Special Session - Aerospace Research in Kentucky

Student Union 104

Associate Director, NASA-Ky: Jacob Owen

Director, NASA-Ky: Alexandre Martin

NASA Kentucky (Kentucky Space Grant Consortium and NASA EPSCoR Programs) presents current and ongoing research from NASA-related projects conducted at institutions across the state. NASA KY supports research in aerospace, aeronautics, space science and related disciplines such as energy, physics, geosciences, biomedical, human health and performance, and computer science.

The National Space Grant College & Fellowship Program was initiated by Congress in 1987 in response to the need to help maintain America's pre-eminence in aerospace science and technology. Kentucky Space Grant Consortium (KYSGC) is a diverse group of 29 affiliate members, including 18 Kentucky universities, colleges and community colleges, 5 industry partners, 4 science centers and 2 STEM educational organizations, partnered with NASA to support Kentucky college students, faculty and pre-college outreach. The national Space Grant network includes over 1,000 affiliates from universities, colleges, industry, museums, science centers, state and local agencies.

The NASA Established Program to Stimulate Competitive Research (EPSCoR) supports partnerships with government, higher education and industry designed to effect lasting improvements in a state's research infrastructure and R&D competitiveness. Kentucky's NASA EPSCoR Program supports NASA-related research projects and partnerships in the state for any Kentucky institution of higher learning and their industry partners.

2:30 - The Economics of Outer Space Exploration

First Author
Steven Lugauer
University of Kentucky

2:45 - Suborbital Evaluation of Medical Technology for Exploration Spaceflight

First Author
George Pantalos
University of Louisville

Co-author
Sienna Shacklette
University of Louisville

Co-author
Clara Jones
University of Louisville

Co-author
Brooke Barrow
University of Louisville

Co-author
Dalton Aubrey
University of Louisville

Co-author
Kessalyn Kelly
University of Louisville

Co-author
Erica Sutton
University of Louisville

Co-author
Michael Ray
University of Louisville

Co-author
Thomas Roussel
University of Louisville

3:00 - Spatio-temporal Renewable Energy Potential Analysis with Application to Hydrogen Supply for Future All Electric Aircraft

First Author
Rosemary Alden
University of Kentucky

Co-author
Dan Ionel
University of Kentucky

3:15 - Exploring Hydrogen-Metal Interactions for Aerospace Applications

First Author
Xingsheng Sun
University of Kentucky

3:30 - The development of an origami robot and its applications to Aerospace engineering

First Author
Minchul Shin
Northern Kentucky University

Co-author
Emmanuel Augustine
Northern Kentucky University

Co-author
Leslie Ferrao
Northern Kentucky Univeristy

3:45 - Combining Tensegrity and Origami: Advancements in Aerospace Deployable Structures

First Author
Muhao Chen
University of Kentucky

Co-author
Shuo Ma
Zhejiang University of Technology

Co-author
Robert Skelton
Texas A&M University

4:00 - Calculating Effective Thermal and Mechanical Properties of Fibrous Materials Using Lattice Particle Method

First Author
Donglai Liu
University of Kentucky

Co-author
Hailong Chen
University of Kentucky

4:15 - Stochastic uncertainty quantification of structured carbon ablator (FiberForm)

First Author
Luis Chacon
Univeristy of Kentucky

Co-author
Savio Poovathingal
University of Kentucky

KY Academy of Sciences: Aerospace Research in Kentucky -- Special session at NKU, Friday Nov 3, 2023

Hosted by the NASA Kentucky Space Grant and EPSCoR Program

Economics

The Economics of Outer Space Exploration

Lugauer

This research's central theme is the question of how best to deploy people and resources to efficiently explore outer space. The rise of private space companies has poured billions of dollars into the space sector, potentially transforming the funding for basic science and increasing the potential for off Earth production and tourism. Governments around the world have also been spending on space related initiatives. Ultimately, the research seeks to build a conceptual framework to analyze what might be the optimal share of our resources to invest in space-related activities, taking into account the possible spill-over effects from space-based innovation to life on Earth.

