will provide opportunities for underrepresented groups (e.g., female gradate students) to be involved in research, but also will improve the research and education infrastructure at Marshall University. Besides, new graduate-level courses in the area of Advanced Manufacturing (such as Smart Manufacturing as well as Computational Modeling of Manufacturing Processes) will be developed in support of the Master of Science in Mechanical Engineering (MSME) program at Marshall University. Finally, this project will accelerate the growth of advanced manufacturing and consequently will enable creation of well-paying jobs not only in the State of West Virginia, but also nation-wide.

22-2022 R3-0079

"Appendix A, Biological and Physical Sciences (BPS):Study of Regolith Composites for Three-Dimensional Printing of Electronics

University of Delaware

Prof. William Matthaeus

Additive manufacturing is an important opportunity for NASA. Space missions will transport three-dimensional printers, feed stock, and CAD programs in place of many items needed upon landing and an inventory of replacement parts for items that fail. The feed stock can be further reduced if regolith at the landing site is used in manufacturing of these parts. Regolith is unconsolidated, heterogeneous matter covering the solid surface. It includes dust and small rocks and is present on the moon, Mars, some asteroids. As much as 95% by volume regolith can be included in the feedstock along with thermoplastics like acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). We have already included 80% by volume inorganic ceramic in composite structures.

For this work we will study the properties and use of regolith based composites for forming electronic devices and sensors, where we already have considerable experience. We have fabricated tuned antennae and circuit boards. Passive elements, like capacitors, resistors, and inductors, placed on dielectric platforms are well within the reach of current technology. We will extend our expertise to include fabrication of sensors for detecting pressure, humidity, temperature, and specific gases. This multidisciplinary research effort will combine advances in material science, advanced manufacturing systems and electronic devices and systems.

Before devices are fabricated the compatibility of the regolith with the thermoplastic will have to be determined. To form stable composites some simple processing of the regolith may be required. We will use lunar simulants in anticipation of a lunar mission. In particular, to gain experience with a variety of lunar regoliths, we will use Mare, nearside Highland, farside Highland, and high anorthosite Highland. Accelerated testing of the formed composites will be necessary to determine the compatibility of the thermoplastic and the regolith. To enable printing of various electrical circuits we will explore the development of composites that include electrically conductive components in both liquid and powder forms. Emphasis will be placed on optimizing the materials to achieve the device performance and lifetime reliability required. Once stable composites are found, several devices will be fabricated.

22-2022 R3-0080

"Appendix A, Biological and Physical Sciences (BPS):Study of Regolith Composites for Three-Dimensional Printing of Electronics

University of Delaware

Prof. William Matthaeus

In the past decade, advances in technology and medical care have dramatically improved access for those with disabilities. While no individual with a known physical disability has flown in space to date, feasibility is becoming less of a factor. Inclusion of parastronauts, while considered technologically feasible, will require additional study and engineering risk assessment. Successful inclusion warrants a comprehensive understanding of overall mission risk comprised of both engineering and human systems risks, particularly in the areas of emergency procedures and spacesuit and spacecraft design.

National Aeronautics and Space Administrations (NASA) Office of the Chief Health Medical Officer (OCHMO) engaged the Potomac Institute for Policy Studies to conduct a study on the feasibility of sending parastronauts (i.e., an individual with a lower leg deficiency, short stature, and/or leg length difference) to space. Some of the proposed solutions require explicit experiments in space to validate safety and performance, and will be the objective of this study. Significant hurdles including technical, operational, and medical challenges are related to parastronaut inclusion. These include space suit design/interface considerations, functional testing of emergency ingress and egress procedures, and interior spacecraft interface adaptations.

Our team will develop a timeline of tasks and crew requirements related to space suit and vehicle interface for NASA supported spacecraft (CEV, SpaceX Dragon, and Boeing Starliner). Generate an assessment of risk areas in the operations timeline for each of the parastronaut classifications being considered, and recommendations for functional aids or procedure modifications to mitigate the risks. Develop critical time / performance study procedures to be conducted that address identified areas of risk for each of the parastronaut classifications. Conduct performance testing using the established protocols, perform data analysis and generate recommendations. At the conclusion of this work NASA will have established first order data to facilitate the inclusion of parastronauts in flight activities, and dramatically expand NASA Diversity, Equity, and Inclusion standards.

