Innovative Design and Construction of 3D Architecture Si/Li$_2$S Batteries
Melissa Cronin
Mentors: Morteza Gharib, Isabelle Darolles, and Azin Fahimi

Since 1990, lithium ion batteries have ruled the portable devices industry. However, they have major drawbacks such as their flammable electrolyte, degenerative effects, and low storage capacity. A safer battery with greater storage capacity is needed for the upcoming market of next generation smartphones, electric vehicles, and smart grid technology. Two materials, silicon and lithium sulfide, are promising candidates as electrodes for a new lithium ion battery - which will have more than three times the specific energy of current lithium ion batteries. Certain drawbacks have made the use of these electrode materials impractical, however the Gharib lab has designed a new battery that allows the use of these electrodes. Through the use of 3D architecture, a carbon nanotube scaffold, and a solid electrolyte, silicon and lithium sulfide's drawbacks are negated. We seek to build a prototype battery to begin testing, and have made progress towards its completion. Both electrodes have been tested in these electrode materials impractical, however the Gharib lab has designed a new battery that allows the use of these electrodes. Through the use of 3D architecture, a carbon nanotube scaffold, and a solid electrolyte, silicon and lithium sulfide's drawbacks are negated. We seek to build a prototype battery to begin testing, and have made progress towards its completion. Both electrodes have been tested in coin cells in a half cell configuration with the ARBIN cycling machine. The carbon nanotube lattice is grown with a Lindburg/Blue furnace, with carbon nanotubes being grown successfully on a metal current collector over 1 mm high. Experiments are currently ongoing as to maximize the height of the grown carbon nanotubes, and to scale the carbon nanotube up to a larger furnace. A prototype is currently in development and is expected to be done by the end of the summer.

Transition States of Porous Media When Injected With Fluid Using Fine Needles
Salwan Alhani
Mentors: Morteza Gharib and Cong Wang

The behavior of fluids injected into porous media can provide valuable insight into injection phenomenon for medicine and geology. Our goal is to investigate the characteristics of fluid flow through needle injection into dry sand and observe the transition between the funicular and slurry states of porous media during injection. We measured and recorded injections of fluid into hydrophilic and hydrophobic sands ranging from 0.05 mm to 0.5 mm in diameter constant injection speed and needle size to observe the funicular state. Constant velocity injections show a logarithmic increase in propagation regardless of surface properties. We then measured the critical velocity to determine when the transition from funicular to slurry state occurs and if a relationship exists. Our data suggests that the critical velocity formation profile for sands of increasing size follows an exponential decay curve.

Self-Assembly of Large Structures in Space Using Lagrangian Mechanics
Carmen Amo Alonso
Mentor: Michael Ortiz

In-orbit assembly of structures is a costly and time-consuming task at present. The approach carried out in this research relies on the invariance of the Lagrange mechanics equations under change of time sign. With this strategy, the most natural self-assembly mechanisms are easily found, which allows an innovative and efficient way of self-assembly that has not been studied before. The work focuses on the dissolution of a rotating structure in a spiral shape composed by discrete units held together. The structure increases its angular velocity until the peripheral units start to detach as an effect of the centrifugal acceleration. As the structure losses mass, its angular velocity increases, so it can result in the complete dissolution of the spiral. For this to happen the rate of emission needs to be stable, what can be reached by imposing the laws of conservation and some design requirements. Just by changing the sign of time, the way to provide the discrete components and the appropriate geometry of the structure in order to assure the continuous assembly is reached.

A Wavelet-Based Finite Element Approach to Atomic-Scale Mechanics
Daniel V. Leibovici
Mentor: Michael Ortiz

Numerical simulations of microscopic material are often performed at an atomistic scale in order to study phenomena like crack-tip or dislocations. However due to their high computational cost, multi scaling and mesh reduction methods have become key points in computational mechanics. This research project deals with the implementation of a new method to perform mesh coarsening, based on the wavelet theory. Thanks to the properties of hierarchical refinement of the scaling functions, a lattice can be reduced or refined hierarchically on different levels of precision. The aim is to study how a phenomenon, like a wave, would propagate in uniformly fine and coarse models, and in the future in a combination of both. The study of wave-reflections between areas of different level of refinement, and the development of new integration methods to avoid them opens a broad area of research: the aim is the development of a revolutionary method of simulating molecular dynamics which would highly reduce the current computational costs.
Optimized Design of the Wing Structure of a Lightweight Aircraft
Paul J. Grad III
Mentors: Michael Ortiz and Arnold Nde

Airplanes require load-bearing structures that are optimized to be lightweight to maximize fuel efficiency, yet still safe and cheap to manufacture. Aircraft structural analysis employs methodologies from aeronautical engineering and computational solid mechanics to design and simulate structures that satisfy these demands. Our goal is to design a wing structure for a common lightweight aircraft, the Piper 28-140 Cherokee, which can support an ultimate load factor at minimum weight and cost. We determine the ultimate load distribution along the span of the wing by Schrenk’s Approximation. We then use Euler-Bernoulli beam theory and the finite difference method to calculate the deflection and the normal and shear stresses. We do a trade study to decide which structure material offers the best combination of durability, lightness, and cost. From our material properties, manufacturing standards, and solid mechanical theory we design a wing structure within 3% of the optimal weight that is also affordable and safe. Finally, we perform a 3-dimensional, finite element analysis to verify and compare our results.