Biomedical

Suborbital Evaluation of Medical Technology for Exploration Spaceflight

Pantalos, Shacklette, Jones, Barrow, Aubrey, Kelly, Sutton, Ray, Roussel

Introduction: Human suborbital spaceflight began with the NASA X-15 in 1959. In 2021, passengers began flying on commercial suborbital spacecraft. We conducted ground, parabolic flight, and automated suborbital flight experiments in preparation for human-tended suborbital research. Methods: Following a successful suborbital flight of our automated surgical fluid management system in 2021, we conducted parabolic flights using this system that requires frequent surgeon interaction during surgery. In our simulation, the surgeon, working alone, performed tasks with custom surgical instruments in a scripted sequence on a bleeding wound model inside a glovebox; other team members only observed and provided verbal sequence prompts. Assessment mimicked flights on the Virgin Galactic SpaceShipTwo and on the Blue Origin New Shepard suborbital spacecrafts with attention paid to surgeon position for each spacecraft. A second evaluation took place in SpaceShipTwo and New Shepard cabins with the glovebox mounted inside. A comprehensive assessment of surgeon activity was considered by an astronaut trainer and a human factors/safety engineer. Results: Parabolic flights were conducted in May 2022 with four surgeons performing scripted tasks for 15 parabolas in both spacecraft configurations. Typically, 15 surgical tasks were successfully completed. Suborbital spacecraft in-cabin evaluation emphasized safe movement and investigator restraint was well as efficient choreography of task flow inside the glovebox, and maximizing pre-flight rehearsal to optimize flight productivity. Discussion: With careful planning and prior experience working in reduced gravity, a researcher will be able to successfully and safely accomplish many sequential and intricate research tasks in suborbital spaceflight. [NASA 80NSSC21K0359, NASA KYSGC] Cardiovascular Innovation Institute, University of Louisville

Hydrogen and alternative fuels

Spatio-temporal Renewable Energy Potential Analysis with Application to Hydrogen Supply for Future All Electric Aircraft

Alden, Ionel

Toward the planning and development of future electric power systems with extremely large penetration of renewable resources (DERs), detailed assessment of power and energy potential is needed considering both spatial and temporal data per region. Within this presentation, a methodology for spatio-temporal DER capacity potential estimations, machine learning clustering of continuous DER zones, and airport hydrogen hub fueling and storage requirements will be described. A case study for Kentucky is completed with state-of-the-art utility scale solar photovoltaic (PV) panels, wind turbines, and publicly available data from the National Aeronautics and Space Administration (NASA) Earthdata resource and the National Land Cover Database (NLCD). Annual estimates of wind and solar PV generation resources for the example region are found to meet the state's public annual energy requirement, even in the low land usage case. Consideration is given to meeting the state aggregate annual power imbalance minute-to-minute using hydrogen and battery energy storage. The Northern Kentucky/Cincinnati International Airport is employed for hydrogen hub calculations with NASA Integrated Zero Emission Aviation (IZEA) cryogenically cooled hydrogen fueled aircraft. The research reported was supported by the NASA KY GF-80NSSC20M0047.

Exploring Hydrogen-Metal Interactions for Aerospace Applications

Sun

The National Aeronautics and Space Administration (NASA) is developing advanced energy storage materials and conversion techniques to meet the expected energy needs of human exploration systems. In this respect, hydrogen (H) has been identified as one of the clean and renewable energy sources due to its high energy density and zero air pollution. H-based techniques and fuel cells have been used in various fields of aerospace technologies, e.g., International Space Station, space shuttles and Apollo program. As H-based energy systems become more prevalent in aerospace applications, material challenges associated with H detection, storage and transport remain a bottleneck to be addressed. The interactions between H and metals, therefore, are of paramount importance, as they profoundly influence the mechanical, electrical, and chemical properties of those metallic materials in aerospace applications. In this talk, I will present the employment of two numerical methods to investigate H-metal interactions across multiple timescales. The first method, referred to as Diffusive Molecular Dynamics (DMD), is adopted to simulate the transport of H atoms in metals over a diffusive time-scale (on the order of seconds or longer). In contrast, the second method, Molecular Dynamics, can explicitly solve the displacive thermal vibrations of H and metal atoms over a very short time-scale (on the order of nanoseconds). Detailed findings unraveled by these two methods will be presented, including potential energy at multiple H concentrations, separation and dynamics of hydride phases, spatial distribution of H-induced lattice defects, and H-trapping sites in the vicinity of lattice defects.

Deployable structures and robotics

The development of an origami robot and its applications to Aerospace engineering

Shin, Augustine, Ferrao

The goal of this work is to develop sheet-based multi-legged self-folding robots that can investigate the physical condition of highly uncertain terrain after its transformation of such robots on rough terrains. The flat-packed robot has smart material layers for robot morphing from sheets and locomotion without bulky power sources or accessory systems. The device is generally applicable in various hard-to-reach regions in space and enables rich and robust measurement operation for unpredictable environments in space. This research project targets the design of morphing walking robot platforms from a sheet and the measurement of the physical properties of planet ground after its transformation by using dynamic model between their feet and space ground. The research team designed a self-folding robot driven by heating, which consists of two material layers (polymer/metal). Also, multi-legged systems using the ceramic smart material have a high driving force and large moving distance. Another task is to design a SWARM system that integrates an onboard micro-controller and self-assembly algorithm for robot interaction to operate various tasks including investigate the physical condition of highly uncertain terrain. In future, this algorithm will be used for the origami robots.