22-2022 R3-0082

Appendix I, Commercial Space Capabilities (CSC) Research: Small Reentry System for Commercial Payload Return

University of Delaware

Prof. William Matthaeus

As the commercial spaceflight industry grows, so will the need for recovering small payloads from orbiting spacecraft and space stations in Low Earth Orbit (LEO). Several technologies have been developed and demonstrated to return large cargo containers from orbit, including rigid and deployable aeroshells and decelerators, often in conjunction with parachutes, but all require advanced systems and significant recovery support. Commercial payloads will require a new paradigm to reduce operational costs and risks in order for commercial enterprises to be economically efficient. Many of the previously developed aeroshells and decelerators were developed for large payloads but could be scaled to smaller payload sizes. Steerable parachutes are in use, but offer limited range to control the landing location. Therefore, a next-generation small commercial payload reentry and delivery system must be able to have an extended flight envelope to account for lower tolerance entry interface operations. In addition, the payload delivery system must be simple and safe to operate from the time the payload is inserted on orbit, to the time when it lands on the ground. The more that can be done to expand the size of the payloads post-reentry flight radius, the lower the tolerance required from the entry interface equipment, and the lower the mission cost. Therefore, a design that efficiently transforms from an orbital decelerator geometry to one that generates lift with control surfaces that enables the payload to be flown and guided to a precision landing site will make the difference between an economically viable payload delivery operation and payloads that are costly to recover at a risk to lives and property.

This program will develop a 2-stage inflatable system that can be ejected from a spacecraft in Low Earth Orbit (LEO,) deploy an aeroshell, enter the atmosphere, slow to an acceptable speed, morph into an aircraft and fly autonomously to a landing site. Deployable inflatable structures are proposed to minimize the stowed volume of the delivery system to reduce launch costs (smaller vehicles), and conserve critical storage space inside spacecraft. The payload would be loaded into an insulated canister/rigid aeroshell in the packed reentry system while inside a spacecraft, and then ejected toward earth at a prescribed velocity with a simple system at a designated moment in the vehicles orbit to establish a general trajectory towards the landing site. A tensioned cone decelerator consisting of an inflatable torus and a softgoods cone will deploy with a frontal area large enough to slow the small payload during reentry. The softgoods cone is a double layer design with the layers connected with strategically shaped softgood spars. After the tensioned cone slows the system to subsonic speeds, it will morph into an inflatable aircraft using ram-air to pressurize the space between the softgoods cone layers. The connecting spars are designed that the resultant inflated & tensioned structure is an aerodynamic lenticular lifting body with control elevons. The aircraft will be equipped with a GPS driven guidance system that will send signals to actuators on the aircrafts control surfaces to guide the vehicles flight path. The vehicle will land smoothly to protect the payload. The payload will be surrounded by the inflatable aerostructure and will therefore be a flying airbag, so it will absorb any unforeseen impact loads, and reduce the risk of damage to property on the ground if off-nominal conditions are encountered and an impact occurs.

22-2022 R3-0083

NASA EPSCoR FY22 R3 Appendix I (CSC): A recovery system for the KRUPS re-entry capsule

University of Kentucky

Prof. Alexandre Martin

The Kentucky Re-entry Universal Payload System (KRUPS) is a small entry capsule designed as a technology test-bed, built at the University of Kentucky. For this first incarnation, KRUPS was designed to test TPS material and instrumentation. KRUPS recently completed an hypersonic atmospheric entry flight, where two capsules successfully returned from the space station. The data obtained from the flight was temporarily stored within the capsules, and the transmitted to the Iridium network. The mission was a complete success, and the gathered data will be used to reconstruct the flight environment.

Another flight of KRUPS capsules is planned in 2023, where 5 capsules will be testing various heat shield, as well as a new instruments designed to study the hypersonic shock wave in front of the vehicle. A new ejection mechanism is also planned. For all past and manifested KRUPS flights, the capsule was not designed to be recovered.

The overall objective of the proposed project is to take the KRUPS project to the next logical step and integrate the capsule into a recovery system. This includes a precision orbital entry, followed by a guided parachute descent, concluded by an Unpiloted Aircraft System recovery. To keep this proposal within reasonable bounds, only the retrieval system will be developed. It is expected that, after a year of active development, a demonstration of the retrieval system can be demonstrated through a suborbital sounding rocket test.

