Contents

24-2024 R3-0001
RFA-011: Parameters Estimation for Informed Orbit Capacity Models, STMD

Iowa State University
Dr. Sara Nelson

The safety of the Low Earth Orbit (LEO) environment is threatened by the constantly growing number of orbital debris, which represents a continuous hazard to the satellites. As space operations are increasing and new satellites are launched weekly, it is crucial to be able to perform a rapid and accurate estimation of the long-term effects of current decisions and events that affect space sustainability. This proposal aims to develop a new model that analyzes the long-term evolution of the Resident Space Objects (RSO) population with the goal of estimating the LEO orbital capacity. The selected source--sink model, MOCATSSEM, is a multishell multispecies model, which includes different object species, such as active and derelict satellites and debris. The model quickly predicts the future LEO population as its initial conditions and settings are changed. This feature allows the user to try different solutions and analyze how multiple actions in the present have repercussions in the far future. Thus, businesses and governments can use the model to predict the long-term effect of their proposed launches and space activity, resulting in a global assessment of sustainably. While the model already provides an estimate in its current version, the work suggested in this proposal aims to improve the current version by fitting and training the system with real data from TLE to increase accuracy. In its current version, the model relies on empirically evaluated parameters whose values have not yet been validated. Thanks to the results obtained in this project, every parameter and coefficient of the model will be considered an unknown random variable that has been estimated. Starting from a deterministic system, stochasticity and uncertainty will be added to the model, and high-order nonlinear estimation will be conducted. The end goal of the proposed statement of work is to derive the best set of parameters that correctly describe the real interactions among the different space species. The model's parameters and coefficient will be estimated thanks to the development of a new filter, which will later undergo a smoothing algorithm. The use of real data publicity available from the community and accurate forecasting evaluated via the Monte Carlo (MC) models (available from our collaborators) supply the source-sink model with plenty of training data to perform fitting and measurement updates. Due to the elevated amount of data, the estimation of the parameters will be furthermore analyzed according to a Maximum Likelihood approach and compared to its Bayesian estimation counterpart. The final result of this proposal is a new set of dynamical equations that perfectly describe the future behavior of the LEO space environment, validated using their MC model counterparts but requesting none of the computational effort, such that multiple predictions can be computed sequentially. Lastly, an assessment of the Least Square approach, with the feasibility of creating a Neural Network based on the Mean Square Error, will investigate the possibility of estimating the model parameters according to Machine Learning algorithms for model fitting.

24-2024 R3-0004
RFA-057: Towards mitigating human-induced changes on coastal communities employing advanced data analytics (SMD-ESD)

Louisiana Board Of Regents Dr.
T Gregory Guzik

Coastal ecosystems are experiencing unprecedented pressures from human activities that disturb the subtle ecological equilibrium within coastal ecosystems, leading to impacts on habitats and biodiversity. Human activities play a pivotal role in affecting coastal physical, geomorphological, and ecological variability. Increasing human population and urbanization have resulted in insightful variations in coastal environments.

Urbanization is changing land use patterns, which leads to habitat loss. An eminent hazard is posed to marine life due to pollution from industrial and agricultural activities. Further, extreme weather events (e.g., hurricanes, floods, storms) due to climate change have exacerbated coastal vulnerability. As such, it is imperative to comprehend and mitigate the impacts of human activities on coastal communities to enhance resilience while sustaining the long-term health of coastal environments. This project aims to explore these intricacies to develop a profound understanding of the complexities confronted by coastal ecosystems in the State of Louisiana. Even though progress has been made in understanding the impacts of human-induced variations on coastal ecosystems, existing approaches fail to fully account for the complexities due to the integration of socioeconomic characteristics with environmental data and predicting the long-term effects of human activities on coastal communities.

This project contributes to bridge these important gaps by leveraging data analytics and socioeconomic data to enhance our understanding of the hurdles encountered by coastal communities in Louisiana. We propose a data-driven model employing advanced data analytics to interpret remotely sensed data to achieve inclusive insights into the human-induced changes influencing coastal communities. The model will be developed based on the integration of convolutional neural networks and long-short term memory to interpret vast amounts of remotely sensed data (e.g., satellite imagery, aerial photographs, LiDAR data) as well as socioeconomic characteristics. By predicting future scenarios and exploring associated risks, the proposed deep learning-based model empowers decision-makers with valuable insights to develop proactive mitigation strategies while considering both ecological and socioeconomic features.

This project aligns seamlessly with NASA's Science Mission Directorate (SMD) vision of promoting scientific knowledge to tackle coastal resilience and equity justice. This work is classified under the research focus area ""Impacts of human activity on coastal physical, geomorphological and ecological Variability"" with research identifier number RFA-057. It represents a collaborative effort among NASA and Louisiana Tech University leveraging a range of expertise from Hazard Resilience, Sustainability and Climate Change Adaptation, Data Analytics, and Social Science. The findings of this project will foster a deeper understanding of the human impacts on coastal communities, leading to promotion of sustainable and resilient coastal development. In addition, the results will assist stakeholders and policymakers make optimal and informed decisions while taking proactive measures to mitigate the adverse effects of humaninduced changes in coastal communities in Louisiana.

24-2024 R3-0006
RFA-028: 3D-printable regolith--shape memory polymer composites for long-term lunar habitats (SMD-BPS)

Louisiana Board Of Regents Dr.
T Gregory Guzik

Given NASA's strategic goal of extending human presence to the Moon and on toward Mars for sustainable long-term exploration, lunar habitats and permanent bases will need to be set up in the foreseeable future. 3D printing and polymers have emerged as promising choices for fabrication method and material, respectively, to build many structural and functional components of such habitats. Among polymers, shape memory polymers (SMP) offer an attractive choice especially for lightweight, selfdeployable structures owing to their ""active"" microstructure that dynamically responds to external stimuli such as thermal heating. Several SMP-based structures have already undergone spaceflight experiments.

Despite their promising aspects, SMPs suffer from poor thermal stability and low recovery stress, specific strength and stiffness. SMP-based composites can overcome these limitations by combining the superior thermo-mechanical properties of composites with the functional shape-memory and self-healing properties of SMPs. Motivated by the recent discovery by the co-I of a 3D printable hollow glass microsphere (HGM)--SMP composite that exhibited excellent thermal stability, mechanical properties, shape memory response, flame retardancy, and self-healing, the goal of this proposal is to develop an equivalent 3D printable regolith--SMP composite for application in lunar habitat constructure enabled by in-situ resource utilization (ISRU), and to generate fundamental understanding of the processing-structure--property--performance relationships of such composites.

In this study, we will synthesize an SMP-based particulate composite by mixing a lunar regolith simulant with a polymeric mixture of a high-temperature SMP and photo-initiator. Using our validated Digital Ink Writing method for such composites that features UV and thermal curing, we will 3D print regolith--SMP composite specimens. We will validate and optimize our composite fabrication method based on Scanning Electron Microscopy (SEM) of the printed samples. To understand the process--structure--property-performance relationships of this composite for the extreme lunar environment, we will conduct thermomechanical and materials characterization on a number of test samples fabricated with different regolith weight percentages and 3D printing parameters. The following tests will be conducted to evaluate the mechanical and shape memory performance: quasi-static and high strain rate compression tests in a wide range of temperatures from (-150°C--120°C) and under a wide range of loading rates (10-3--103 s-1), quasistatic and high strain rate tests after successive thermal cycling (0 to 60 cycles), quasi-static free shape recovery tests, CT scanning (to evaluate microstructural defects), impact damage tests, and SEM (to evaluate self-healing and crack closure after damage).

By developing the first-ever regolith--SMP composite, the proposed study will create an immediate, positive impact on NASA's efforts to design space-resilient structures via ISRU for its strategic goal of longterm deep space exploration. The proposed work targets the RFA-028 ""Materials Science"" research focus area of the NASA's Division of Biological and Physical Sciences (BPS). Our proposal is in line with the MATRICES (Manufacturing Materials and Processes for Sustainability in Space) research campaign recommended by the Decadal Survey on BPS Research in Space 2023--2032 and will contribute to answering two key scientific questions posed in this survey (i.e., KSQ 6 and KSQ 9). Due to its focus on a smart, lightweight material, this study will positively impact several high-priority technologies for NASA under technology taxonomy areas TX11 and TX12. Further, this project will enhance the mechanics and polymers research infrastructure and workforce training in Louisiana. NASA Marshall Space Flight Center (MSFC) will directly collaborate with us on this project in an advising and oversight role.

24-2024 R3-0007

RFA-005 A Combined Digital Image Correlation + Explicit Finite Element Method Approach to Determine Rate Dependent Composite Material Properties for the LSDYNA MAT213 Model. Subramani Sockalingam

College of Charleston
Dr. Cassandra Runyon

We propose to develop a combined digital image correlation (DIC) + explicit finite element method (EFEM) approach to characterize strain rate dependent composite material model parameters for the LS-DYNA MAT213 material model developed by a team led by NASA and the FAA. MAT213 is a combined plasticity and damage material model developed for simulating the impact response of composite materials and structures. To characterize the rate dependent material response, we will perform dynamic tension tests on off-axis composite specimens (i.e., fibers are oriented at angle ¸ with respect to the loading direction) in a split Hopkinson pressure bar (SHPB) with high-speed optical DIC. Since high strain rate loading of off-axis composite specimens produces non-homogeneous and transient stress/strain states that are atypical of classical SHPB analysis that assumes homogeneous deformation, we will develop and apply a novel DIC+EFEM approach to determine the transient stress fields. The DIC+EFEM approach will utilize force- and DIC- displacement/acceleration measurements as input. The measured input will be used to calculate internal forces, and hence the stress fields, within each continuum finite element by solving the governing equations of motion.

To characterize the post-peak strain softening material response under dynamic loading conditions, a series of dynamic experiments will be performed using a notched specimen such as single edge notch tension or compact tension. Specifically, dynamic tension experiments along both the in-plane and through thickness directions will be performed. The DIC+EFEM technique will be applied to determine the post-peak strain softening material response. The proposed research has the potential to significantly reduce the time-intensive design and certification timeline of aerospace composite structures.

24-2024 R3-0008

RFA-010, Integrating Bipolar Membrane Electrochemical Cell with PdCu Dilute Alloy Cathodic Catalysts for One-Unit CO2 Capture and Utilization, STMD. MingYang

College of Charleston
Dr. Cassandra Runyon

In collaboration with NASA Jet Propulsion Laboratory, we propose a design and validation of an integrated electrochemical system featuring 1) bipolar membrane (BPM) functions to enable reversible CO2 capture and recovery and, synergistically, 2) cathodic catalyst layers (CL) using atomically precise PdCu dilute alloy catalytic centers for selective methane or ethylene production as either fuel or building block molecules. The proposed work will facilitate a robust and competitive space technology in combating U.S. climate change while producing value-added chemicals for space operations. To support NASA missions on in situ resource utilization (ISRU), the successful development of the proposed CO2 capture and conversion technology will contribute to sustainable chemical/fuel production for applications in low Earth orbit (e.g., space station, transit vehicles) and the Mars environment.

The present mainstream technology for capturing and converting CO2 into CH4 is a multi-stage and energy-consuming process. This involves water electrolysis to produce highly flammable H2 in the first stage. The H2 then reacts with the recovered CO2 at elevated temperatures through a Sabatier reaction to generate CH4 or further pressurized reactions to generate C2H4. In addition, capturing CO2 usually requires a separate unit with an intensive process to recover the CO2 as a concentrated gaseous reactant stream. Together, these bear significant energy loss, multi-step operations, and safety/ environmental concerns.

In response to these technical challenges, the overarching goal of the proposed work is to develop an integrated CO2 capture and conversion by leveraging the electrochemical potentials and tailored BPM and CL. Unlike the mainstream work reported in the literature that typically adopts a concentrated gaseous CO2 feed stream only for electrocatalytic CO2 reduction reaction (eCO2R), we will use KOH-based electrolytes as inexpensive and efficient adsorbents to capture dilute CO2. Next, in our integrated electrochemical system, the CO2 in its aqueous ionic carbonate and bicarbonate forms, which are mostly catalytically inert, can react with the in situ generated H+ from the BPM with a reverse bias to recover gaseous and dissolved CO2 molecules in affinity to the CL featuring atomically precise PdCu dilute alloy catalysts to produce CH4 or C2H4 selectively. Our proposed technology will have the following advantages when measuring against the benchmark: 1) a reusable single-stage reaction system is needed to capture, release, and convert CO2; 2) the entire process will take place at ambient temperature and pressure; 3) the production of highly flammable and hard-to-liquify H2 is not required. Building upon our preliminary findings of BPM for CO2 recovery and dilute PdCu alloy catalysts for high-yield eCO2R, we plan to achieve ~70 % overall CO2 utilization efficiency and ~70 % Faradaic efficiency in the current densities range of > 100 mA/cm2 for CO2 conversion when completing the project.

The proposed research work centering around carbon capture and utilization by NASA to combat U.S. Climate change (RFA-010) provides our students, particularly from underrepresented groups and small-tomedium-size departments and institutions in South Carolina, a fertile platform to ignite research interests and career passion gearing toward the targeted industry sector of clean and sustainable energy and highpriority research field of advanced materials and system engineering defined by Vision 2030: South Carolina Science and Technology Plan. In collaboration with STEM outreach and DEI initiatives at Clemson and South Carolina NASA EPSCoR, our team aims to disseminate the science and ignite the research passion in diverse groups of students.