Combining Tensegrity and Origami: Advancements in Aerospace Deployable Structures

Chen, Ma, Skelton

Tensegrity and origami are key paradigms in deployable structures. Tensegrity, used in space habitats, towers, and cable domes, boasts advantages like mass efficiency, energy absorption, and shape control. However, it lacks a protective cover and requires intricate joint fabrication. Meanwhile, origami, applied in space solar panels, robotics, and metamaterials, allows for intricate folding shapes, compact storage, affordable manufacturing from 2D sheets, and adaptable metamaterial properties. Yet, origami's weaknesses lie in its low stiffness and challenges in controlling dynamics during shape change. The debate over which paradigm is superior continues. Some highlight tensegrity's presence in natural systems such as cells and spider fibers, while others endorse origami, referencing mechanisms in biostructures like flowers and lobster tails. Rather than choosing one, integrating both could be advantageous. Still, comprehensive studies on this combined system are very limited. This discussion seeks to unify these paradigms, offering a comprehensive method to model and study tensegrity and origami together. Such integration could revolutionize the design and creation of large deployable aerospace structures.

Hypersonics and thermal protection systems

Calculating Effective Thermal and Mechanical Properties of Fibrous Materials Using Lattice Particle Method

Liu, Chen

Fibrous materials are extensively employed as thermal protection system in aerospace engineering. Numerical simulation is a very important tool to predict or evaluate the performance of materials and structures. One challenge for numerical study of the carbon fibrous materials is that the macro-material properties are unknown. A possible solution is to calculate the effective material properties by numerical simulations on a small domain of the material which contains enough information about the structure of the materials, which is referred to as computational homogenization.

In this study, the effective thermal and mechanical properties of a carbon fibrous material is predicted based on the micro-structure using a nonlocal Lattice Particle Method (LPM). The micro-structure is represented as voxel-based binary files obtained by scanning the fibrous sample. LPM is a nonlocal discrete method that treats a material domain as an assemblage of regularly packed material particles. This feature makes LPM a desirable tool for computational homogenization based on microstructures by directly taking voxel information as input file. We focused on thermal conductivity and mechanical properties in this study. We conducted a convergence study of calculated material properties with respect to different ratio of particle resolution and voxel resolution. Then the effective thermal conductivity tensor and effective mechanical properties are predicted for several set of microstructures.

Stochastic uncertainty quantification of structured carbon ablator (FiberForm)

Chacon, Poovathingal

FiberForm is a carbon ablator that is used in the thermal protection system (TPS) to mitigate the heat load and reduce the maximum temperature that reaches the surface of the spacecraft when entering the atmosphere of a planet. FiberForm is a material that has a structure and its overall microstructure properties have been studied in the past. However, our approach is to look directly at the thermo-physical properties like permeability, conductivity, and radiation absorption to create a probability distribution of each property based on different arbitrary characteristic lengths and study mean values, variance, and possible connection between each property. The motivation of this work is to better inform material response code by feeding them a range of possible values for material properties instead of a single constant for each property. Ten samples from different locations of a FiberForm tile were extracted and X-ray computed tomography (XRCT) was performed on the samples to extract their microstructure to study them statistically. The direct simulation Monte Carlo (DSMC) technique is used to solve the flow of each microstructure and extract the effective permeability using Darcy's law.

Engineering session

Aerospace Topics in KAS Engineering session (Fri 9am-12noon)

Electric propulsion

Research on Electric Motors and Power Electronics for Future Battery and Hydrogen Operated Aircraft

Lewis, Ionel

The presentation describes a recently proposed electric machine topology combining a coreless Halbach PM array axial flux unit and a PM-less synchronous hybrid excited radial flux unit to take advantage of opportunities available in the unique usage profile for aviation. The development of electrically propelled aircraft requires electric machines that are fault-tolerant, compact, and efficient at multiple operating points. The coreless axial flux PM (CAFPM) motor consists of two Halbach array PM rotors, two stators, and an integrated cooling plate to enable high efficiency at maximal current density. The stator DC-excited synchronous (SDCES) motor operates using AC 3-phase and DC stator windings employing concentrated non-overlapping toroidal coils with a reluctance consequent-pole rotor. Combining both units takes advantage of the high specific power and efficiency of the CAFPM due to the Halbach array and cooling potential and the fault tolerance of the SDCES, with no potential for demagnetization. The research reported was supported by the National Aeronautics and Space Administration (NASA) University Leadership Initiative (ULI) #80NSSC22M0068 on Integrated Zero-Emission Aircraft. Early versions of a coreless permanent magnet motor with a printed circuit board stator PCB motor and drives were supported through NASA Grant no. KY GF-20-055.