The proposed work is in response to FY2022 NASA EPSCoR Rapid Response Research (R3) announcement (NNH22ZHA004C) Appendix I: Commercial Space Capabilities (CSC) Research and the topic of I.1.2: Small Reentry Systems.

22-2022 R3-0084

Appendix H: NASA SMD Planetary Science Division, Topic H.1.3: Infrasound Noise Mitigation for Aerial Platforms on Venus

Oklahoma State University

Dr. Andrew Arena

Venus surface temperatures have prevented seismic measurements of Venus, even though it is considered an essential topic by the Venus Exploration and Analysis Group. The Venusian middle atmosphere is less severe, which makes it possible for sensors to survive given current technology. Thus, seismic measurements of Venus are possible today if seismological studies could be performed remotely from an aerial platform. Seismological events on Earth can serve as analogs for similar events on Venus. Earthquakes emit sound waves at frequencies below human hearing (termed infrasound) that have been detected from sensors suspended from floating balloons. Our team is currently collaborating with NASA JPL researchers to determine the lower limit of detectable earthquakes. Our team has been responsible for flight operations, having launched over 50 balloons equipped with infrasound sensors to date. A technological limitation to the threshold for earthquake detection is the sensor noise floor, which includes the impact of wind noise. While it has been demonstrated that balloon-based sensors have a much weaker impact from wind noise than ground-based sensors, there is relative motion between the sensor and the drifting balloon. This problem becomes more significant the longer the tow line, which are needed to determine direction of arrival while minimizing data rates. This problem will be present on Venus given the expected wind shear of 5-10 m/s per km. Thus, the current project aims to identify wind noise mitigation strategies to lower the threshold of detectable Venus-quakes (or other infrasound producing physical processes within the Venus atmosphere).

The goal is to identify compact, lightweight solutions that suppress incoherent noise while minimizing attenuation of coherent signals. This will be achieved via laboratory, outdoor-ground, and flight testing. The laboratory testing will perform a parametric study leveraging established techniques from ground-based methods. Coherent sources will be supplied along with incoherent wind to a test and reference microphone. The performance will be quantified via comparative spectral analysis of the coherent source and wind noise (defined without the coherent source). A subset of designs will be tested outdoors at ground-level to assess their performance under real wind conditions. Final designs will be flown on solar balloons, termed heliotropes. Heliotropes float at a desired altitude (~20 km) from shortly after launch until sunset, unless a cut-down system is employed. Lightweight infrasound sensors and radiosondes will be suspended from a heliotrope. Launches will target periods when coherent infrasound signals from natural (e.g. severe weather) and anthropomorphic (e.g., explosions) sources are expected. At the conclusion of the project we expect to have lowered the noise floor of infrasound sensors deployed from an aerial platform. This will directly address an open research question that would promote the development of this technology, which could enable performing seismology of Venus remotely from its middle atmosphere. In addition, this will promote continued collaboration between our team in the EPSCoR jurisdiction of Oklahoma and NASA JPL with us furthering our role as the flight operations lead.

22-2022 R3-0085

Appendix A.1.6.2 – Effects of Chronic and Fractionated Ionizing Radiation Exposure on Multigenerational Growth of Invertebrates: Using Tardigrades and Nematodes to Identify Divergent Multigenerational Responses to Long-Term, Low-Dose Radiation

University of Wyoming

Dr. Shawna McBride

Beyond Earths protective atmosphere and magnetosphere organisms, including humans, are exposed to increased levels of high-energy ionizing radiation. While increased exposure of humans to radiation is detrimental, the exact effects of such exposure on developmental and reproductive biology, gene expression, and genomic integrity are not fully understood. To safely plan for deep-space missions and prolonged terms for astronauts on the International Space Station, the moon, and beyond, it is critical to understand how long-term exposure to ionizing radiation effects critical biological phenomena.

The goal of this project is to understand how prolonged low-dosage exposure to ionizing radiation affects different biological systems at the level of genome integrity, gene expression, developmental as well as reproductive biology. To achieve this goal we will execute three Specific Aims which are detailed below.