24-2024 R3-0012
RFA-006: Multiscale Modeling of Fiber-Woven Composite through Fusion of NASMAT and Peridynamics, STMD

University Of North Dakota, Grand Forks Dr.
Caitlin Milera

In this proposal, a hybrid multiscale modeling tool will be developed to integrate the NASA Multiscale Analysis Tool (NASMAT) with peridynamics. The expanded tool will be able to model fracture initiation, trace fracture propagation, and capture the physics of composite failure at different levels. On the NASMAT side which intends to capture the continuum responses of composite materials, the High-Fidelity Generalized Method of Cells (HFGMC) is to be implemented. HFGMC enhances traditional continuum models in that it captures the microstructural effect of the composite and models its micromechanical responses under loads accurately. Peridynamics will be used in the fracture process zones, which could trace fracture initiation, propagation, and finally material disintegration. The proposed methodology will target two different materials: Carbon fiber reinforced polymer composites and fiber-woven composites. In fiber woven composites, fiber-fiber interaction, fiber tow-fiber tow interaction, and the support of matrix system will be the key mechanisms to be modeled, while carbon fiber reinforced polymer composites will focus on fiber and matrix interaction. Several case studies are considered for both materials.

The handshake method will be adopted to join different scales in the continuum domain and the fracture process zones. Weakform peridynamics will be developed to connect the micro-potential of each node with different horizon sizes. The micromodulus and critical stretch for fiber, matrix, and fiber-matrix interface will be derived and validated through experiment data. In the end, a multiscale integrated hybrid Peridynamics-NASMAT tool will be able to model materials from intact to total failure with consideration of complex microstructures.

24-2024 R3-0013
RFA-032: Simulating Accidental Combustion Phenomena at Cryogenic Conditions (SOMD)

University Of North Dakota, Grand Forks
Dr. Caitlin Milera

This project will develop a computational tool (that is readily transferrable to NASA) to determine the ignitability and reactivity of liquefied natural gas (LNG) and oxygen plumes resulting from leaks/boil-off that originate from cryogenic storage tanks (during storage) or vehicles (on the launch pad). Capitalizing on

OpenFOAM software's unstructured meshing framework, the tool will use as inputs: CAD files of representative storage tank/launch vehicle geometries, vent locations, and surrounding structures to simulate the plume dispersion and combustion scenarios in a geometrically realistic manner.

Unique aspects of this tool that helps overcome several of the shortcomings in the current State-of-Art (SoA) include: (1) the use of Reynolds Stress Models in conjunction with robust pressure-velocity coupling schemes to model the anisotropic turbulent stresses resulting from the stabilizing effects of density in the vicinity of the leak; (2) modeling the effects of condensation/re-evaporation of fog droplets through appropriate source and sink terms in the scalar and enthalpy transport equations. These can become important at high levels of relative humidity during which the fog cloud can overtake the LNG vapor cloud thereby slowing down the process of LNG vapor dissipation; (3) employing multi-step skeletal reaction mechanisms of sufficient fidelity for CH4 and C2H6 to account for the composition variations within the LNG cloud when establishing flammability limits. These compositional variations in the cloud may result from the compositional variations of LNG itself as well as due to differential boil-off (volatilities) of the various constituents in the storage tank; (4) an accurate characterization of over pressure and thermal hazards in the event of a flash fire including predicting the concentrations of all relevant radiating specie (including soot) and resolving the directional effects of the highly anisotropic intensity on an established flame field.

Outputs from the tool will include: safety distance (d), dispersion safety factors (DSF), the conditional probabilities of developing a flash fire or vapor cloud explosion (VCE) (evaluated on the basis of leakage rates and ambient conditions) and associated pressure-time histories. The safety distance (d) will be expressed both in terms of its: visible boundary (dvis) (estimated from the fog formation model) and the point where the composition reduces to 50% of its lean flammability limit LFL (dLFL). DSF will then defined to be equal to dvis/dLFL. In the event of a flash fire or VCE, safety distances will be computed based on radiative fluxes of 3 kW/m2 or over-pressures of 1 psi as threshold values for injury onset. For the oxygen release simulations, a plume temperature of 233 K (to characterize low temperature hazard) and a volume fraction of 30% (considered as a threshold concentration for accelerating combustion phenomena) will be employed to identify hazard zone boundaries. Twelve scenarios variations in: LNG compositions (CH4, 85 and 95 vol %, rest C2H6), boil-off rates (10 and 100 gallons/day), relative humidity (RH 30 and 70%), atmospheric Pasquill stability class (D5: neutral, wind velocity of 5 m/s and F2: very stable, wind velocity of 2 m/s) and ground heat fluxes (30 and 300 kW/m2) will be simulated to encompass the entire range of dispersion scenarios that are anticipated to be encountered."

24-2024 R3-0015

RFA-078: Detecting Infrasonic Signatures of Venus Seismic Activity by Balloon-Borne Sensors at 55 km Altitude (SMD-GRC)

Louisiana Board Of Regents
Dr. T Gregory Guzik

The proposed research will initiate the first systematic study for Venus exploration in Louisiana. The Science-I is actively involved in international collaborations on planetary science missions for Venus, Mars, Titan, and Saturn.

The project will contribute to aerial seismology on Venus by addressing surface-to-atmosphere acoustic coupling, propagation, and detection of venusquake-generated infrasound. Thus, the proposed work answers to the atmospheric, dynamical, and geophysical components of NASA's Solar System Workings program and as such is highly relevant. It also addresses the need for studies of planetary interior structure, lithospheres, volcanism, and evolution and modification of surfaces. These elements are addressed in the proposed work whose premise is to detect acoustic signatures of seismic activity on Venus.

Central to the problem is understanding the mechanisms by which surface dynamics couples to the atmosphere through acoustic waves. On Earth, earthquakes can produce infrasonic waves that can travel over long distances, with relatively small attenuation. The hot and dense atmosphere of Venus makes it considerably more ``acoustically friendly'' than Earth owing to i) the roughly 70 times more efficient transfer of acoustic energy from surface motion into the atmosphere and ii) small sound attenuation, especially at infrasonic frequencies. These factors, pointing to an efficient surface-to-atmosphere coupling, are especially encouraging for mid-atmospheric sensing of surface-generated infrasound.

In order to be able to detect Venus geodynamic events, landers have to be built to extreme specifications to withstand the planet's harsh environment for long time periods. The work proposed here will ultimately lead to developing an atmospheric remote-sensing approach by which infrasonic arrivals, detected by high-altitude balloons, can be used as a direct probe of Venusian seismic events. The goal of the proposed work is to develop a predictive framework for detecting and quantifying mantle/crustal dynamics on Venus through their acoustic coupling with the atmosphere. The science objectives are: 1) understanding surface-atmosphere dynamical coupling via seismoacoustic infrasound generation, and 2) developing a catalog of synthetic venusquake- generated infrasonic waveforms detected on a freely floating balloon at 55 km.

24-2024 R3-0016

RFA-024, SMD-BPS, Quantum Chemical Computation of PAH Spectral Features in the Age of JWST

University Of Mississippi
Dr. Nathan Murray

The launch of JWST in late 2021 has provided the most high-resolution space-based infrared spectra ever produced. This has opened the spectral mining of such observations in the finest detail, but elucidation of such spectra (along with subsequent astrophysical insights) can only be determined with clear molecular spectral benchmarks. Quantum chemistry promises to be the most efficient means of producing such data for the large numbers of possible molecular carriers necessary to characterize JWST IR spectra. This work will focus on providing the absorption spectra of polycyclic aromatic hydrocarbons (PAHs) from a trained semi-empirical method developed by the PI as part of a previous NASA APRA grant. These fast electronic structure computations will be conjoined to vibrational perturbation theory in order to benchmark the method and then produce fundamental vibrational frequencies for more than 20 unique and novel PAHs some with up to 9 rings. The data will be included in the NASA Ames PAH IR Spectroscopic Database (PAHdb) where the blend of spectral features can be utilized by astronomers from all over the world to compare with and explain JWST observations.

24-2024 R3-0023
RFA-005, Development of Experimental Framework to Characterize Rate and Temperature Dependency in Composite Material Properties for the LS-DYNA MAT213 Model, ARMD

University Of Mississippi Dr.
Nathan Murray

Space launching and reentry systems and aerospace structures could experience unexpected high-energy impact damage as shown in the wing damage of space shuttle Columbia on the STS-107 mission and the fan blade-out impact damage to the Southwest Airlines Boeing 737 in 2003 and 2018, respectively. To address this issue, the MAT213 model was developed by a consortium led by the Federal Aviation Administration and the National Aeronautics and Space Administration (NASA) to simulate high-speed impact damage in composites. Co-I/Science-PI Kim has been collaborating with engineers at the NASA Glenn and Langley Research Centers to develop an experimental framework to characterize key material input parameters for MAT213 from lab testing and validate the input parameters through simulations. The previous study was focused on Toray Cetex TC1225 Low-Melt PolyArylEtherKetone (LMPAEK) thermoplastic reinforced by T700GC unidirectional carbon fibers. The key material properties and full-scale stress-strain curves of the material were experimentally characterized and an MAT213 material input card for the material was built. Currently, the deformation sub-model of MAT213 for the material is being built and validated through dynamic testing of non-damaged specimens. Based on this progress and achievement, the proposed work is focused on obtaining experimental data to build and validate a damage sub-model of MAT213. The main objective is to characterize rate and temperature dependency in composite material properties from the experimental data for high-fidelity simulation of impact damage under high-energy impact loading. Building and proposing an experimental framework for the experimental characterization of the rate and temperature dependency is also of primary interest.

The experimental work will begin with drop-weight impact tests on the NASA-supplied composite specimens. This test stage intends to obtain an understanding of the impact damage and subsequent dynamic response of the material at the low strain-rate regime under room temperature. These tests will be conducted based on ASTM D7136 using an Instron Dynatup 9250 HV Impact Tower and digital images will be collected for DIC analysis of displacements and strains induced over the specimen surface. Based on the experimental data, a test matrix for ballistic impact tests will be established. The tests will be conducted using a REL Split Hopkinson Pressure Bar system (30-ft long) with an inTest Thermostream system. Considering the glass-transition temperature of the material, several test parameters of strain rates and temperatures will be decided between 200/s and 2000/s and between -60°C and 225°C (-76°F to 437°F), respectively. A test fixture will be designed and fabricated based on ASTM D8101 to induce multiaxial strains in the specimens. Digital images will be captured using a Fastcam SA-Z ultra-high-speed camera (up to 120,000 fps) for DIC analysis. Based on the experimental data from the drop-weight and ballistic impact tests, rate and temperature dependency in the material properties will be characterized. Additionally, an experimental framework to characterize rate- and temperature-dependent composite material properties using the two test systems will be developed and proposed with recommended temperature and strain rate ranges. Lastly, a preliminary damage sub-model of MAT213 for the material will be generated and validated using the experimental data.

The proposal package herein intends to continue the collaborative effort and partnership between CoI/Science-PI Kim and the NASA collaborators to enhance the capabilities of MAT213. More efforts will be made to complete the damage sub-model after the proposed project period is ended. This long-term project will contribute to developing a high-fidelity simulation tool based on the MAT213 model to predict and prevent high-energy impact damage in composites for space launching and reentry systems and aerospace structures.

24-2024 R3-0026
RFA-013-Development of high-temperature multi-principal element silicide coatings-STMD

**Oklahoma State University Dr.
Andrew Arena Jr.**

The rapid response research (R3) grant request aims to develop thermal barrier coatings (TBCs) of multiprincipal element silicides (ME-silicides), newly discovered ceramic materials, that offer microstructural stability and superior mechanical properties at high-temperature (1200-2000 C). These materials are extremely versatile and promising and are being explored as next-generation environmental barrier coatings to protect Nb-alloys against oxidation in rocket nozzles, combustion chambers, and other propulsion components in extreme environments encountered on interplanetary missions such as to Venus. Based on the latest NASA Strategic Plan and R3 solicitation (RFA-013), developing an understanding of fundamental properties that enable higher-performing materials has been recognized as one of the critical challenges to supporting the success of space missions. While several space expeditions have been successfully launched to date, the possible deterioration of mechanical strength and oxidation of materials at high temperatures are still the major bottleneck for ever-growing space expeditions and interplanetary explorations in unknown harsh environments. The long-term emphasis of this research will be to develop a fundamental understanding of the thermophysical properties of ME-silicides for use both in space and on earth and provide promising alternatives as environmentally stable TBCs. The proposed R3 plan will provide the stepping stone to serve this long-term objective where the PI will conduct the studies to produce high entropy silicide thin films and coatings and advance the fundamental understanding of materials properties and atomic/microstructure response to high-temperature conditions. This work will initiate the new collaborations with Dr. Ronald Noebe at Glen Research Center (GRC), who also serves as the point of contact for research focus areas RFA-013.

In the view of atomic-level crystallography, the MES family of materials consists of multiple (typically three or more) elements in the same lattice position that increase the disorderness in the structure, generate new atomic-level interactions, and significantly modify the material properties. However, the grand challenge in designing MES coatings is the inability to gain critical access to a large possible compositional space that can be created by mixing the constituent elements in several different ratios. While traditional metal silicides have already been established as effective TBCs for hot sections of the space components, ME-silicides are hypothesized to supersede the current state-of-the-art performance. Our hypothesis is that the coexistence of selected multiple elements at one cationic site in entropy-stabilized ME-silicides will create diverse M-Si (M = Nb, Hf, Ti, Fe, Cr) bonds from contributing cation elements that significantly modify the characteristic electronic structure and enhance the high-temperature oxidation radiation resistance. The central goal of this rapid research project is to initiate a synergistic effort to test this hypothesis and accelerate the discoveries by studying several materials libraries of ME-silicides using (i)

combinatorial thin film synthesis, (ii) micro-to-atomic scale characterizations and (iii) high-throughput property measurements. This approach will comprehensively advance the fundamental knowledge of possible structures, the role of elemental mixing, and the thermophysical properties of ME-silicides, which have an untapped potential. In addition to the proposed tasks by Dr. Sachan, collaboration with GRC will facilitate high-temperature mechanical testing and environmental testing in air to combustion gases' environment. This collaboration will further help Dr. Sachan and students in career development and longterm networking.