Hypersonics and thermal protection systems

A simulation software for ice particles in hypersonic flows

Huff, Chen

When vehicles travel at hypersonic velocities in the atmosphere, they can strike suspended ice particles, and this can damage the vehicle's surface. However, the state of the ice may change between the time of crossing the vehicle shock and striking the surface, creating difficulty in predicting the level of damage that will occur. Behind the shock, the ice particles are subjected to a high-pressure, high-temperature environment which could cause fracture and fragmentation to occur in addition to any melting that occurs. In order to study the fracture and fragmentation processes of ice particles in hypersonic environments, a coupled fluid-solid mechanics simulation framework is in development which is tailored to the rarefied flows and brittle-type fractures expected in these conditions. Gas is simulated using the direct simulation Monte Carlo (DSMC) method, and solids are simulated using the lattice particle method (LPM). The framework loosely couples the two methods. The LPM simulation receives updated forces from the simulated fluid flow, and the DSMC simulation receives updated surfaces from the simulated solid state, allowing flow to permeate into cracks generated within the solid. This simulation framework can be used to aid in developing simplified fracture models for ice in computational fluid dynamics simulations.

Reverse Monte Carlo ray-tracing radiation solver to model absorptivity and non-isothermal emission of TPS materials

Yassin, Poovathingal

An in-house radiation solver using a reverse Monte Carlo ray-tracing (RMCRT) method is developed to solve the radiative transfer equation (RTE) within ablative materials. The solver is used to model the anisotropic scattering behavior of photons within fibrous material. To model the anisotropic scattering, the analysis used a linear phase function for its mathematical simplicity and a Henyey-Greenstein phase function, which is more precise in describing the anisotropic scattering of fibrous ablators. The medium was homogenized on the basis of the effective radiative coefficients estimated from a previous study. The simulation setup to obtain the spectral absorptivity and emission of a medium, where the medium is confined between two infinite parallel plates. The analysis led to the development of two models: a generalized relation to compute the emissivity of a scattering medium as a function of the scattering albedo and the asymmetry factor, and a novel approach to predict radiative emission from the medium purely from the temperature distribution inside the material. The two models enable an accurate prediction of absorbed radiation and radiative emissions without the need to explicitly solve the RTE.

Numerical simulations to predict permeability and oxidation of thermal protection systems materials.

Mohan Ramu, Poovathingal

Thermal protection systems (TPS) materials used in hypersonic applications undergo physical changes (ablation) when subjected to high heat fluxes during re-entry conditions. Porous carbon composites impregnated with phenolic resin are generally used as TPS materials. The heat fluxes during re-entry conditions eject the phenolic resin through pyrolysis from the microstructure and leaves behind a highly porous charred microstructure. Permeability is an important microscale property that dictates the flow of gases through the complex pores, and it depends on the geometry of the pores, temperature and the gaseous species flowing through the pores. Determination of permeability through physical experiments can be a tedious and time-consuming process. We leverage the capabilities of DSMC simulations to be relevant in both continuum and non-continuum flows to evaluate the permeability of porous char layers in TPS materials and we completely forego the need to use Klinkenberg formulation (first order non-continuum approximation) and evaluate permeability through first principles [2]. In our recently published work, we were able to train a support vector machine that predicts the permeability of TPS materials for a wide range of pressure, temperature, and pyrolysis gaseous species [3]. The database required to train such a model was possible through repeated runs of the SPARTA DSMC solver. The charred microstructure further degrades because of the oxidation of carbon fibers with high temperature gaseous molecules transporting through the porous (charred) material. In parallel to the work on permeability, we build upon the unique insights gained from detailed micro scale (DSMC) simulations of individual carbon fibers subject to oxidation and work towards developing a supervised learning model capable of predicting the oxidation of individual fibers. The supervised learning model once trained will provide an effective pathway to link the micro scale simulations with macro scale modeling.

Engineering session continued

Experimental Characterization of Radiative Transport in Thermal Protection Systems
Gore, Maddox, Poovathingal

Developing MISL-DAQ and MISL-Expansion Layers for CubeSat Research
Whittington, Bussell, DeVore, Sun

Additional sessions
***** Aerospace topics were presented in several other sessions: Physics & Astronomy, Chemistry, Health Sciences and Computer and Information Sciences**

Aerospace topics in KAS Poster presentations

Engineering Poster Session

Castleberry, Baral	**Mechanical Characterization and Modeling of AA2024-T3 Aerospace Aluminum Alloy**

Physics & Astronomy Poster Session

Carini, Poore	**TESS Observations of blazars: Extracting the Best blazar Light Curve from TESS FFIs**

***** More aerospace posters were included in other sessions**