In each of these aims two closely related panarthropod models, the tardigrade Hypsibius exemplar is and the nematode worm Caenorhabditis elegans, will be used. We have selected these organisms for the following reasons: First, both are animals, possessing complex organs and tissues (e.g., nervous systems) and the same three primary tissues (ectoderm, endoderm, mesoderm) that humans consist of. Second, both are evolutionarily related and belong to the panarthropod clade making them excellent comparative models. Third, H. exemplar is radiotolerant, while C. elegans is comparatively susceptible to radiation exposure allowing for comparisons to be made between how these organisms are affected differently by radiation. Finally, existing transcriptomic and genomic datasets exist for both these organisms that will facilitate differential gene expression and genome resequencing efforts essential for this project.

Throughout this project two different radiation sources will be used. First, we will use X-rays, as these highly energetic photons are highly ionizing and provide a good proxy for galactic radiation while allowing for easy access and usage (see letters of support). Second, we will use high energy ultraviolet light (254nm) as this near-ionizing radiation source provides an important control and will allow for comparison of results between ionizing and non-ionizing radiation.

Aim 1: Assess the effect of prolonged, low-dose, exposure to ionizing radiation on the multi-generational development and reproductive success of biological systems. Here we will quantify how long-term fractionated exposure to ionizing radiation affects the development and reproductive success of C. elegans and H. exemplar is over multiple generations.

Aim 2: Assess the effect of prolonged, low-dose, exposure to ionizing radiation on the gene expression of biological systems. In this aim, we will use transcriptomics to assess how exposure to ionizing radiation affects gene expression in tardigrades and nematode worms identifying commonalities, but also differences in how an intolerant versus tolerant animal responds to radiation at the transcriptional level.

Aim 3: Assess the effect of prolonged, low-dose, exposure to ionizing radiation on the genomic integrity of biological systems. In this final aim, single animal genome re-sequencing will be performed to allow us to identify mutational rates and specific regions within genomes where mutational frequencies differ between tardigrades and worms exposed to long-term, low-dose, ionizing radiation.

Combined, our experiments will reveal how different organisms respond over multiple generation to prolonged low-dose ionizing radiation. Our results will allow us to compare these changes between two closely related panarthropod animal systems one of which is highly tolerant to and the other which is highly susceptible to radiation at the level of genome integrity, gene expression, developmental and reproductive biology.

22-2022 R3-0086

Appendix C.1.2 - Topic 2: On-Chip Tissue Models for Experimental Carcinogenesis Under Controlled Radiation Exposure

University of Wyoming

Dr. Shawna McBride

It has been extensively documented that extended spaceflight affects astronaut health in a variety of ways and stands as a significant hurdle to long-duration manned missions. While the effects of microgravity upon physiology and function have been studied extensively, exposure to the variety of radiation endemic to space habitats has been received less empirical attention. This proposed project will establish a microfluidically integrated tissue chip platform for the differentiation and extended culture of tissue layers formed from induced pluripotent stem cells (iPSCs). This platform will allow the frequent, and repeated dosage of cells with ionizing radiation and the subsequent optical monitoring of cells for hallmarks of carcinogenesis. The technology development goals of this project build upon existing capabilities and expertise of the collaborating senior personnel and contribute toward the primary project outcome: validating the hypothesis that nuclear size can be used as a facile biomarker to accurately diagnose the carcinogenic transformation of cells as it is commonly used by pathology laboratories to diagnose cancers. Nuclear size will be measured and cross referenced against DNA damage, cellular proliferation and motility, and apoptosis resistance, all hallmarks of a cancerous state.

The tissue chip will enable the longitudinal chronic exposure of cells to ionizing radiation while culturing under controlled conditions. Working with iPSCs will ensure uniformity across experiments and also allow questions related to the timing of irradiation and its affects on cellular differentiation and carcinogenesis to be independently addressed. Elucidating the underlying mechanisms guiding the genomic response of eukaryotic cells to radiation will produce an understanding of the effects of extended radiation exposure and the development of countermeasures to create salubrious conditions for long duration human spaceflight. Successfully realizing the focused outcomes of this limited project scope will allow the platform to be adapted to more ambitious studies involving physiological transformations of functional tissues, such as microvasculature models, or three-dimensional micro-tissues or organoids.