24-2024 R3-0027
RFA-078--Universal Infrasound Noise Mitigation for Aerial Platforms on Venus—SMD

Oklahoma State University Dr.
Andrew Arena Jr.

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. A technological limitation to the threshold for earthquake detection is the sensor noise floor, which includes the impact of wind noise. Our team has collaborated with NASA JPL researchers for the past few years leading flight operations for infrasound equipped solar balloons, including work developing a lightweight, compact windscreen for infrasound sensors on aerial platforms. A design using a canvas material combined with a dense foam was identified that suppressed the noise by up to 12 dB at speeds up to 6.5 m/s. However, the final design was customized based on the type of infrasound sensor being used and not readily adaptable to other infrasound sensors. Thus, the current project aims to modify the previous windscreen design to make it independent of the sensor in order to lower the threshold of detectable Venus-quakes (or other infrasound producing physical processes within the Venus atmosphere).

The goal is to modify the original windscreen design such that it has a standard acoustic inlet without degrading the performance (i.e., suppression of incoherent noise without attenuating coherent signals) or increasing the size and weight. 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 sensor. 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 demonstrated the ability to suppress wind noise on aerial platforms using multiple infrasound sensors. 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.

24-2024 R3-0028

RFA-042, Identification of High Latitude Cloud, Aerosol, and Blowing Snow Layers with Machine Learning of Lidar and Polarimeter Data (SMD)

University Of North Dakota, Grand Forks
Dr. Caitlin Milera

The Arctic has experienced unprecedented change with a warming, more humid climate with increased sea-ice melt. Overall, the changes seen in this region have led to the nomenclature of a ""New Arctic"" which is dominated by a lack of multi-year sea ice (e.g. only seasonal coverage) and an increased hydrological cycle with more precipitation. Clouds, aerosols, and blowing snow are all critical components of the Arctic system with many unknowns surrounding their impacts on surface-atmosphere interactions including the energy and water budgets. While these processes can be observed with various NASA satellites and airborne field campaigns, separating these processes can be challenging.

In response to RFA-042: 'AI/ML algorithms to obtain and improve 3-dimentional remote sensing of the Earth's aerosols, clouds, oceans and lands using advanced lidar and polarimeter data.', the primary objective of this proposal is to apply Artificial Intelligence (AI) / Machine Learning (ML) techniques to classify layers of clouds, aerosols, and blowing snow from remotely sensed measurements. This objective will be achieved by modifying algorithms already developed for surface-based measurements that successfully separate falling and blowing snow. These algorithms will be trained on data from past NASA satellite missions as well as the current Arctic Radiation-Cloud-Surface-Aerosol-Interaction Experiment (ARCSIX) NASA airborne field campaign.

The results of this work will pave the way to better understanding of the Earth's climate system which falls under NASA Strategic Goal 1.1. Specifically, the algorithm and classification of atmospheric layers will have utility to a broad group of Earth scientists working to better understand the Arctic climate system. Products will directly support ARCSIX science objective while also being applicable to the polarimeter instrument onboard the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) satellite mission.

24-2024 R3-0029

RFA-015: On-Demand Manufacturing of Soft Bioionic and Bioelectronic Devices for In-Space Cell Studies, STMD, ESDMD, SOMD

Iowa State University
Dr. Sara Nelson

NASA's Artemis program aims to reestablish human presence in outer space, with the long-term goal of establishing a permanent lunar base to facilitate the feasibility of human missions to Mars and beyond. The prolonged habitation of humans and other biological species in outer space presents unique challenges from a biological perspective. It necessitates a deep understanding of how biological systems may evolve and adapt to space environments, where many key factors such as gravitational field, radiation index, diurnal and annual cycles, and the Milankovitch cycles either significantly differ from those on Earth or are entirely absent. Precision hardware and electronics tailored to the exact in-space experimental conditions are essential in conducting studies needed to gain such understanding. There is a need for ondemand in-space manufacturing to support science mission activities and allow crew members to fabricate these specialized items and conduct necessary experiments, facilitating the study of biological systems in space environments.

NASA's Advanced Manufacturing initiatives are intended to broaden the scope and capabilities of ondemand manufacturing in space. This proposal aims to investigate and develop two manufacturing technologies, laser-assisted on-demand manufacturing and on-demand electro-hydrodynamic jet (e-jet) printing, for their potential applications in the study of biological systems in space environments to facilitate a deeper understanding of how spaceflight and space environments affect physiological attributes of biological systems.

This project aligns with NASA's In Space Manufacturing/On-Demand Manufacturing of Electronics (ODME) and Biological and Physical Sciences (BPS) RFAs. One of our collaborators, Dr. Jesica Koehne, is leading ODME RFA and is an expert in advanced and adaptive manufacturing of miniaturized electronics. Our other collaborator, Dr. Richard Everroad (also a collaborator of Dr. Koehne), is a research scientist in the Exobiology branch at Ames Research Center with expertise in both Astrobiology and Space Biology. He has contributed to three ISS microbiology investigations (two as the leader).

Building upon our preliminary studies, the primary goal of this proposed study is to develop a technical platform for the advanced and on-demand manufacturing of a novel class of soft electronics. This development aims to support the exploration and comprehension of how biological systems evolve and adapt to space environments. The objectives of this EPSCoR proposal are targeted for completion within one year and are outlined as a set of comprehensive preliminary studies for future studies beyond this project. Two main objectives are proposed:

Objective 1. On-demand manufacturing of soft electronics in simulated space environments
Objective 2. Assessing the viability of these soft electronics by prolonged (three to six months) in vitro studies of biological systems in simulated space environments

We expect the outcomes of this study to demonstrate that in-space on-demand manufacturing technologies can be developed to create soft electronics for studying how biological systems evolve and adapt to space environments. The primary contributions and the impact of this research on the field are:

1) Development of novel technologies for in-space on-demand manufacturing of soft electronics to support mission activities and in-space research. The impact of this contribution is expected to extend beyond space applications and benefit advanced manufacturing technologies by introducing new capabilities.

2) The knowledge we gain on the evolution and adaptation of biological systems in simulated space environments, using the on-demand manufactured soft electronics, would have an impact on our understanding of how biological microsystems--and in long-term humans, animals, and plants--are affected in prolonged space missions and adapt to space environments."

24-2024 R3-0038
RFA-026, RFA-022, Bubble emulsions in microgravity, BPS

Brown University
Dr. Ralph Milliken

An emulsion is a dispersion of liquid droplets into another liquid; due to their prominence in many industrial applications and natural phenomena, these dispersed two-phase flows have been studied extensively. Since the density difference between two immiscible liquids is generally small, emulsions are relatively stable (drops remain suspended and dispersed). If we consider the dispersed phase to be a gas, bubbles instead of droplets, we could form a bubble emulsion. The unique properties of such fluids could have novel applications. For instance, resulting from the compressibility, the speed of sound in bubble emulsions would be significantly slower than that of pure liquids. However, due to the large density difference between gases and liquids, a bubble emulsion would quickly separate making it difficult, if not impossible, to use them on Earth.

Without gravity, a bubble emulsion would be stable due to the absence of buoyant forces. Such a situation has been studied theoretically and numerically but, to our knowledge, no experiments exist. There are some two-phase bubbly flows in microgravity, including flow boiling experiments on the ISS, but none of them have studied the properties of bubble emulsions. Of particular interest for practical applications is the formation process and stability of such emulsions. We foresee a myriad of future applications in space engineering, such as thermal control (a porous liquid would have unique insulating properties), propellant handling (bubbles significantly change the performance of liquid propeller thrust), and water remediation (the performance of aeration tanks would be vastly changed in microgravity).

However, the formation process and stability of these emulsions are not known. We propose to study these two processes experimentally. We conjecture that, in microgravity, stable bubble emulsions can be produced by mechanical agitation. To conduct this investigation, an experimental setup suitable for microgravity laboratories will be designed and fabricated. The sound attenuation properties of bubble emulsions will also be assessed. The setup will consist of a truncated cube-shaped tank containing a liquid and gas, initially separated. The agitation will be produced by eight impellers, located on each truncated corner, rotated by DC motors. The use of such an impeller arrangement will produce isotropic homogeneous turbulence throughout the liquid. The fragmentation will continue until a balance between surface tension and turbulent forces is reached. Our study will determine these conditions. Once the emulsion is formed, the impellers will be turned off to study the stability of the emulsion. We will also use a hydrophone-speaker arrangement to measure the speed of sound and attenuation through the mixture. The tests will be conducted in the short-duration microgravity environment available in drop towers and zero-g parabolic flights. Initial tests at NASA Glenn drop tower are scheduled for Spring 2024 (2.2 seconds of microgravity). A significant portion of the budget of the present proposal will be used to pay for the zero-g flight experiments, using the same experimental setup.

This project is aimed to answer fundamental questions about the behavior of bubble emulsions in microgravity. Our experiment will also address the difficulties of both engineering and design in space. For the case of NASA's EPSCoR R3, this proposal falls in the interest of NASA BPS Mission Directorate, specifically, the Research Focus Area in Fluid Physics (RFA-026). The results of the project will also have practical implications for the Research Focus Area: RMAF Facility for the Common Habitat Architecture (RFA-022), particularly for the area of 3D printing, where bubbles are known to cause serious performance problems. Furthermore, the need for basic research, for multi-phase flows in microgravity, is included in the Established Program to Stimulate Competitive Research 2024, Appendix A.3.7."

24-2024 R3-0042

RFA-016: On-demand, in-space additive manufacturing of soft and stretchable electronics ODME

University Of Nebraska, Omaha
Dr. Scott Tarry

The research objective of this proposal is to adapt a direct ink write 3D printing method for in-space manufacturing of soft and stretchable electronics, sensors, and supporting hardware using a space-grade functional emulsion ink. The proposed space-grade emulsion ink will comprise of spherical liquid metal microdroplets dispersed in a space-grade prepolymer matrix, allowing for the creation of a soft and highly extensible elastomeric composites. Previous research funded by NASA NE Space Grant demonstrated the controllable transformation of spherical droplets into elongated ellipsoids, which ultimately control material properties. The initially isolated droplets can also be formed into connected networks, enabling the creation of insulating or conductive regions. Such capability in space would allow on-demand programming of physical properties and fabrication of new electronics and sensors. Three objectives will accomplish the overall research objective of developing a space-grade material system and an effective manufacturing strategy for in-space production of sensors and electronics. Objective R1- Compatibility Verification: My research team and I will validate the compatibility of space-grade silicone elastomers such as 93-500 (Dow) or SCV-2585 (NuSil) with the existing manufacturing process. This critical step will ensure the feasibility of utilizing high-performance materials for in-space applications. Objective R2- Microelectronic Compatibility: My research team and I will measure the minimum electrical trace pitch and via size. A minimum trace pitch < 0.8mm will allow integration with a wide range of microelectronic components, expanding the versatility of the proposed technology. Objective R3- Fully Printed Stretchable Electronics Circuit: My research team and I will demonstrate the manufacturing capability by creating a fully printed and stretchable electronic circuit for sleep monitoring. This application showcases the adaptability and real-world potential of our technology for on-demand creation of electronics in-space. By accomplishing these objectives, our research team will establish a robust foundation for on-demand, inspace manufacturing of stretchable electronics, thereby advancing the frontiers of space exploration and technology.

24-2024 R3-0049

RFA-015, Computational Design of 3D-Printed Battery Architectures for Flexible Solid-State Sodium Batteries, MDs (SOMD, ESDMD, STMD)

Brown University
Dr. Ralph Milliken

This project aims to develop a multiscale computational design toolset for 3D-printed conformal-andflexible polymer-solid-electrolytes-based sodium-ion solid-state batteries (Na-Poly-SSBs).

The proposed research is a critical element for NASA's In-Space Manufacturing/On Demand Manufacturing of Electronics (ODME) technical focus area. NASA's future in-space and planetary expeditions and longduration manned space missions require in-space manufacturing technologies with in-situ resource utilization (ISRU). Due to the lack of lithium in space, the current state-of-the-art lithium-ion batteries are not suitable for such applications, The moderately volatile sodium (Na) is more abundant on the Moon and Mars, thus more suitable for ISRU and ODME. The integration of electrode materials containing abundant elements (e.g. sodium nickel iron manganese oxide) with mechanically flexible polymer solid electrolytes will open up new possibilities for on-demand 3D printing of conformal-and-flexible and safe energy storage devices. However, so far, 3D-printed Na-Poly-SSBs have not been explored, especially for their full potential for in-space manufacturing, neither experimentally nor computationally.

To enhance NASA's In-Space Manufacturing ability on Na-poly-SSB, we propose to develop a multiscale computational design toolset to accelerate the design process. To overcome the challenges of lack of input parameters for typical continuum-level battery performance design models (e.g. implemented in COMSOL), the multiscale modeling approach will leverage data from density functional theory (DFT) predictions and experiments. We will further take advantage of machine learning algorithms to obtain transferable parameters for the 3D battery design. Thus, this model will be able to adopt the everincreasing options of the newly developed advanced electrode and solid electrolyte materials. We will first develop 1D Models and transferrable materials parameters for Na-poly-SSB with different materials, then extend the 1D model to a 3D model with coupled electrochemical mechanics to explore 3D battery architecture design for the balanced energy density and mechanical properties. For the missing material properties, such as interfaces fractur energies, DFT-based calculations will be performed to provide the inputs.

