Mechanical Engineering and Aerospace

Session G

Room: 115 Gates-Thomas

The Effect of Cultivation Season on Mechanical Properties of 3D Printed Spirulina Biomass

Amelia Burns
Mentors: Chiara Daraio and Israel Kellersztein

Spirulina (blue-green algae) is a cyanobacteria which has been identified as a potentially valuable biomass source to replace plastics and wood in the packaging and construction industries, due to its abundance and environmental sustainability. This project uses 3D printing to produce samples of pure dehydrated spirulina biomass. Samples undergo 3-point bending tests to obtain measures of their mechanical properties. We compare properties of samples printed from two different crops of spirulina that were cultivated during two different seasons (spring of 2022 and summer of 2021). We found compositional variations between the different spirulina crops: the crop cultivated in the summer had a significantly higher proportion of proteins, and a slightly higher proportion of carbohydrates. These compositional differences are concluded to be the main contributor to differences in the flexural and rheological properties of 3D printed samples; the spring crop had a higher yield stress and produced samples with a flexural modulus and a lower work to fracture and maximum deflection. Additionally, morphological analysis was performed by scanning electron microscopy to characterize the structure of the fractured surfaces of the final 3D printed samples before and after mechanical testing.

Designing and Testing Aortic Endografts That Prevent Endoleaks

Mehmet Naci Keskin
Mentors: Chiara Daraio and Connor McMahan

Every year, aortic aneurysms are responsible for thousands of deaths, if not successfully treated. Endovascular aneurysm repair (EVAR) entails the implantation of an endograft within the artery and is the most successful treatment available. However, it often causes serious post-operative complications: Endoleaks entail the flow of blood into the aneurysmal sac, diminishing the effect of the endograft. They occur when blood leaks through the endograft seals or due to backward blood flow to the aneurysm from the local smaller branching arteries. In our project, we aim to develop a new endograft that will prevent endoleaks and prevent further progress of the aneurysm. This endograft will change shape into a variable-radius cylinder during the deployment process to take the shape of the aneurysm. The aim is for this new endograft to exert enough outward radial force against the arterial wall to create a powerful seal between them. This project uses previous work done by the Daraio Group on shape-changing architected materials. The initial prototypes suggest that this type of endograft is possible. With further work, the endograft could be applied to the treatment of aortic aneurysms.

Designing Composites With Spatially and Temporally Programmable Fracture Behavior

Athena Kolli
Mentors: Chiara Daraio and Tommaso Magrini

Composite materials are ubiquitous, due to their high mechanical performances combined with their light weight, making them the material of choice in many structural applications in the civil, automotive, and aerospace sectors. Nevertheless, composites have limited fracture resistance and suffer from poor defect tolerance. To address these problems, we aim to intelligently design materials that have programmable damage behavior and whose fractures can be designed in both the spatial and temporal regimes. In this study, we created a model composite, reinforced across different lengthscales, using a polyjet 3D printer and we performed Single Edge Notched Tension tests to probe the evolution of fractures. Digital Image Correlation was used to retrieve the strain fields during testing and gather useful insights on the interactions of the damage process with the reinforcing elements of the composites. Through our observations, we have gained an understanding of the fracture behavior of these hierarchically reinforced polymer composites. Building up on the knowledge we have acquired during the project, we plan on designing a new hierarchical architecture which exhibits fracture behavior that can be reliably predicted. My project demonstrates that by understanding the role of hierarchical mechanical reinforcement in a composite material, one can design materials to have specific mechanical properties and fracture behavior.

Investigating the Mechanical Behavior of Anisotropic Structured Materials Using Digital Image Correlation
Perry Samimy
Mentors: Chiara Daraio and Jagannadh Boddapati