22-2022 R3-0087

Appendix E: Additive Manufacturing of Nuclear Fuels for Deep Space Missions

Wichita State University

Dr. Leonard Miller

The goal of this research is to additively manufacture 3D complex ceramic nuclear fuels for space nuclear propulsion applications. As a major step toward the goal, the objective of this research is to apply direct ink writing (DIW) technique to print ZrC ink, which contains ZrC particles mixed in an organic solvent, in isooctane bath to maintain the structure integrity. The research objective will be achieved via close collaboration between Kansas State University (KSU), Idaho National Laboratory, and NASA Marshall Space Flight Center (MSFC). The proposed research is directly aligned with the research goals of NASAs SMD Biological and Physical Sciences program and is of considerable importance to the local Kansas aviation industry.

Background. Ceramic fuel is used to heat the propellant to generate thrust and impulse the space vehicle in space nuclear propulsion. The design of complex nuclear fuel geometries increases the energy outputs and enhance performance; however, it is a significant challenge for conventional manufacturing to consolidate and perform the post-processing of near-net-shapes.

Three-dimensional ceramic parts have been successfully printed by several additive manufacturing (AM) processes, including binder jetting, extrusion-based printing, stereolithography, powder bed fusion, and direct energy deposition. NASAs Space Nuclear Propulsion program is exploring carbide fuel to generate propulsion for deep space missions, where UC can be the basis to explore AM feasibility with surrogate material ZrC. Work with radioactive materials may require strict safety measures, material traceability, and a certified laboratory by the U.S. Nuclear Regulatory Commission (NRC). Due to the complexity of working with radioactive materials we will tailor this research effort to surrogate work, where non-radiological materials can be explored to arrive at a proof of concept. Thus, this proposed Rapid Response project will focus on 3D printing of ZrC structures with high density.

22-2022 R3-0088

Ap. B: Quantifying Thermal Conductivity Heat Transfer in Porous Thermal Protection System Materials

Montana Space Grant Consortium

Dr. Angela Des Jardins

Motivation: Thermal protection systems (TPS) are crucial to atmospheric reentry vehicles in order to shield the intense heat generated by propulsion systems as they enter into the atmosphere of planets. Porous TPS materials, among others, have been extensively used to build TPS for their low thermal conductivity, light weight, cost-effectiveness and high reliability. Central to the design and application of porous TPS materials are our fundamental understanding of the heat transfer processes within such materials as well as our ability to accurately model and predict their thermal transport properties. Heat transfer through a porous medium includes combined contributions from conduction along its solid matrix, radiation across internal voids (pores), and conduction through gases filling the voids. However, due to the complex morphology of the porous materials and the intrinsically coupling nature of different heat transfer mechanisms across scales, modeling this process has been an extremely challenging task. In particular, this modeling effort is especially inhibited by the lack of high-fidelity experimental data, which is imperative to informing model development and validation.

Objectives: The goal of the proposed research is to: (i) experimentally quantify the thermal transport mechanisms individually in porous medium for a range of relevant temperatures to further our fundamental understanding; (ii) provide experimental data to allow for the development of models for predicting the effective thermal conductivity of porous TPS materials of interest to Entry Descent and Landing projects and missions at NASA. Specifically, we propose to build a novel model porous medium with precisely controlled thermal and physical properties (i.e., morphology, thermal conductivity, emissivity, etc.), allowing us to isolate the individual contributions of solid conduction, gas conduction, and radiation to the overall effective thermal conductivity of porous TPS materials. The contribution by gas conduction will be turned on/off by controlling the pressure conditions employing a vacuum chamber, whereas the radiation heat transfer will be isolated by precisely tuning the surface emissivity under otherwise identical conditions enabled by novel nanofabrication techniques. This research effort represents a key to understanding the detailed heat transfer mechanisms as well as rigorously validating and supporting the predictive model that is currently developed at NASA.

Intrinsic Merit: These innovative measurements will enable the isolation of the radiative heat transfer from the conductive heat transfer through a TPS material, allowing for the contribution of each of these heat transfer mechanisms to be characterized independently. The data will be made available to the TPS materials modeling groups at NASA to improve thermal conductivity models, thus directly addressing a critical need of NASA. Additionally, this proposed research will facilitate the identification of new fundamental physics, thus achieving new knowledge of individual heat transfer modes in porous media and revealing unverified assumptions. The new knowledge enabled by this effort can potentially impact a range of other applications, such as thermophotovoltaics, thermal rectification, thermal imaging and energy systems like fuel cells. This project will support one graduate and two undergraduate students for one year. The research outcomes will be integrated into outreach activities through the MSU Explore camp and Family Science Day.