*The scope of work is Fundamental Research and has civil and military applications.

24-2024 R3-0050
RFA-078: Multi-altitude Guidance and Control System (SMD, STMD)

Nevada System of Higher Education
Dr. Eric Wilcox

Background: Robotic platforms (e.g., Superpressure Balloon by Jet Propulsion Laboratory (JPL), Air Ballast Balloon by Google Loon, Hybrid Airship by Northrop Grumman, and Japan's Venus climate orbiter Akatsuki, etc.) [1] [2] need multi-altitude guidance and control systems to allow them to work optimally to explore and collect data in Venus's atmosphere. However, there are currently few research and development efforts related to the guidance and control of Venus's aerial platforms [2]. Without these measures in place, the Venus aerial platforms are not able to operate efficiently or collect data.

Objectives and Methods: This project's five SMART objectives and five associated deliverables will lead to the creation, testing, and validation of two algorithms. These algorithms will address the challenges NASA faces when navigating Venus's atmosphere and enable precise aerial platform positioning, ensuring optimal altitude and path finding within the planet's middle atmosphere. To achieve these SMART objectives and deliverables, first, we will develop a localization algorithm, called the maximum correntropy criterion-extended Kalman filter (MCC- EKF), to allow the aerial platform to locate itself in Venus's middle atmosphere. Second, we will develop a vertical and lateral control algorithm that considers the localization outcomes and supports the aerial platform to find an optimal altitude and lateral path. The vertical control will be constructed based on the artificial potential field approach, and the lateral control will be done via the belief-based online partial observable Markovian decision process (POMDP). These algorithm developments will allow us to understand the aerial platform localization and navigation needed to explore Venus's atmosphere.

Plan and Collaboration: This work will be performed by the Science PI, Dr. Hung (Jim) La, and his Ph.D. student in collaboration with NASA JPL scientist Dr. James Cutts. He will support Dr. La's team by facilitating access to and interpretation of Venus data to train and validate the developed algorithms (see the letter of support). Dr. La will have the opportunity to collaborate with Dr. Cutts to work on Venus's aerial platforms, even validating the proposed algorithms on the newly developed Venus Variable-Altitude Aerobot (VVA) simulation and prototype [3]. With the support of Dr. Cutts and his team, Dr. La can focus on atmospheric modeling and navigation for this VVA platform. Additionally, JPL will provide insight into their data to help Dr. La's team analyze and interpret it to feed the localization and navigation algorithms. The insights from JPL scientists are critical for this project since the analyzed radar and SAR data will lay the foundation for the next objective: creating a vertical and lateral navigation control algorithm. The project fits NASA's focus area (RFA-078) ""Aerial Platforms for Missions to Measure Atmospheric Chemical and Physical Properties.""

Expected outcomes: The major outcomes created as part of this project are the localization algorithm and the control and navigation algorithm. Since JPL is currently lacking efficient guidance and control mechanisms for Venus's aerial platforms, it is difficult for NASA to launch Venus's exploration mission. Thus, these two algorithms will advance science and meet NASA's research needs. The new development of the MCC-EKF-based localization and the belief-based online-POMDP for lateral motion planning will help mankind explore our sister planet.

24-2024 R3-0056

RFA-075, Investigating the Deleterious Effects of Radiation in a Human Microphysiological Vascular Platform, HEOMD

South Dakota School Of Mines & Technology
Dr. Edward Duke

The chronic exposure to ionizing radiation (IR) that is experienced by astronauts in space poses major cardiovascular health risks. IR-induced activation of the inflammasome complex in endothelial cells may lead to further systemic inflammation and the onset of cardiovascular disease. To combat the deleterious effects of IR, human biomimetic models must be developed and exposed to doses of IR that emulate the conditions that astronauts experience. Here, we propose such a model and method. We will develop a microfluidic device where we culture endothelial cells in a 3D environment that mimics the in vivo physiological conditions to grow a capillary bed. The device will then be exposed to IR with an overall dose of 0.5-2.0 Gy for up to 14 days, and we will evaluate the subsequent inflammatory response that is indicative of inflammasome activation. Specifically, we will use ELISA to measure levels of caspase-1, IL-18, and IL-1B, collect output media from the device to test for the presence and quantity of cells that may have undergone pyroptosis, and then harvest the cells from the hydrogel channel to collect rt-PCR data on NLR protein expression. At the completion of this project, we expect to have developed an in vitro microvasculature device and acquired data to determine if low dose IR leads to inflammasome activation. Future studies may include the implementation of drugs or materials that can block or reverse inflammasome activation.

24-2024 R3-0057

RFA-061, Precipitation extremes and land-sea biogeochemical connections in the California Current System, ESD

Brown University
Dr. Ralph Milliken

As the climate changes, precipitation extremes are projected to impact the US west coast with increased frequency leading to periods of drought, but also to higher occurrences of wet extremes. Flooding from these wet extremes has the potential to impact coastal ocean biogeochemistry through more extreme river runoff events, which may deliver nutrients, and particularly micronutrients, to open ocean ecosystems. The objective of this study is to quantify the impact of storm-driven river run off on open ocean primary production in the California Current system. To accomplish this goal, we will couple Lagrangian analysis of offshore transport with satellite ocean color observations. This work will also use in

situ observations from the NASA Sub-Mesoscale Ocean Dynamics Experiment (S-MODE). This proposal addresses RFA-061 "Impacts of hazards related to climate extremes, such as storms and heat waves, on biogeophysical aspects of the coast". This proposal will advance synthesis of satellite and in situ observations. The work will contribute to understanding the biogeochemical connections between the land and the oceans with implications for global and regional models and understanding impacts of climate change and urbanization on the marine environment.

24-2024 R3-0058
R3 ARMD RFA-006: Multiscale Modeling of Heterogeneous Architected Materials under Impact

University Of Kentucky, Lexington
Dr. Alexandre Martin

NASA is spearheading the initiative to bring humans back to the Moon for extended exploration and utilization, paving the way for subsequent missions to Mars and other destinations. As the preeminent enabler for aeronautics technology, NASA is developing transformational tools for new materials and structures. Ultra-lightweight materials, possessing high energy absorption capabilities, are crucial for aircraft survivability and spacecraft and moon base protection. Innovative heterogeneous architected metamaterials show great promise in combining strength, energy dissipation, and minimal weight, but there remains a lack of fundamental understanding of deformation mechanisms and energy dissipation pathways, as well as the structure-property relationships that could be leveraged to devise novel structural arrangements for enhanced survivability. The primary goal of this proposed R3 project is to formulate a multiscale modeling approach capable of predicting the dynamic mechanical response of heterogeneous architected materials when exposed to impacts. This method is poised to significantly enhance the efficiency of computational design processes for innovative architected materials, extending their potential applications within the realms of aeronautics and space industries. The computational methods crafted in this project, will be integrated within NASA's multiscale modeling tool, NASMAT software suite, and will find practical application in future NASA systems. This integration will accelerate the design process for revolutionary material architectures, empowering scientists to swiftly transform innovative ideas and materials into breakthroughs at the system level.

24-2024 R3-0059
RFA-023: Gravitational-wave informed pointing of short-GRB observations (SMD)

Nevada System of Higher Education
Dr. Eric Wilcox

Following the joint observation on 17th August 2017 of both ³-rays and gravitational waves (GWs) emitted during the merger of a neutron star binary, a new field of transient multimessenger astrophysics (MMA) was kickstarted. Plans for a next generation (XG) set of GW observatories, like the proposed US-based Cosmic Explorer, sensitive enough to observe a binary neutron star (BNS) merger around once per minute out to redshifts of < 2 and beyond. Such an event rate will be near-impossible to follow-up for both current (e.g. Swift) and future space-based ³-ray observatories given the finite time required for both rapid satellite-to-ground communication and repointing towards the GW-inferred sky location. In reality, not all BNS mergers will be observable from Earth as short ³-ray bursts (GRBs). Even though all BNS mergers are expected to emit ³-rays, this radiation will be highly collimated and hence not visible unless pointing along, or close to, the line of sight.

A typical BNS transient detected with a XG-GW facility is expected to be observable for tens of minutes, or up to hours, before merger. In this study, I propose to investigate the potential to use the early-warning GW signal, ending a few minutes before merger, to constrain the position of the source (both sky location and distance) as well as the viewing angle of the binary orbit. With this information in hand, it will be possible to make an informed decision about the expected observability of both the ³-rays (emitted at merger) and the subsequent afterglow (most prominent in X-rays/UV/optical wavelengths during the first few minutes post-merger), as they both depend on the binary orientation. The project would consist of simulating a large population of BNS signals, as observed in GWs by both current and XG facilities, at a range of distances (up to redshift < 1 2, corresponding to expected observing capabilities of Swift and future space observatories). The inferred BNS location and orientation would then be compared to the true values for each simulated signal and provide a gauge for how likely Swift would be to observe the electromagnetic (EM) counterpart given an inferred binary location and orientation. These joint EM-GW observations are crucial to further our understanding of fundamental neutron star physics, BNS mergers as one of the most energetic astrophysical transients in the Universe and as independent probes of our cosmological models.

This project would enable a better informed operation of the current Swift mission, and provide insight into the technical and operational requirements for future high-energy EM space observatories (such as the proposed NASA mission STAR-X and the international ULTRASAT mission, where NASA is a partner). Having the capability to reliably perform these MMA observations is also crucial to fulfil the goals of the Physics of the Cosmos science theme as defined by the NASA Science Mission Directorate's Astrophysics Division. From the Astro2020 Decadal Survey, NASA's current international leadership in high-energy time-domain EM observations is emphasized (Section J.5.1), but also says ""new NASA-led time- domain missions with enhanced capabilities are urgently needed, both to ensure long- term continuity in this developing core field and to successfully capitalize on the science that will come from advanced gravitational wave detectors and the Rubin Observatory."" This project is therefore crucial to maximize the success of current and future high-energy, time- domain NASA missions, provide a streamlined and more informed mission design and operation and enable MMA observations of high-energy astrophysics in the Universe for decades to come.

24-2024 R3-0064
RFA-016, Additive Manufacturing of Dielectrics from Lunar Regolith using Dry Aerosol Deposition; SOMD

New Mexico State University Dr. Paulo Oemig

A major challenge in colonizing the moon will be establishing infrastructure with minimal materials sourcing from Earth. This means in-situ resource utilization (ISRU) and identifying manufacturing processes compatible with the unique environment. Dry Aerosol Deposition (DAD) is a new and rapidly developing type of additive manufacturing (AM) which is entirely compatible with (in fact reliant upon) the vacuum environment for densification of ceramic, metallic and composite materials. It requires no binder, fluid (water) or heat like other forms of direct write do, rather; DAD utilizes only kinetic energy to build robust coatings, lines, pads and low-profile structures. The pressure differential between powder source chamber and vacuum environment far exceeds gravitational forces and therefore renders zero- or microgravity conditions moot. Because DAD is an ambient temperature process, all manner of substrate, including polymeric, is possible, multi-material deposition without chemical interaction is feasible, and ultrafine (nano) scale grain structure is maintained.

As one of the only laboratories in the nation with DAD capability and know-how, our work has demonstrated the use of lunar mare simulant (LMS) as feedstock to build fully dense and structurally and chemically uniform coatings on glass, steel, aluminum alloy and polyimide (Kapton). The mechanical integrity of the coatings has been thoroughly described in a recent paper (Calvo & Fuierer, Int'l J. Appl. Ceram. Tech, 2022, https://doi.org/10.1111/ijac.14235). Very recently, we have, for the first time, measured the dielectric properties (permittivity and loss) of DAD-built, ceramic thick films from lunar regolith. On Demand Manufacturing of Electronics (ODME) in space is an extension of this and ongoing work in the Fuierer DAD lab. The US Army desires agile manufacturing of hybrid electronics on the battlefield, where the goal is to build passives for sensing and communication on flat circuit board substrates and other curved surfaces. In this work, robust, thick dielectric pads and conductive copper lines have been fabricated using DAD and commercial dielectric and metallic powders. The dielectric/electronic properties are being characterized, and resonating structures are being designed and built.

Technical Merit. The research proposed herein will build upon this work tailoring to NASA ODME initiatives. We will use LMS and also highlands simulants as feedstock to build dielectric structures on aluminum, alumina and glass. We will do copper metallization in the very same deposition system. The dielectric behavior of parallel plate, multilayer and interdigital capacitive structures will be characterized from low to high frequency. The Goal is to enable the building of simple electronic components for sensing and RF communication, and capacitors for energy storage using lunar soil as the dielectric. Future work will use Kapton substrates, and extractable constituents of regolith including separated minerals for dielectrics and Al or Fe for metallization.

Interactions with Curtis Hill (in-space ODME project lead at NASA, MSFC) are anticipated to stay informed of specific mission needs for sensors and power electronics. Knowledge of dielectric properties (along with work function) is also fundamental for the possibility of using local regolith itself for passive lunar dust protection of surfaces. Collaborations with other named NASA scientists at MSFC and GRC, involved in space-manufacturing, ISRU, lunar dust and surface coatings, are also expected to grow during this project.