Supersonic Retropropulsion Technology for Mars Entry, Descent, and Landing
Nicholas Mejia
Mentors: Joseph Shepherd and Bryan Schmidt

Current entry, descent, and landing technology is not suitable for landing payload masses of over 900kg on Mars. This project investigates supersonic retropropulsion (SRP), an enabling technology for heavier payload masses. SRP utilizes rocket propulsion whose thrust is directed into the oncoming freestream in order to provide propulsive deceleration while the descent vehicle is moving at supersonic speeds. This project is intended to observe whether we can replicate data from a previous study by NASA. A 5-in.-diam 70 deg sphere-cone forebody with a single-central 4:1 area ratio nozzle was used inside a Mach 4 cold flow, blowdown wind tunnel. The model was designed to match the model used in the NASA study. Two force sensors are vertically aligned behind the aftbody and a pressure transducer is tapped into the nozzle reservoir allowing measurements of axial force and total pressure of our jet. Supplemental data included high-speed schlieren video. An analysis of drag, bow shock standoff distance, and bow shock behavior is included in this report.

Modifying and Characterizing a Polyalphaolefin Flow Loop Intended to Cool Electronic Chips for Aircraft
Juliane Preimesberger
Mentors: Beverley McKeon and Tess Saxton-Fox

This project focused on altering an existing experimental setup designed to measure the convective heat transfer coefficient of a prototype cooling plate in order to determine if the cooling plate could be used to cool electronic chips for aircraft. A more efficient system to cool electronic chips is needed because of increased heat generation from modern, complex circuit boards. Lockheed Martin proposed a prototype cooling plate made of offset metal fins sandwiched between two aluminum plates cooled by polyalphaolefin (PAO). Previous work involved designing and building a flow loop to test the cooling plate. This project’s goals were to measure the pressure and temperature change across the test section, thermally isolate the system from the environment, and design and implement a cooling system that would keep the PAO at a constant temperature; the existing flow loop was modified to reach these goals. Once these properties were quantifiable, experiments could be run to characterize the system, by calculating the convective heat transfer coefficient of the prototype cooling plate.

Numerical Analysis of Thermocapillary Patterning of Polymer Films
Dahan Choi
Mentors: Sandra M. Troian and Chengzhe Zhou

Thermocapillary forces are believed to be a dominant cause of spontaneous growth of nanopillars from molten polymer nanofilms subject to a transverse thermal gradient. According to this mechanism, the difference in polymer film thickness causes disturbances in film surface temperature, which results in the rearrangement of film material towards colder regions. We examine the highly nonlinear equation governing the evolution of the film height under thermocapillary forces. Linear stability analysis was used to model a flat film perturbed by a small amount, and to calculate dispersion relation between the growth rate and the wavenumber of the perturbation. Several different initial film configurations were numerically simulated. Results yielded a nearly perfect match between LSA and numerical computations for early times, but failed to capture the long term behavior of the instability. Subsequent work will be aimed at understanding this long term behavior of the instability.
The rapid spreading of an insoluble surfactant monolayer along the surface of thin liquid films of higher surface tension is known to be driven by Marangoni stresses. These forces, which pull the monolayer and underlying liquid toward regions of higher surface tension, are proportional to the local magnitude of the surface tension gradient caused by the local concentration gradient. Previous experiments in our lab using liquid films of the order of 10 microns have verified the propagation of an outer stable circular ring behind which there often develops a bifurcating fractal front. While theoretical models predict that the ring should advance in time as $t^{1/4}$, we consistently find higher exponents ranging from about 2/5 to 1/2. Image analysis of systems undergoing bifurcation and for which there exist no theoretical predictions by various thresholding and edge detection techniques have also revealed differences with conventional systems. In contrast to the well-known fractal exponent of 1.67 for hydrodynamic systems prone to the Saffman-Taylor instability, we find values closer to 1.85. This significant difference may help elucidate the physical mechanism responsible for the fingering instability observed.

Molecular monolayers, used to reduce the surface tension of the liquid on which they are deposited, will typically spread over the entire liquid surface until the interface is characterized by a constant surface concentration. Marangoni forces responsible for this phenomenon generate complex traveling waves in an effort to minimize gradients in surface concentration on the way toward equilibrium. In this study, we have built a monochromatic interferometric system to quantify wave front propagation in ultrathin liquid films subject to Marangoni forces. This imaging technique is particularly suited to this study since these traveling waves exhibit significant variation in surface slope, which is highlighted by the distortion of interferometric fringes. From analysis of the distortion patterns, we aim to deduce the spatiotemporal behavior of several moving fronts, indicative of stable and unstable propagation. The speed of these small amplitude waves as a function of time will then be directly compared to theoretical predictions based on the hypothesis that the traveling waves exhibit self-similar dynamics during propagation.