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Appendix C: Radiation-Induced Carcinogenesis Biomarker Identification withHydrogel-Based Organ-on-a-Chip System

Wichita State University

Dr. Leonard Miller

One of the primary hurdles to long duration exploration missions to destinations beyond the Earth-Moon system is space radiation (SR)-induced carcinogenesis. Identifying early biomarkers of elevated SR risk for early intervention is crucial for ensuring safe, sustainable human space exploration. Early biomarker detection indicates a need for heightened cancer screening, ultimately improving health outcomes. Traditional approaches involving 2D cell culture or animal models do not fully represent human cells/tissues/systems in vivo, introducing substantial uncertainty when applying results to humans. We have established a 3D microfluidic system utilizing hydrogel-based biomaterials for cell growth to form in-vivo-like microtissues and organoids that recapitulate human cell functions. Cell/hydrogel patterning and microstructure/membrane based perfusion techniques have been demonstrated, including liver and gut-on-a-chip. This project will build upon experience at Kansas State University (KSU), the University of Kansas Medical Center (KUMC), and Wichita State University (WSU), working toward SR biology experiments for identifying novel biomarkers of elevated SR cancer risk.

The project goals are: (1) Establish a research team with members from three Kansas universities conducting collaborative, NASA HRP Space Radiation Element (SRE)-relevant work, and (2) Develop preliminary data for future studies involving the search for novel SR carcinogenesis biomarkers. The project objectives are: (A) Demonstrate digital microfluidics (DMF) to culture complex, hydrogel-based tissues, with a focus on liver and colon; (B) Irradiate samples using Kansas-based radiation sources in the absorbed dose range of interest; and (C) Evaluate samples for known biomarker changes.

This project addresses a significant gap in availability of ideal model systems for SR biology research. It has been established that these organ-on-a-chip models are superior to traditional cell cultures or animal models, but SR biology research requires a model system that can be maintained with minimum intervention to avoid system disruption and for future long-term, in-space investigations, achievable with the proposed system. Additionally, using surgical samples of colon and liver will serve as a proof of concept for investigation of individual variability impacts on biomarkers for organs that are susceptible to SR-induced carcinogenesis. Furthermore, fast neutron exposures are of great interest to NASA, since most space neutron dose is delivered by neutrons with energy > 100 MeV. Our neutron exposures will use the greatest neutron energy possible outside of large accelerator facilities. DMF-enabled dynamic cell cultures have not been used in SR biology research to our knowledge. This work will employ surgical samples from individual people in lieu of immortalized cell lines, which are unlikely to exhibit responses representing normal tissues in vivo due to altered physiology. KSU has unique, space-relevant radiation sources, including the D-T neutron generator and a nuclear reactor. This project will establish a hydrogel-based, organ-on-a-chip model to discover and validate cell based and circulating biomarkers of SR cancer risk.

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Appendix B: NuSil CV-1144-0 Impact on Carbon Phenolic TPS materials for Mars Entry Applications

University of Vermont

Prof. Bernard Cole

In this work we aim to study the impact NuSil� CV-1144-0 coatings present on phenolic impregnated carbon ablator (PICA) TPS materials aimed at Mars atmosphere entry applications. This will be done by subjecting PICA and PICA-N samples to inductively coupled plasma environments tailored to Mars entry trajectory conditions. An array of pre-test, in situ, and post-test experiments are proposed to assess performance augmentation these coatings incur. These experiments include: tracking key boundary layer specie volatiles (via emission imaging), assessing surface coating and penetration depth performance (via SEM/EDS), assessing temperature jump phenomenon (via surface temperature and video imaging), studying conductive heating penetration affects (via TC instrumentation), and developing in-house coating strategies (via manual application and potentially automated application from senior design efforts). The results acquired are anticipated to be readily distributed to appropriate NASA collaborators for numerical validation efforts intended to improve the fidelity of future Mars entry system design.