24-2024 R3-0065
RFA-074: Strategic Approaches in Space Medicine: Assessing Human Immune T-Cell Responses to Radiation Exposure (HEOMD)

Nevada System of Higher Education
Dr. Eric Wilcox

As humanity embarks on the audacious journey of space exploration, the imperative of ensuring astronaut health and safety comes into sharp focus, especially against the backdrop of the formidable challenges presented by space radiation. This insidious hazard, composed of a myriad of energetic particles and electromagnetic waves, poses a significant threat to the human immune system. The complexity and severity of this threat grow as we venture further into the cosmos, underscoring the need for innovative, comprehensive strategies to mitigate its effects effectively.
At the heart of our research initiative lies the development of sophisticated screening methodologies designed to evaluate the efficacy of compound-based countermeasures in neutralizing the biological impacts of space radiation. These innovative methodologies are critical for identifying the effectiveness of various compounds in modulating the body's response to radiation exposure. Our research places particular emphasis on addressing high-priority health risks such as cancer, cardiovascular diseases (CVD), and central nervous system (CNS) disorders, all of which are exacerbated by prolonged exposure to space radiation.

To facilitate this groundbreaking work, we utilize state-of-the-art acoustic levitation technology to create a simulated microgravity environment. This environment is essential for conducting detailed studies on Tcells, indispensable components of the immune system, allowing us to observe their behavior under various levels of radiation exposure with unparalleled precision. The integrity of sensitive biological samples is preserved through this method, enabling a meticulous analysis that lays bare the nuanced ways in which T-cells respond to space radiation. Further enhancing our research arsenal is the deployment of the Lymph Node-on-a-Chip technology. This cutting-edge innovation provides a functional mimic of the lymph node's complex structure and microenvironment. It facilitates comprehensive studies into T-cell interactions within a context influenced by space radiation, marrying advanced technologies with sophisticated screening methods to forge new frontiers in space medicine.

Our research endeavors to uncover the mechanisms by which space radiation impairs immune function and to systematically evaluate the protective efficacy of various compounds against these adverse effects. Through a holistic approach, we aim not only to develop targeted strategies for astronaut protection from space radiation hazards but also to expand our knowledge base regarding treatments for radiationinduced health conditions.

In summary, our research stands as a testament to our unwavering commitment to the future of space exploration and the safeguarding of astronaut health. By arming astronauts with the knowledge and tools necessary to navigate and overcome the challenges of space, we are laying the groundwork for a new era in space exploration--one characterized by resilience, preparedness, and a profound dedication to advancing human health and safety. The advancement of platforms and tissue chips promises to revolutionize our approach to studying and treating diseases on Earth. These technologies provide a unique lens through which we can gain deeper insights into human physiological responses, paving the way for breakthroughs in drug discovery and personalized medicine.

24-2024 R3-0066
R3 SMD RFA-023: High-Resolution, High-Precision Laboratory Spectroscopy of Organic Astrochemical Molecules

University Of Kentucky, Lexington
Dr. Alexandre Martin

Organic molecules are key building blocks of the Universe, and the understanding of their evolution from the molecular cloud to planetary systems is essential to constrain the emergence of life on Earth and possibly Earth-like planets. The objective of this proposal is to support current and future NASA space missions, including the James-Webb Space Telescope (JWST) and the Atacama Large Millimeter/submillimeter Array (ALMA), by generating a unique high-accuracy (sub-kHz) spectral database of carbon-bearing molecules for the identification and analysis of astronomical spectra. In the proposed research project, we will conduct high-resolution, high-precision laboratory spectroscopy measurements and spectroscopic prediction of target molecules, including small organic molecules of astrochemical interest, prebiotic complex organic molecules, polycyclic aromatic hydrocarbons (PAHs), and CN-tagged PAHs. Utilizing a novel continuous-wave optical parametric oscillator (CW-OPO) as the light source, infrared (IR, »=2.2-4.0 µm) spectra of transitions to the CH- and CN-stretch fundamental levels of the target molecules will be recorded. The Doppler-broadened spectra can be used to identify molecular carriers of spectral features observed by the Near-Infrared Spectrograph (NIRSpec) and Fine Guidance Sensor/Near InfraRed Imager and Slitless Spectrograph (FGS/NIRISS) onboard JWST. Furthermore, kHz spectral resolution and sub-kHz frequency accuracy can be achieved using a unique Doppler-free saturated absorption spectroscopy apparatus with the pump and signal beams of the OPO frequency-stabilized to optical frequency combs (OFCs). High-precision molecular constants extracted in simulating and fitting the rotationally resolved Doppler-free IR spectra can be used to predict pure rotational spectra of organic astrochemical molecules to guide their future detection in the millimeter-wave region with ground-based telescopes, including ALMA and the Green Bank Telescope (GBT). The expected experimental and computational results will play a pivotal role in detecting the target molecules in the interstellar medium (ISM) and exoplanetary systems, in understanding the formation of stars and planets, and in the search for extraterrestrial life. Using the proposed research project as a platform, the PI and his collaborators will develop a state-wide astronomy and astrophysics (A&A) education program to enhance the participation of members from underrepresented groups in STEM.

24-2024 R3-0067
R3 SOMD RFA-070: Use of Velocity Monitoring to Prescribe Appropriate Flywheelbased Inertial Training (FIT) workloads for Exercise in Space Flight

University Of Kentucky, Lexington
Dr. Alexandre Martin

Space flight exposure induces rapid loss of skeletal muscle strength which is a function of loss of muscle size as well as motor unit recruitment which is primarily attributed to muscle unloading. Flywheel-based Inertial Training (FIT) is a non-gravity dependent form of resistance exercise that shows promise in mitigating space flight-induced muscle atrophy and is routinely used by European crew members aboard the ISS. Conventional FIT protocols have inadequately addressed FIT workload on an individualized manner with respect to subject strength. Terrestrial precision health solutions indicate that velocity-based training (VBT) elicits greater gains in muscle size, strength, and physical function than conventional load-based paradigms. Furthermore, use of velocity monitoring has been determined to be an effective means of prescribing appropriate FIT workloads in athletes. This proposal aims to determine how use of velocitybased training domains during FIT exercise affects motor unit recruitment and muscle remodeling during a 30d unilateral lower limb suspension (ULLS) protocol. Furthermore, this proposal explores two candidate biomarkers as potential precision health assessments for future studies. We hypothesize that ULLS will reduce voluntary muscle strength, size, and motor unit recruitment, but that these effects will be prevented in subjects completing FIT. Deliverables from this project include actionable precision resistance training interventions for crew members using established hardware and training protocols from terrestrial settings. Furthermore, our data will provide an advanced understanding of motor unit recruitment and muscle remodeling that occurs with prolonged unloading.

24-2024 R3-0068
R3 STMD/ARMD RFA-013: Development of Refractory High Entropy Alloys Structures Produced via Additive Manufacturing for Extreme Temperature NASA Applications

University Of Kentucky, Lexington
Dr. Alexandre Martin

This proposed work seeks to develop new refractory-based high entropy alloy materials for use as resilient structural components in the extreme temperature environments found for common NASA applications. This work will leverage two unique capabilities at the University of Louisville, including an ultrasonic alloying and atomization platform capable of producing pre-alloyed metallic powders suitable for additive manufacturing (AM) and a 5-axis, powder-based directed energy deposition system for capable of fabricating large, non-planar structural components. Using these capabilities, three distinct refractory high entropy alloy (RHEA) compositions will be developed as AM feedstocks and evaluated post-build for potential NASA structural applications. AM specimen microstructures will be characterized via scanning electron microscopy, and mechanical performance will be tested at elevated temperatures. In particular, yield strength, ultimate strength, and creep behavior will be tested from room temperature up to 1,200 deg C.

24-2024 R3-0077
RFA-005 - Determination of Rate Dependent Composite Material Properties for the LS-DYNA MAT-213 Model, ARMD

University Of Alabama, Huntsville Dr.
Lawrence Thomas

Fiber-reinforced polymer matrix composite (PMC) materials are highly desirable in aerospace applications due to their high strength-to-weight ratio. A key design consideration is how the PMC material will deform and fracture during crash events. Crashworthiness analysis of PMC components is difficult due to the highly complex mechanical behavior exhibited by these materials, including high anisotropy, multiple possible fracture modes (matrix-fiber delamination, matrix cracking, fiber breakage), and the post-peak stress degradation response [1-4]. An additional complexity that has not been considered in-depth to date is how the material mechanical response changes at different strain rates. Crash events will result in high rate loading of the PMC components, yet most mechanical characterization tests are performed at low loading rates. For accurate crashworthiness analysis, the material behavior at high rates must be assessed and incorporated into the modeling and design of PMC components.
Therefore this project will involve high rate mechanical testing of a PMC material. As outlined in the solicitation, the material will be supplied by the NASA technical collaborators (Robert Goldberg, Justin Littell, Mike Pereira), and chosen such that the material is one which low rate data is already available, such as T700/LM PAEK [5]. The experiments will be performed using the PI's specialized split-Hopkinson bar (SHB) high rate testing apparatus. The various tension, compression, and shear tests performed in different orientations relative to the fiber direction that are outlined in the solicitation will be performed. The stress vs. strain behavior up until the point of fracture will be determined, as well as additional material properties such as the elastic moduli, elastic Poisson's ratios, plastic Poisson's ratios, and post-peak stress degradation behavior. In addition a novel non-standard high rate shear test currently under development by the PI will be utilized to determine the behavior under shear loading.
The experimental data generated by this product will be used by the NASA collaborators to develop a strain rate sensitive finite element analysis (FEA) material model. The orthotropic combined plasticity, damage, and failure model MAT-213 in the commercial FEA code LS-DYNA is chosen. MAT-213 has the capability to incorporate the strain rate dependent effects of the PMC material into the model, although to date little has been done to utilize this capability [4, 6-8]. The experimental and analytical techniques developed through this project, and the assessment of the

high rate mechanical behavior of the PMC, will be instrumental in creating more accurate crashworthiness analyses of PMC components and structures. This in turn will allow for safer and more robust design of aerospace and automotive vehicles that utilize PMCs, enabling more widespread adoption of PMCs with their accompanying advantages in weight reduction, fuel efficiency, and corrosion resistance.

24-2024 R3-0078

RFA-029 : Telomere length as a biomarker of plant stress response and fitness, SMD

West Virginia University Dr. Melanie Page

Telomeres are evolutionarily conserved protein-DNA complexes that cap linear eukaryotic chromosomes. In humans, the length of telomeric DNA shortens with each somatic cell division and is thus viewed as the most accurate cellular marker of biological age, but in plants the significance of telomere length changes in response to environmental signals is largely unclear. Our central hypothesis is that genotype-specific telomere length (long or short) can differentially impact vegetative and reproductive plant fitness, depending on the environmental conditions. This hypothesis has been formulated largely on the basis of our recent exciting discoveries indicating that telomere length in different accessions of the model plant Arabidopsis thaliana and in varieties of two major crop species, rice (Oryza sativa) and maize (Zea mays), negatively correlates with latitude and the timing of floral transition. Furthermore, our recent findings in A. thaliana demonstrated that telomere length variation impacts reproductive fitness and plant responses to mild drought and high growth temperature. Specifically, genotypes with longer telomeres produce less seeds in control growth conditions but more seeds under environmental stress. The overarching research objective for this proposal is to test the hypothesis that telomere length can differentially affect fitness of model plants and crops depending on soil quality (poor or control). We will first test this hypothesis by growing a number of Arabidopsis genotypes (natural accessions and T-DNA mutants of telomere biology genes) with short and long telomeres in contrasting abiotic environments (normal vs sandy soils) and measure reproductive and vegetative fitness parameters, changes in telomere length and telomerase activity, and plant responses to genotoxic stress. For the second part of the project, we will evaluate telomere length in agriculturally important Brassica oleracea cultivars, which represent economically important vegetables (cabbage, kale, broccoli, cauliflower) and can provide a great source of plant-derived vitamins, nutrients and fiber for long space flights and growth in extraterrestrial soils. We will specifically focus on a panel of geographically and genetically diverse kale varieties from the collection of kale accessions maintained by the U.S. National Plant Germplasm System. A. thaliana and B. oleracea are close relatives, and thus, we will test if telomere length variation in this crop is also associated with plant vegetative fitness. Our results may ultimately lead to novel strategies to develop crops with improved stress tolerance and yield. Specifically, our experiments will help provide important information on whether telomere length can be manipulated in crops to achieve higher yields in extreme environments on Earth and eventually in harsh conditions of the lunar and Martian surfaces.

24-2024 R3-0080

R3 STMD RFA-067: Unsteady measurements of ultra-low permeability for TPS samples

University Of Kentucky, Lexington Dr.
Alexandre Martin

Ablative thermal protection systems (TPS) generate pyrolysis gases during heating that must flow out through the TPS porous structure. The TPS permeability is critically important since low permeability requires a large pressure to push the pyrolysis gases to the surface. This high pressure can result in material damage as has been observed on some modern TPS systems during flight tests. State-of-the-art models rely on the material permeability to predict the internal flow and resulting internal stress, but this permeability can vary significantly across the material and can change by many orders of magnitude during ablation. Complete characterization of the permeability requires measurements spanning a large range of conditions. An experimental facility at the University of Kentucky (UK) has been developed for measurements of Darcy permeability from 10-10 m2 down to at least 10-15 m2. A unique process for sealing irregularly shaped TPS samples has also permitted measurements on TPS with varying degrees of char. However, virgin (uncharred) materials provided by NASA collaborators have permeabilities that are much lower than that accessible with the current approach. This proposal seeks to extend the capability of the UK facility by at least three orders-of-magnitude for lower permeabilities and permit measurements of NASA's current TPS with ultra-low permeability. This new capability will be enabled by unsteady analysis of flow through the porous TPS. The current approach determines permeability from the steady state pressure drop across a TPS sample as a function of mass flow rate. Achieving steady state conditions with permeabilities below 10-15 m2 require time periods exceeding days to weeks for a single measurement, which is not feasible. The proposed work will develop an unsteady measurement approach and analysis to determine permeability from dynamic pressure measurements following step changes in mass flow rate. The approach will be developed and tested against current samples with permeability in the range of 1014 to 10-15 m2 that can be measured by both techniques. Following this development, measurement of materials with lower permeabilities provided by NASA collaborators will be measured in their virgin state. Using the UK facility for charring samples, these will then be charred over a range of mass loss focusing on low mass loss percentage, relevant to the early stages during the ablation process when high pressures from low permeability are most likely. The results of permeability versus char will be shared with collaborators and published for publicly available materials.