In the past, mechanical behavior of materials was often characterized through uniaxial testing of isotropic samples whose material properties are direction independent. Anisotropic materials, by contrast, have complex asymmetric internal geometries that lead to direction dependent properties. This anisotropy can cause a material to experience shear even when under a purely uniaxial load, a phenomenon called shear-normal coupling. Although this behavior can be observed in nature, advancements in software and fabrication have greatly expanded the design space of these materials. This project explores the effects of shear-normal coupling by studying the variations in mechanical response upon altering both material and geometry. Sources of fabrication error as well as the effects of boundary conditions are also investigated. Acrylic and a two-phase material (DM8530 and Tango Black) are considered, each with five geometries. Four of the geometries are asymmetric and exhibit shear-normal coupling. The fifth is a symmetric control geometry that does not. After cleaning the samples and applying a layer of speckled paint via airbrush, a uniaxial tension test is conducted. Throughout the test, a load cell collects force measurements, and a camera captures images of sample deformation. Digital image correlation is then used to generate full-field displacement contours from the images. As anticipated, the symmetric geometry yielded a load ratio of 0% in both materials. Using the first asymmetric geometry, however, Acrylic and two-phase samples experienced a shear force to axial force ratio of 14% and 17% respectively. This difference could be due to the linear behavior of acrylic compared to the viscoelastic response of the two-phase material. Interestingly, both values differ from the simulated ratio of 25%. The remaining three geometries also resulted in force ratios that differ from finite element simulations. Further DIC analysis is being conducted to determine the source of this discrepancy.

LATTICE: System Integration of a Driving Module for a Stake-Cable Network
Kaila M. Y. Coimbra
Mentors: Soon-Jo Chung, Matt Anderson, and Lu Gan

The Artemis Mission is NASA's next endeavor to bring humans back to the Moon. One of the key pillars of the mission is to expand the range of surface exploration and in-situ resource utilization (ISRU) demonstrations. Craters at the lunar South Pole are of particular interest for ISRU because the permanently shadowed regions (PSRs) likely contain volatiles, such as water ice, carbon dioxide, etc. Robotic technologies capable of navigating extreme lunar terrains, such as steep craters, are now in need. Thus, we present the development of a robotic system, the Lunar Architecture for Tree Traversal in-service-of Cabled Exploration (LATTICE), which utilizes a stake-cable network and tensioning robots for terrain agnostic traversal. This presentation focuses on the system integration of the driving module that will drill three 2 m long stakes into sloped ground for the final technology demonstration in October. This paper also discusses some of the side projects I have been working towards as part of developing skills that are necessary to tackle the technological challenges that arise with robotics projects such as LATTICE.

Supporting UAV Autonomy With Application to Volcanic Sciences
Diana Frias Franco
Mentors: Soon-Jo Chung and Matt Anderson

Volcanoes are one of nature's most colossal forces. Observing and measuring topographic changes of a volcano is key to helping scientists understand the processes that cause eruption and erosion of landforms. To achieve this, volcanologists study maps of the ground surface called Digital Elevation Models (DEMs). DEMs can be produced through UAV-based photogrammetry, in which UAVs are used to capture aerial images of the surface of interest and then the images are processed through a Structure from Motion (SfM) pipeline to perform topographic reconstructions of a terrain and measure distances between objects in the photographs. This research focuses on using the existing image-capture and GPS capabilities of our current fumarole-sampling Volcano Drone and the SfM workflow from OpenDroneMap, an open source photogrammetry tool, to georeference the 3D point cloud model SfM produces and then generate these DEMs. To evaluate the results, flight paths with varying overlap and sidelap percentages were flown for testing of the Caltech North Field, and the produced DEMs were compared with satellite images of the terrain surface and elevation data. Encouraging results demonstrate that our open-source DEM generation workflow is comparable to commercial photogrammetry softwares for larger terrains, ultimately providing a means for generating high-quality, low-cost DEMs.

Improving UAV-Based Volcanic Lake Sampling Methods
Michael Gonzalez
Mentors: Soon-Jo Chung and Matthew Anderson

Volcanic eruptions can seriously damage human establishments and natural ecosystems. One way of preventing this is to predict eruptions early enough to evacuate at-risk areas. A well-documented prediction method involves sampling water from volcanic lakes using passive sleeves. However, these sleeves are prone to degassing during collection and transportation. In this presentation, we propose a collection system utilizing actuated flasks to collect and store samples without risk of degassing. We implement several improvements on an existing UAV intended to deploy the sampler. We then perform field tests with the sampler and UAV to assess its reliability and success rate relative to current methods. We find that the prototype system is adequately suited for UAV deployment and reliably produces higher quality, more representative water samples than from passive sleeves. With further development, volcanic activity predictions can improve in both consistency and timeliness, saving lives in the process.