24-2024 R3-0081

RFA-006 - RAMSA: Rapid Assessment of Structural integrity of Additively Manufactured composites

University Of Alabama, Huntsville
Dr. Lawrence Thomas

In light of the rapid advancements in large-scale multi-material additive manufacturing (AM) for high-performance structural applications, there is a pressing need to develop tools for assessing the fatigue performance of these structures, considering microstructural variability. This proposal introduces an innovative approach utilizing evolving full-field surface temperatures resulting from self-heating measured using infrared thermography (IRT) under cyclic loading. Recent experimental investigations by PI Gururaja demonstrated an equivalence between stabilized surface temperatures and stiffness degradation under cyclic loading 20wt.% C/ABS short fiber thermoplastic composite processed via AM followed by compression molding, a manufacturing process developed by Oakridge. When coupled with a staircase loading methodology, the temperature-based approach, as proven by PI Gururaja, emerges as a promising tool for accelerated fatigue testing and characterization of AM composites. In particular, the proposed approach demonstrated a 96 times speed up in determining fatigue limit compared to the traditional SN-based approach.

The proposed study would leverage this extensive experimental data. The objective is to develop a user material constitutive model for fully coupled thermo-mechanical continuum damage mechanics based fatigue damage accumulation in a 3D repeating unit cell. This model will explicitly account for microstructural morphology, such as fiber length distributions, fiber orientation distributions, porosity distributions, clustering, etc. Additionally, the viscoelastic constitutive behavior of the thermoplastic matrix is considered to account for anelastic effects. The model will include a semi-empirical damage evolution model for the matrix and address the impact of frictional sliding at the fiber ends of the chopped fibers. Following the user material model development, a multi-scale framework will be developed to comprehensively understand the micro-scale response as a reduced-order model that retains the microstructural morphology as fatigue indicator parameters consistent within the NASMAT framework. The success of this proposed work would enable Rapid Assessment of Structural integrity of Additively Manufactured composites (RAMSA). Thus, the proposed work provides pathways for future implementation within NASMAT in line with NASA Vision 2040, focusing on Models and Measurements and Multi-scale measurement and characterization tools and methods. Specifically, the proposed work will fill a gap in existing NASA GRC tools to simulate damage evolution in a unit cell under a fully coupled thermo-mechanical formulation under fatigue loading.

The proposed work aligns with NASA GRC's Materials and Structures for Extreme Environments core competencies while addressing the RFA-006: Multi-scale Modeling of Heterogeneous Materials with NASMAT of the NASA Rapid 2023 call. It also aligns with topic

D.2.2.1 Development of Cyber-Physical-Social Ecosystem Associated with Vision 2040, subtopic D.2.2.1.4 Demonstration of benefits of Integrated Computational Materials Engineering (ICME) Infrastructure of Topic D.2 Transformational Tools and Technologies (TTT) Project of the NASA NRA NNH19ZEA001N solicitation under Strategic Thrust 3: Ultra-Efficient Commercial Vehicles and other ongoing projects utilizing thermoplastic composite systems. The proposed project also aims to propel Alabama EPSCoR research priorities, focusing on key areas of advanced manufacturing, automotive and aerospace technologies, and metals and advanced composite materials.

24-2024 R3-0082

RFA-004-Lubrication Mechanisms of Friction Modifiers Under Electric Field: Towards Enabling Ultra-Low Viscosity Lubricants for Electrified Vertical Takeoff and Landing Vehicles-ARMD

Oklahoma State University Dr.
Andrew Arena Jr.

Energy-efficient lubricants are critically needed to enhance the flying range of electrified aircraft. By formulating lubricants with lower viscosities, we can minimize undesirable churning losses in powertrains. However, lower viscosity lubricants form thinner fluid films at sliding/rolling interfaces, thereby increasing the likelihood and severity of surface asperity contacts between mechanical components in motion. This can give rise to elevated friction and wear-induced failures during operation. To address this challenge, lubricants are formulated with performance additives that enhance the efficiency and reliability of powertrains. Friction modifiers are one such important class of lubricant additives that minimize friction between mechanical components. Friction modifiers work by adsorbing and reacting on contacting surfaces to form tribofilms. These surface-bound tribofilms counteract friction by lowering the shear strength of sliding interfaces. Traditionally, the additives are designed to perform under harsh stresses and temperatures at sliding contacts. However, the occurrence of bearing currents in electrified powertrains can influence the mechanisms and effectiveness of lubricants. Unfortunately, the growth behavior and properties of tribofilms at electrified contacts are not well understood, which is a major obstacle in designing high-performance lubricants for electrified aircraft. The future aircraft will have increased power densities with even higher operating electric fields. Thus, scientific study is urgently needed to understand lubrication mechanisms at electrified interfaces. This Rapid Response Research (R3) application aims to contribute to solving this problem by using in-situ tribometry and nanoscale characterization methods to develop a quantitative kinetic and thermodynamic understanding of tribofilm formation mechanisms under electric fields. This project will contribute to enabling single-fluid lubrication and cooling technologies for NASA's Electrified Vertical Takeoff and Landing (eVTOL) Vehicles program.
In this research, we will investigate tribofilm formation by two important types of friction modifiers: 1) an oil-soluble organomolybdenum compound, and 2) a water-soluble ionic liquid. These additives will be dissolved in ultralow viscosity synthetic fluids, polyalphaolefin and polyalkylene glycol, respectively. These ultralow viscosity lubricants are selected because of their ability to serve the dual function of lubricating gears and bearings, as well as the thermal management of electric motors. We will determine the independent effect of interfacial electrical potential on the growth behavior and frictional properties of tribofilms by using a ball-on-disc tribometer capable of applying controlled voltages across sliding/rolling contacts. An optical interferometer attached to the tribometer will be employed to measure the growth kinetics of tribofilms in situ. The test conditions for these measurements will be determined in consultation with the NASA Glenn Research Center to mimic contact environments encountered in the

powertrains of eVTOL vehicles. Tribofilm formation is traditionally modeled as a stress-assisted, thermally activated mechanochemical reaction. In this research, this model will be extended to account for the effect of electric fields on tribofilm growth rates. Further, ex-situ structural and chemical characterization will be performed to shed light on the mechanisms of tribofilm nucleation and growth under applied voltages. By establishing how electric fields affect the fundamental mechanisms of tribofilm growth, this research will help identify superior lubricant additives for electrified powertrains. The findings of this research will inform the predictive design of next-generation aircraft lubricants.

24-2024 R3-0084

RFA-001: Design Optimization of Battery Packs for Electric Vertical Takeoff and Landing Aircraft Using Quantitatively Predictive, Physics-Based Cell Models, ARMD

West Virginia University
Dr. Melanie Page

This project will bridge the gap between physical models of lithium-ion batteries for electric aviation and battery pack and system design. In the current state-of-the-art, a significant amount of the physical understanding available for lithium-ion cells does not influence the design of battery packs, because of the heavy computational requirements of ""outer loop"" calculations such as optimizers. The main outcome of this project will be a proof-of-concept that applies a physics-oriented cell modeling approach to design optimization for electric aviation battery packs.

Electric Vertical Takeoff and Landing (eVTOL) aircraft require high power density at takeoff and landing, and high energy density for range. Precise battery pack designs could help meet these requirements in a manner that optimizes weight, safety and battery lifetime. However, this requires models that are predictive at the cell level. Most current models of battery packs utilize empirical models at the cell level that are fast evaluating. A demonstrated, viable strategy for optimization using physical models at the cell level will thus present opportunities for advancing towards pack design specific to the power system requirements of eVTOLs, while also moving in the opposite (top-down) direction: optimal system analyses could provide targets for cell development that are specific to the physico-chemical properties of cell materials.

In this seed project, off-the-shelf cells typically used in aerospace applications will be characterized using cycling data and impedance, and cell parameters appearing in physico-chemical, reaction-diffusion models will be estimated from the data. These physical models will feature embedded data-driven elements (fast, decomposed Gaussian processes) that quantify the dependence of cell parameters on state of charge. Parameter identifiability issues will be addressed through first principles calculations of quantities such as activity coefficients and transport parameters, using the method of strong priors within a Bayesian parameter estimation methodology.

In the project's second phase, pack-scale models corresponding to real-world devices will be constructed and validated against data collected in flight tests. The pack models will take advantage of model reduction available at the network level, along with fast modes of solution such as spectral methods. A simple optimization problem related to the design of battery packs for eVTOL aircraft will be formulated and solved using pack models consisting of physics-based cell models, in a simultaneous mode of solution in which the model solution is accomplished within the optimizer.

The result of the project will be a proof-of-concept that could lead to significant improvements in the way that power systems for electric aviation are designed. Electric aviation promises to decarbonize one of the most carbon-intensive sectors: NASA's goal is fleet-scale zero-emission aviation by 2050. In accomplishing this goal, completely new systems for powering aircraft must be designed. Modern engineering tools that take advantage of powerful optimization algorithms will be made more effective by increasing the quantitative accuracy of the fundamental physical models used within them.

24-2024 R3-0090

RFA-071: Numerical Modeling of Perivascular Cerebrospinal Fluid-Induced Optic Disc Edema in Astronauts, SOMD, HEOMD

Iowa State University
Dr. Sara Nelson

With increasing efforts toward the human exploration of space through NASA's Artemis program, the health and sustenance of astronauts subjected to prolonged exposure to microgravity pose key challenges. Optic disc edema (ODE; swelling of the optic nerve head in the posterior part of the eye) has been welldocumented in astronauts both during and after spaceflight, which, in severe cases, can lead to visual impairment. I propose high-precision numerical modeling of the alteration of cerebrospinal fluid (CSF) dynamics and optic disc expansion in astronauts during long-duration space flights. Specifically, I am proposing to model the CSF flow disruption in the perivascular spaces in the optic nerve sheath under exposure to microgravity. This approach deviates from the traditional viewpoint on the role of CSF in optic disc edema and considers the most current understanding of CSF flow in the brain, namely the glymphatic system (a recent breakthrough in neuroscience). Preliminary results relate a smaller pre-flight optic cupvolume with high ODE risk in space without any intracranial pressure elevation, similar to recent experimental observations. The development of the numerical model can, (1) improve pre-flight assessment of ODE risk by accurately predicting OD expansion in space,(2) provide insights into the factors leading to variability in experimental cohort data of optic disc measurements in returning astronauts, and (3) help determine preventative countermeasures against ODE-risk in astronauts. By supporting long-term human space exploration and mitigating the highest risks to crew health and performance, the proposed research will align with the goal of the "Bioscience and Human Health sector" of the Iowa Economic Development Authority. By driving medical breakthroughs to maintain neuro-ocular health in astronauts, the work contributes to the "Strategic goal 2. Extend Human Presence to the Moon and on Towards Mars For Sustainable Long-Term Exploration, Development, and Utilization" in the NASA Strategic Plan 2022. Specifically, the work will contribute to the NASA Human Research Roadmap (spaceflight-associated neuro-ocular syndrome or SANS ranks first in the risk research portfolio). Finally, the collaboration between Iowa State University and NASA-Cardiovascular Vision Lab will foster the improvement and growth of Iowa's research infrastructure and national R&D competitiveness, aligning with the goals of the Iowa NASA EPSCoR program.

24-2024 R3-0092

RFA-003, Non-Invasive Partial Discharge Detection in Electric Motors Using Acoustic Emission Sensing, ARMD

University of Arkansas, Little Rock
Dr. Constance Meadors

This proposal seeks to develop and demonstrate a non-intrusive, environmentally robust, early partial discharge (PD) detection technology with acoustic emission (AE) sensing for monitoring and predictive maintenance of electric motors. Understanding and mitigating PD within electric motors is paramount for the safety and lifetime of electrified vertical takeoff and landing (eVTOL) propulsion systems. Partial discharge can undermine the motor's insulation system, leading to device failures that may compromise system safety, incur economic losses, and diminish public trust in advanced urban mobility. There is a pressing need to monitor the health of eVTOL propulsion systems in real-time without disrupting their operations. Acoustic PD detection technologies are among the most promising options due to their nonintrusive monitoring feature and robustness to environmental conditions such as temperature and humidity.

Nevertheless, existing acoustic PD detection technologies produce large volumes of data that require expert analysis owing to the required high sampling frequencies and a lack of mechanistic modeling of PD-induced acoustics. The need for sophisticated data interpretation can delay action and increase the reliance on highly trained personnel. To address these challenges, we propose to integrate wideband frequency AE sensing with on-device machine learning to enable real-time sensing and data interpretation of acoustics in electric motors. Firstly, coupled electrical and thermal modeling will be performed to identify the acoustic signatures of PD-induced thermal effects. Secondly, transient AE testing using the identified acoustic signatures and the technical data management solution will be adopted to significantly reduce the volume of acoustic data recorded during tests. Thirdly, machine learning models with short-time Fourier transform and sequence-to-sequence (seq2seq) regression will be used to localize PD and predict PD inception and extinction voltages. Preliminary AE tests of stacked substrates reveal the acoustic signatures for abrupt changes in the discharge. Compared to electrical PD detection methods, the proposed technology enables non-intrusive PD detection of motors during operations using a lowcost, portable system, thereby reducing cost and device downtime. This technology is particularly useful for early-stage PD detection, which may not lead to strong enough electrical signals, e.g., surface discharge on the stator winding insulation due to contamination. It will enable a critical early-warning mechanism to detect the onset of electrical insulation breakdown before it escalates into a catastrophic failure, thereby enhancing the safe operations of eVTOL vehicles. Moreover, by proactively addressing PD and allowing for timely maintenance, this technology will contribute to the extended lifetime of the motors, thereby improving the economic model of urban air mobility.

24-2024 R3-0094

RFA-031: Advancing In-Space Construction through Cold Welding, SOMD

Iowa State University

Dr. Sara Nelson

We investigate the feasibility of a lab-built cold-welding setup by (i) validating it for target materials of interest for in-space construction (Al-2219, Al-5456, and In-Ag) and (ii) characterizing the microstructure and nano-mechanical response of the cold-welded samples when subjected to extreme temperatures experienced in deep space missions. Welding is a metal joining process in which two or more parts are bonded by applying heat, pressure, or both to become a unified whole. Proven as a flexible and robust process suitable for joining many (even dissimilar) materials, welding is a potential solution to a variety of in-space fabrication needs where high strength and better temperature performance are required, including in-flight repairs of electrical/electronic devices and structural/mechanical components and sealing/resealing rigid containers with high structural/environmental integrity for long-term protective storage or transport. Deploying welding technologies in the space environment offers options for habitat structure damage repair and new parts manufacturing during a long-duration space mission in and beyond low earth orbit.

Current state-of-the-art joining methods available come with a myriad of challenges and limitations. Often requiring laborious extra-vehicular work from astronauts, high quantities of fasteners, and heavy equipment. These methods pose a risk to those tasked with executing them and tremendously increase the work required and task complexity. To circumvent these challenges, our team has proposed the use of cold welding as the dominant method of joining for in-situ space construction. Cold welding has the ability to substantially improve the required joint complexity, ease of use, integrity, and strength of the bond. However, the primary challenge in the cold-welding process is overcoming surface contamination and roughness, particularly the stable oxide layer that forms on metals like aluminum, which impedes metalto-metal contact necessary for cold welding. To ensure optimal bonding conditions, meticulous surface preparation is required, involving flattening, polishing, and cleaning, followed by bonding in an ultra-high vacuum to prevent oxide reformation and facilitate atomic diffusion. The process may also incorporate controlled heating to enhance diffusion rates, given that diffusion in metals is temperature dependent. This proposal aims to advance in-space cold welding by examining atomic diffusion mechanisms, the impact of pressure and surface roughness on bond strength, and by assessing the mechanical properties and microstructural changes in materials post-welding, using advanced characterization techniques.

The overall goals are:

i) Correlate the temperature and pressure with minimum time required to bond similar and dissimilar weld joints using Al 2219-T6 and Al 5456-T6.

ii) Use high throughput nanomechanical testing to interrogate the strength of the cold-welded joints under extremes of elevated and cryogenic temperatures (from +150 to -150 ºC) expected during in-space applications and correlate it with the cold-welding parameters.

iii) Based on their mechanical performance, tune the cold-welding parameters to produce repeatable and reproducible successful cold-weld bonds in the relevant environment in a laboratory setup to achieve TRL4 within the scope of the funding.

This research presents a significant leap towards sustainable and efficient space exploration, offering a robust solution to the challenges of assembling and repairing structures in the harsh conditions of outer space. By enabling the creation of strong, durable bonds without the need for heavy equipment or the risks associated with traditional welding methods, this approach could dramatically enhance the safety and versatility of space habitats and vehicles.

24-2024 R3-0101

RFA-023, Ultracool Subdwarfs: Using WISE to train for Roman Space Telescope discoveries, SMD

University Of Delaware
Dr. William Matthaeus

What is the nature of star formation at very low masses and very low metallicities? Future NASA missions offer the opportunity to identify thousands of metal-poor brown dwarfs belonging to the Galactic Halo, thereby enabling a direct comparison of the substellar mass functions at 1/10, 1/100, and lower metallicities to the mass function of the current state-of-the-art solar-metallicity Galactic Disk sample. These large samples can also be used to probe the cooling rates and atmospheric properties of these objects that share many physical properties with gas giant exoplanets. This project aims to develop machine learning training sets and methodology in order to identify and classify these rare objects in the billions of sources that will be observed by the NASA Nancy Grace Roman Space Telescope plus NSF Rubin Observatory Combined Sky Surveys. The training sets will be based on new results from the NASA ``Backyard Worlds"" Citizen Science which is itself based on the past NASA Wide-field Infrared Explorer (WISE).

The Delaware personnel will work closely with the NASA Backyard Worlds PI, Marc Kuchner, and the Backyard Worlds lead for subdwarfs, Aaron Meisner. This work addresses the scientific question ``How did we get here?"" and the NASA Astrophysics Strategic Objective ``Explore the origin and evolution of the galaxies, stars and planets that make up our universe"" through analysis of data. It will enable development of the partnership between NASA Goddard and the University of Delaware's Department of Physics and Astronomy and Data Science Institute.

NASA Office: Science Mission Directorate, Astrophysics
Research Focus Area: Astrophysics Technology Development Research
Identifier: RFA-023

24-2024 R3-0103

RFA-037: Exploring the Network and Computation Foundations for Cybersecurity Mesh Architecture (CSMA), SMD

Oklahoma State University Dr.
Andrew Arena Jr.

In today's ever-changing work environment, cybersecurity is more important than ever. With remote work, bringing your own device (BYOD), and cloud access becoming the norm, perimeter-based network security is no longer enough to protect enterprise data and resources. A ""Zero Trust Architecture,"" driven by the principle of ""Trust nothing, Always Verify,"" is uniquely suited for the emerging enterprise infrastructure, including NASA, whose missions are too critical, and stakes are too high for any cyberattacks like ransomware.
This research aims to explore the network and computation foundations for a Cybersecurity Mesh Architecture (CSMA). CSMA is the latest Zero Trust Architecture proposed by Gartner, which defined it as ""a composable and scalable approach to extending security controls, even to widely distributed assets."" Rather than having many security tools running in silos, CSMA enables distributed security services to form an integrated security mesh. The Mesh features distributed identities, consolidated policy/management, consolidated dashboard, and security analytics.
Scientific / Technical Merit
The project seeks to identify the network and computation foundations needed to support CSMA layer 1: security analytics and intelligence. To achieve this goal, we will pursue three objectives: (1) Identify the communication overhead for network segments. (2) Estimate computation overheads in network devices. (3) Analyze security-overhead tradeoff. While existing work has focused on CSMA's organizational benefits and migration strategies, this project will be the first to understand its technical requirements and potential limitations.

Relevance to NASA
This project addresses RF-037 (Digital Transformation: Zero Trust, Cybersecurity Mesh Architecture) in NASA R3 solicitation. Digital Transformation (DT) is an agency-level strategic initiative that aims to modernize and transform NASA using digital advances. Zero Trust Architecture (ZTA) is one of the six technology foundations for NASA to leverage to transform its workforce and workplace and drive mission outcomes as outlined in NASA's DT Strategic Framework and Implementation Plan (2022). Among various ZTA constructs, Cybersecurity Mesh Architecture (CSMA) is the most promising in its agility, scalability, and resiliency toward future threats.
Since CSMA is still evolving, this research will identify any technical barriers for NASA use cases. NASA can then produce a maturity roadmap to help organizations scale adoption and maximize benefits. This research will also lay the foundation for using artificial intelligence and machine learning to enhance CSMA security analytics to secure and defend the information environment in real time.

24-2024 R3-0105

RFA-029: Biophysics-based rhizosphere-water and -carbon management for inhospitable soils using engineered lunar or Martian regolith simulant, SMD

University Of Wyoming Dr.
Shawna McBride

Utilizing lunar and Martian regolith as an in situ plant growth medium is a sustainable method to provide fresh vegetables for crew members involved in space exploration missions to these extraterrestrial destinations. The average particle size of surface lunar regolith is silt sized, resulting in a water management challenge for containerized plant growth media. The reduced gravitational force at Lunar- (1/6 g) or Martian-gravity (1/3 g) would likely result in water-logged conditions of the rhizosphere without monitoring and proper management practices. The absence of organic matter in lunar and Martian regolith exacerbates the challenge. Therefore, engineering and optimizing growth media physical properties, along with innovative water and carbon (C) management tools, are crucial for space agriculture using in situ resources. The overall goal of this project is to utilize established techniques on Earth, including engineering soil texture, sensor-based irrigation management, the "cut-and-come-again" method, and photosynthetic microbiomes, to optimize rhizosphere development and plant growth in inhospitable plant growth substrates. Water distribution in containerized media is affected by particle size and distribution as well as media depth. Lunar regolith consists of a wide range of grain sizes, which could be engineered by manipulating particle size (texture) and by layering to optimize the volume of liquid and gas within the container profile. In addition to engineering soil texture, sensor-based irrigation management can provide optimal rhizosphere water content by securing optimal ratios of water- and airfilled voids for the roots and microbes to thrive. The "cut-and-come-again" method is a management system utilized on the International Space Station. This project will incorporate the concept of the "cutand-come-again" method coupled with no-till management in order to add root residuals as a regenerative C source to contribute to organic matter build-up in lunar and Martian regolith after the aboveground edible plant parts are harvested. Apart from innovative C management, soil carbon can be enriched via terrestrial algae (Tetradesmus deserticola), which have exhibited the capacity to enrich carbon contents through photosynthesis in marginal soil on Earth. Using terrestrial algae as a soil amendment for inhospitable soils may promote soil fertility and carbon content, resulting in an improved rhizosphere environment. The objectives of this project are to (1) characterize the impact of engineered soil texture and layering coupled with sensor-based irrigation management on plant growth, rhizosphere development, soil-water and -gas distribution, and plant water uptake; and (2) Determine the effects of cut-and-come-again cropping methods and terrestrial algae amendments on soil fertility of lunar or Martian regolith simulant. The results of this project will describe the biophysical relationship between particle size, layering and Earth's gravitational force within a containerized simulant, fostering healthy rhizosphere development in lunar and Martian regolith. This project endeavors to improve plant water status in hostile soil using novel sensor-based irrigation management. This proposal will develop bioregenerative decomposition methods that utilize root biomass produced from "cut-and-come-again" husbandry to build C in inhospitable soil. Additionally, this project will quantify the effects of Tetradesmus deserticola, a crescent-shaped green algae, on fertilizing inhospitable soils and the application to serve as a sustainable bio-fertilizer for future

space exploration missions. The envisioned project aims to establish principles for sustainable edible plant growth facilities, catering to the needs of NASA human exploration missions.

24-2024 R3-0106
RFA-007, Fiber Optics-based Spectroscopic Sensing of Battery Systems; STMD

New Mexico State University
Dr. Paulo Oemig

In battery-based energy storage systems for space missions, storing and delivering the electrochemical energy in a safe, reliable, and predictable manner is vital for the success of the space missions and the premise for applying any new battery technologies for aeronautics-related applications. For these purposes, a battery management system is a critical component to manage and utilize the electrochemical energy. A typical battery management system monitors output electrochemical parameters such as voltage, capacity, and temperature, etc. Monitoring the chemical information within the cells of practical battery packs has been a long-standing challenge. Such a challenge mostly lies in the fact that battery cells for realistic applications are a fully sealed system that intrinsically forbid measurements of chemical properties in the cells without interrupting the operation. Without the chemical information, how dynamics of physicochemical processes in batteries, in which the properties of batteries are rooted, changes during cell operation, will be an unanswerable question. It will subsequently pose a significant hindrance in understanding why unwanted battery incidents (e.g. voltage drop, capacity fading, sudden failure, etc.) happen and how these incidents can be predicted and prevented.
Considering these challenges, the Sci-I targets to develop a fiber optics-based sensing technology that enables live-collection of fluorescence and Raman spectra in battery cells and live-correlation between electrochemical and spectroscopic properties. The proposed technology will be used to reveal the fundamental chemistry behind the observed electrochemical properties and finally predict the health and failure of cells and battery systems. The Sci-I will attain the objective by completing the following tasks:

Task 1. Optimize the experimental setup. The Sci-I's group will systematically adjust the experimental parameters that can lead to an optimized performance of the spectroscopic sensing system.
Task 2. Online monitor the chemical processes. The Sci-I's group will use the developed system as an online monitoring platform for batteries to probe ""behind-the-scenes"" chemical information in device-level battery cells.
Task 3. Understand the electrochemistry-spectroscopy correlation. The Sci-I's group will perform systematic correlation analyses to reveal the fundamental chemical processes behind the observed electrochemical properties and finally predict the health and failure of cells and battery systems.

The proposed method will advance the sensing technologies for energy storage systems and render a transformative positive impact on research of STMD. It will fill the blank of connecting fundamental physics and chemistry to real-world device systems and may play a vital role in future development of advanced technologies for space missions. The proposed technology can be widely applied to various types of electrochemical energy storage devices and thus will generate extensive and fruitful collaboration

opportunities between the Sci-I's group and NASA research teams. Furthermore, the study will lead to a profound impact on the research capability of the Sci-I's institution and enhance space technology-related STEM education in New Mexico.