Ab-Inito Physical Characterization and Rapid Engineering Development of LATTICE: The Lunar Architecture for Tree Traversal In-service-of Cabled Exploration
Lucas Pabarcius
Mentor: Soon-Jo Chung

Traditional wheeled locomotion systems struggle to climb slopes greater than 20° and are unable to independently return samples from lunar regions of interest such as habitation-enabling, icy permanently shadowed polar craters. To enable a diverse range of future robotic activities within lunar craters, the Caltech NASA Big Idea Challenge team has developed LATTICE, a lightweight, rapidly deploying, long-lived robotic infrastructure. Utilizing a novel cabled locomotion modality, LATTICE provides a scalable framework for transportation of power, information, and mass on the Moon. As team lead, I have conducted a first principles characterization of LATTICE to identify its mass-optimal deployed configuration and delivered value alongside design and engineering work on an Earth-scale demonstrator implementation, described herein.

GPU-accelerated Monitoring of High-rise Building Motions and Deformations
Diego Garcia
Mentor: Monica Kohler

Interest in providing continuous insights on structural health monitoring have led to the contribution to a project aiming to create a proof of concept for a new system that assesses structural damage in buildings. This project is part of the Community Seismic Network. Currently, it is unclear how to accurately and consistently quantify the probability that an earthquake caused extensive damage to a building for people that may be inside, in order to conduct rapid emergency response. The aim of this project will be to provide a system to accurately provide feedback on the state of the structural integrity of the building, and help prevent disasters and to provide immediate response to extensive damage. This method takes advantage of the development of GPU algorithms so that they can be applied to multiple buildings in parallel without needing extensive information or physical modeling specific to the building in advance.

Subgrid Modeling for Large Eddy Simulations of Premixed Combustion
Max Oberg
Mentors: Guillaume Blanquart and Matthew Yao

Being able to model hydrogen combustion is important to understand a wide range of physical phenomena from the destruction of stars, to engineering applications as in understanding hydrogen's use as an alternative fuel source. However, thermo-diffusive instabilities in hydrogen combustion require physical models in Large Eddy Simulations (LES) to account for them. The goal of this project was to assess critically current models for the variance (cv) of the progress variable in hydrogen combustion and propose a new model based on these findings. Using Matlab, and Direct Numerical Simulation (DNS) data by a former graduate-student, the data was filtered and analyzed. Currently, it appears that present models using just cv are not enough to fully represent hydrogen combustion. New models will likely need to be developed that will also take the mixture fraction and the variance of the mixture fraction into account.

Simulating Gas Giant Entry With Multiphysics CFD
Kyle Lethander
Mentor: Guillaume Blanquart

Atmospheric probing of Saturn and Uranus was cited as a high priority mission in the 2013-2022 Planetary Science Decadal Survey, but entry conditions are difficult to predict due to coupling between fluid physics, chemical dissociation, radiative heating, and surface ablation. Therefore, multiple phenomena must be simultaneously modeled to predict the thermochemical environment of entry. The multiphysics CFD code NGA is used to simulate a hypervelocity reacting hydrogen flow over Galileo's entry probe using actual trajectory data. The code solves the 2-D compressible reactive Navier-Stokes equations, using a second-order accurate spatial discretization, an explicit RK4 time integration scheme, and a second-order semi-implicit midpoint scheme for scalars. Forebody stagnation properties are measured, and the impact of high temperature gas effects is demonstrated. The results of this study will help establish design requirements for future planetary entry probes.

Mesoscale Modeling of Microstructure Evolution Using Massively Parallel Phase Field Simulations
John (Jeb) Brysacz
Mentors: Brandon Runnels and Melany Hunt

Microstructure evolution at the mesoscale examines the migration of individual grains and their boundaries in a material when stressors are applied. At a point where three grain boundaries meet, a triple junction (TJ) is formed. We use a multiphase field simulation to simulate this migration, where each grain represents a phase and grain boundary energy was taken from molecular dynamics data. We implement TJ functionality into the model to study migration of TJs in a multiphase field simulation. Analyzing triple junction migration is key to understanding the evolution of a material's structure and has major implications for further understanding of the grain structure of polycrystalline materials, such as metals and ceramics that are use extensively in modern technology. Another application of a robust simulation of materials at the mesoscale includes grain boundary engineering, in which grain boundaries are manipulated to improve the properties of a material.