24-2024 R3-0107
RFA-012: Advancing transition metal and rare-earth containing soft magnets for versatile high-power electronic propulsion systems; ARMD

University Of Idaho
Dr. Matthew Bernards

High-power electric- and nuclear-power based propulsion systems, essential for advanced space exploration, require soft magnetic materials for transformers and inductors that can provide efficient power conversion at high frequencies and high temperature.

The objective of this proposal is to develop rare-earth (RE) substituted transition metal (TM) alloys that have a magnetic induction (Bmax) greater than 0.8 T, low loss densities and operate stably at high temperatures and frequencies in the range of 10 kHz -- 1 MHz.

The central hypothesis is that the antiferromagnetic exchange induced via RE substituents like Gd and Tb, and an anisotropic low-permeability engineered via microstructure changes from Zr and Cr substitutions, lead to high-frequency soft magnetic properties.

The rationale behind this proposal is that antiferromagnetic exchange interactions allow rapid switching of the magnetization state necessary for high-frequency power systems and grain structure engineering enables high-power transformer cores. Moreover, the ability to modify the grain boundary-matrix interface with Zr and Cr substitutions will decrease Eddy currents.

The central hypothesis will be tested by pursuing two specific aims: 1) Determine the effects of moderate RE substitutions on composition-property-performance relationship in TM-alloys; 2) Determine RETM alloy suitability for broadband and high-temperature operating conditions.

We will pursue these aims by identifying the microstructure-property-performance relationship in RETM alloys by varying compositions of the respective substituents in RE-CoFeB and RE-CoTaZr alloys using sputter deposition. Processing and characterization techniques such as field-annealing and electron backscatter diffraction will be employed to engineer and identify the nanocrystalline microstructure, respectively. This research is significant because it addresses the issues of both magnetic induction and high-power capability in soft magnets for high-frequency power systems. It employs loss-density and Qfactor characterization at high-frequencies and quantifies the thermal stability of magnetization at hightemperatures.

The expected outcome of these aims is an RETM alloy with a large magnetic induction and anisotropic permeability that is non-dispersive over a wide frequency range and demonstrates thermal stability up to 400

. These outcomes will have evident engineering benefits to the designs of hybrid-electric or all-electric and nuclear-power systems for advanced air mobility in space, and in the long term can be expanded to integrated inductor and transformer designs."

24-2024 R3-0108

RFA-016: Printable Humidity Sensors for In-Space Manufacturing and Use, STMD

West Virginia University
Dr. Melanie Page

The proposed project's goal is to demonstrate a high-performing flexible humidity sensor prototype based on a novel flexible electrode configuration and a humidity-sensitive flexible substrate. Specifically, cellulose or cellulose-based metal oxide nanocomposites will be employed and studied as both the flexible substrate and sensing material. In addition, coaxial direct ink writing (DIW) will be utilized and characterized for manufacturing novel, moisture protected, conductive electrodes. Then, the electrodes will be secured on the respective substrate locations by DIW of TPU/Ag composite micro-pads.

The proposed sensor configurations are unique since they are not deposited directly on the substrate (sensing layer) thus providing ample sensing area. They also exhibit inherent mechanical flexibility (flexible protecting shell -- conductive core), independent of the substrate mechanics, thus minimizing potential electrode cracking and delamination issues. There are six interrelated objectives carefully planned to successfully conduct this work. In particular, the mechanics of different commercial and lab developed substrates will be explored in relation to their response to humidity. Also, yield stress fluids (inks) formulation science and characterization for flexible electrode and micro-pad DIW printing will be performed. Best-performing inks will then be directly written to fabricate sensor prototypes that will be characterized in the lab and at high altitude using a high-power sounding rocket.

For this work, undergraduate researchers from West Virginia University's Microgravity Research and Experimental Rocketry Teams, along with a graduate researcher, will collaborate to develop the sensors and test a payload for the high-altitude experiments. Our project is complementary to NASA current sensors and wearables efforts. Our proposed concept may hold the key for realizing fully printable and flexible humidity sensors capable of EVA spacesuit humidity and astronaut health monitoring. They may also find applications for in-space plant growth, and space robotics.

24-2024 R3-0109

Flexural Analysis of a Fluid-Filled, Sandwich Core Multifunction Composite (FFSCMC) for Space Structures by Experimental Methods-RFA-014

New Mexico State University
Dr. Paulo Oemig

In nature, shape and structure evolve from struggle for better performance. If this hypothesis is correct, then it makes sense to mimic natural concepts for designing products for better performance. One such natural structure is the human skull that provides optimal protection and environment to our brain that controls all our body functions. Based on the complex structure of the human skull, a bio-mimetic composite was developed at New Mexico Tech (NMT) that has the architecture of a sandwiched panel with face layers (front and rear) made from Graphite/Glass/Kevlar -polymer composite and a core layer engineered from open-cell cellular solids with interstitial pores filled with compatible fluid. For more than 15 years, a team of investigators at NMT has investigated this fluid filled sandwich core multifunction composite (FFSCMC) for multiple mechanical properties including high strain rate impact resistance, acoustic vibration isolation, and passive radiation shielding characteristics. Incorporation of fluid is found to improve the specific stiffness of FFSCMC with an increase in strain rate. The opposite trend is observed for an isotropic material such as aluminum. Acoustic transmission loss was found to be 25% higher than that predicted by acoustic mass law that is applicable to homogenous materials. Interstitial fluid also improves passive radiation shielding characteristics, meeting or nearing that of pure polyethylene by analysis with the Monte Carlo transport code, GEANT4 in SPENVIS. The fluid-filled cellular core (FFCC) of the FFSCMC is a new class of biomimetic design that has not been used in previous NASA architecture.

In order to design an engineering system with FFSCMC, applicable constitutive relations are required. The goal of this Rapid Response Research (R3) opportunity is to experimentally determine the constitutive relation of FFCC due to flexure. This will be done by following a method that we use in the finite element method while assembling a structural stiffness matrix from the stiffness of its elements. Here, we will subtract the stiffness of the face layers from the overall FFSCMC stiffness to arrive at the stiffness of the FFCC. Once the characteristics of the face layers and cellular core without fluid is determined, the stiffness matrix, the ABD Matrix of the FFSCMC will be determined by performing flexural tests using clamped square and circular plates under uniformly distributed load and mid-point concentrated load. All the tests will be done as per relevant ASTM standards. Digital Image Correlation (DIC) will be utilized to measure surface deflections in three dimensions for the top face layer. Data will be gathered for a combination of core type, fluid type, and plate thicknesses. This research will provide a quasistatic basis from which dynamic response may be analyzed in the future.

Researchers at Air Force Research Lab (AFRL), Space Vehicle Directorate, Kirtland, Albuquerque have long been studying how spacecraft materials and components degrade and evolve over time in the space environment. Thus, collaborating with NASA Glenn Research Center and AFRL for this project will enhance the ability of NMT team to accomplish the goal set for this project. This proposal is developed by NMT graduate student and faculty working closely with a senior technologist from NASA Glenn Research Center. At present, NMT has an education partnership agreement (EPA) with AFRL. The objective of the EPA is to facilitate collaborative research opportunities between AFRL and NMT which will allow NMT students and faculties access AFRL scientific information, facilities, and data for this project. A copy of the EPA is provided with the section on ""Facilities and Equipment"".

Proposed project holds immense potential for contributing to the research infrastructure and technical capabilities of both NASA and New Mexico and will be accomplished in 12 months.

24-2024 R3-0114

RFA071: Neuromapping in Space-related Altered Gravity Environments - Unraveling the Mysteries of Brain Adaptation; The Human Health and Performance (HH&P) Directorate

Montana State University
Dr. Angela Des Jardins

Exploration missions to celestial bodies like the Moon or Mars, with their reduced gravity conditions compared to the Earth, pose unique challenges to astronauts' health. Short-term disorientation has been observed in astronauts upon exposure to altered microgravity conditions during spaceflight, yet the underlying neural mechanisms remain widely unknown.

The primary goal of this proposal is to investigate the neuroplasticity effects induced by altered gravitational forces, particularly focusing on how magnetic field gradients affect human neuronal circuitry and function similar to conditions experienced by astronauts during space missions. Previous studies have shown significant changes in brain matter post-spaceflight, impacting sensory and motor functions. However, the adaptation speed of neuronal circuits to microgravitational changes remains uncertain.

Employing a multi-modal magnetic field gradient neuronal cell assay developed in the Kunze Lab at Montana State University, we aim to unravel the neuroplasticity effects under simulated altered microgravitational conditions at a data-omics level using human brain stem cells and organoid tissues. The assay allows for the imposition of static or modular magnetic gradients and mechanical forces, offering a unique platform to study microgravitational effects at the cellular level. This approach overcomes some limitations of rotational tools by providing precise control over magnetic field gradients across macro- and micro-scaled regions within the same cell culture environment. By elucidating the impact of changes in mechanical forces on neuronal function and the time required for recovery, this research aims to contribute to the development of effective countermeasures to support astronaut health during extended space missions. Additionally, loading the neuronal cell assays with magnetic nanoparticles enables the separation of potential high-gradient effects, diamagnetic effects, and mechanical force effects, providing valuable insights into the underlying mechanisms of space-related neuroplasticity.

The proposed study is closely aligned with the NASA Human Research Program, which seeks proof of concept developments for systems biology research approaches, aiming to augment existing risk mitigation plans such as Spaceflight Associated Neuro-ocular Syndrome (SANS). Integrating human brain stem cells and organoids into the multi-modal magnetic field gradient assay enables large-scale biochemical and electrophysiological data acquisition in combination with inflammatory testing and computational modeling to evaluate neuronal network functionality.

The study will be directed by the science-I Dr. Anja Kunze, an Associate Professor at Montana State University. Dr. Kunze has key expertise in neuroengineering, nanomagnetic-based stimulation of neuronal cells and circuits, and basic neuronal signal processing. Moreover, this study will be a starting point to bridge neuroengineering to space science research across disciplines, opening new ways to increase research infrastructure, science, and technology development in Montana. Finally, this proposal will allow us to establish new connections to research centers associated with the NASA Human Research Program."

24-2024 R3-0116
RFA-080 Biofilm Remediation Strategies for Fouled Water Systems during Extended Space Flight (SMD, ESDMD)

Montana State University
Dr. Angela Des Jardins

Water systems are critical elements of primary life support during extended space exploration, necessitating the processing of wastewater to recover potable water. Microbes in the nutrient-rich water grow as biofilms, creating the risk for plugging and system failure. Within the context of space exploration, the longest existing wastewater recycling system is the International Space Station (ISS) Wastewater Processor Assembly (WPA) installed as a flight demonstration in 2008 to process urine distillate and humidity condensate to the potable water bus. In 2010, the WPA experienced system failure due to biofilm overgrowth that had occluded flow in all but one of eight inlets in a solenoid valve, requiring the delivery and installation of hardware replacements. While component replacement is feasible on the ISS, as missions move to the moon and Mars, the need for biofilm mitigation and remediation is evident.

Since 2020, our interdisciplinary team at the Center for Biofilm Engineering (CBE) at Montana State University has worked closely with NASA colleagues through contracts with Marshall Space Flight Center and a MT NASA EPSCoR grant on strategies to prevent biofilm fouling events. We have assessed nutrient limitation, preventative biocide dosing, and antimicrobial surfaces as potential control mechanisms. Our strategy to date has focused on strategies to prevent biofilm formation. The goal of this project is to assess biocides for the ability to remediate microbially fouled water systems to restore operation as well as to continue to assess biofouling potential when systems are under shutdown conditions during uncrewed operation. The proposed work aligns with FY24 NASA Research Focus Area RFA-080 ""Addressing Knowledge Gaps in Planetary Protection for Crewed Mars Mission Concepts - Microbial and Human Health Monitoring"" which states the following call: ""OPP is interested in technologies and approaches for mitigation of microbial growth in space exploration settings.""

The proposed research will utilize the CDC Biofilm Reactor system, with a modified protocol developed at the CBE to model biofouling in the tank of the ISS WPA. The model uses synthetic wastewater based on WPA tank influents and a microbial consortium of four bacterial and one fungal strain isolated from the ISS WPA. The planned workflow is as follows:
Aim 1: Down-selecting biocides for killing efficacy. Biocides from a 2021 growth prevention biocide screen will be down-selected and top candidates retested for killing and removal efficacy. Biofilms will be grown on ISS WPA tank material (Inconel) coupons in the CDC Biofilm Reactor and biocide treatments will be assessed using the ASTM Single Tube Method.
Aim 2: Assessing remediation of down-selected biocides in continuous flow CDC Biofilm Reactors.

Concentrations and biocides identified in Aim 1 will be used to assess killing and efficacy after a mature biofilm has formed in the CDC Biofilm reactor under continuous flow operation before and after biocide dosing.

Aim 3: Continued testing of a long-term dormancy study. Whereas the ISS water recycling system is under continuous operation, future water systems will undergo periods of shutdown during uncrewed operation. This aim will support extension of a long-term tube study of six simulated shutdown procedures (shut-in, potable water flushing without and with biocides, and dry-out conditions) started in November 2023 so as to reach 1.75 years of dormant conditions.

Unique features of this project include: i) realistic, 5-organism consortium in custom synthetic wastewater; ii) first research addressing remediation of fouling (prior work has focused on prevention alone); iii) first investigation addressing microbial stability in water systems during prolonged dormancy conditions relevant to future Mars missions.