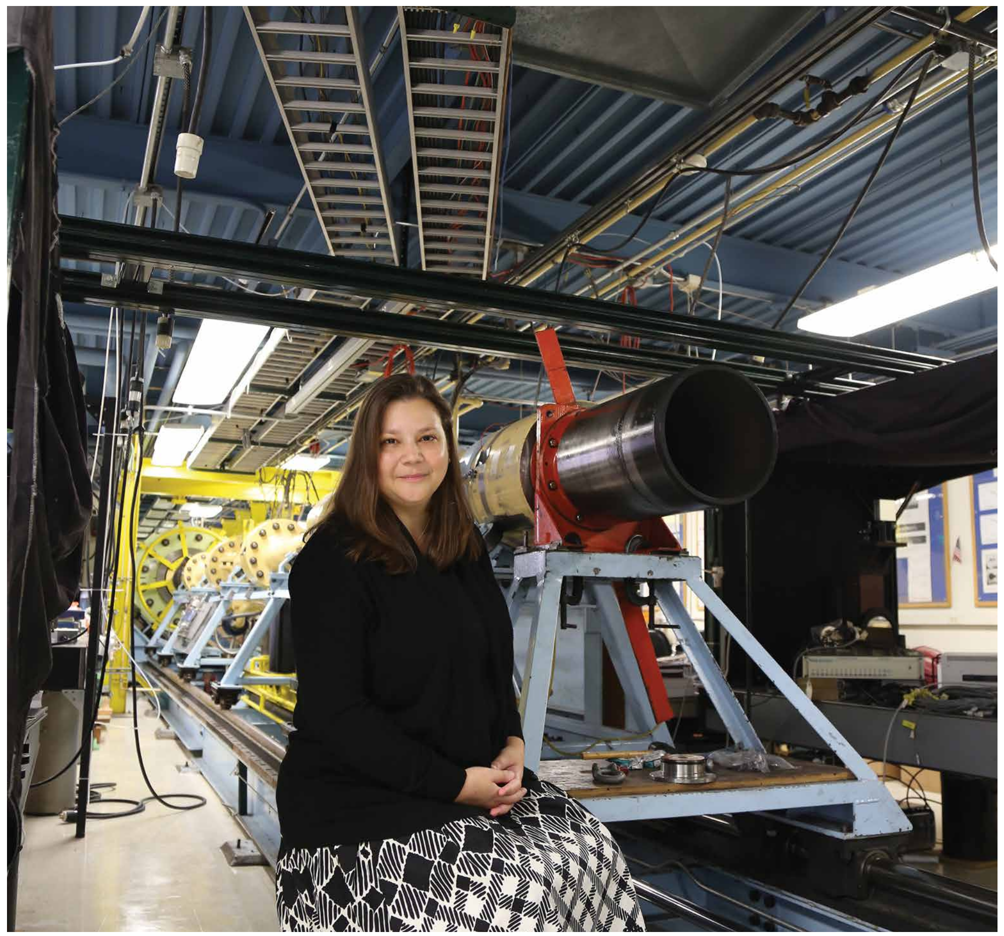
PROGRESS REPORT

# Extending Caltech's Investment in Space Research

by Joanna Austin, Professor of Aerospace

Since returning to my alma mater as a professor in August 2014, I've very much enjoyed working with Caltech students and fellow faculty members—but I have also faced an interesting logistical challenge. In order to forge ahead with Caltech's groundbreaking aerospace research, I've been relocating my research instrument, the hypervelocity expansion tube (HET), from the University of Illinois at Urbana-Champaign, where I built it, to our facilities at Caltech.



Joanna Austin is shown here in the T5 reflected shock tunnel.

This move of the HET to join Caltech's famed T5 reflected shock tunnel creates a full suite of complementary facilities that allows my fellow aerospace engineers and me to explore new ways of preparing space-travel vehicles to withstand the high-speed flows of entry and re-entry into various atmospheres. It's tremendously exciting to see the Graduate Aerospace Laboratories of the California Institute of Technology (GALCIT) investment in laboratory facilities. GALCIT has a long and unparalleled commitment to being at the cutting edge of science, ensuring that we are and continue to be the best at what we do. We are ready to move beyond the limitations that we had previously in terms of access, facilities, diagnostics, and expertise.

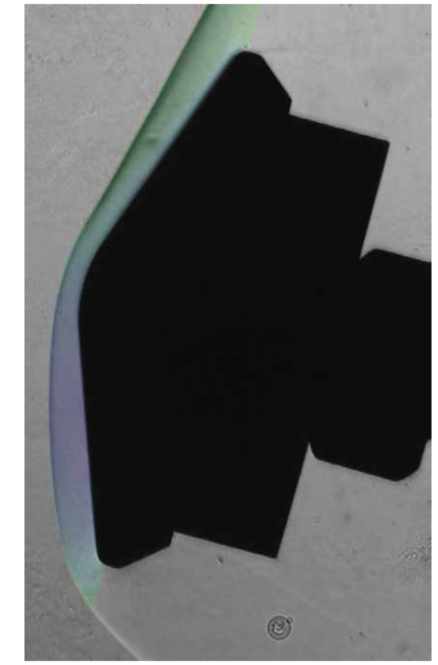
Part of taking engineering and science to a new level involves giving us the tools we need, and Caltech's investment in our new laboratory is doing exactly that! Our lab will feature custom-designed infrastructure, including vacuum systems, gas handling, and the next-generation version of the expansion tube. We'll install the HET in its previous state initially, but then we will expand its operating conditions.

Using the HET and T5 unique suite of experimental facilities, we can simulate flows over objects as they enter an atmosphere. In the case of a Martian mission, for example, our team can create a model of a particular spacecraft configuration, place it in one of these facilities, and then accelerate the gas to replicate the conditions that the vehicle would actually experience during atmospheric entry. Based on these tests, measurements and various models can be developed to help us understand the conditions and measure the heat transfer to the vehicle surface or heat flux, which is critical to the vehicle's survival. It is important to note that we have just a one-millisecond window or less in which to make all the necessary measurements.

When we have very low-speed flows, we can make some simplifying assumptions, including making the density of the flow constant. As we start to increase the flow velocity relative to the speed of sound, then we start to get into a regime where, as a particle of fluid progresses over our model, the density starts to change. Then we start to get shockwaves interacting and we're in a general regime of compressible fluid mechanics.

I'm particularly interested in the flows as they experience these conditions. For hypervelocity flows, not only is the density of the gas changing, but the gas can be reacting and there could also be exchanges between the different energy states of the gas molecules. We want to understand how the energy exchanges and the chemical reactions that are occurring at a molecular level are interacting with the fluid mechanics.

Such studies are extremely challenging because they focus on when and where the vehicles in question experience the highest heat loads and the highest dynamic pressure loading, a very critical regime for a successful space mission. Creating these conditions in an experimental setting is difficult, yet without really understanding this very challenging regime of flight, it's hard to see us progressing to larger vehicles such that we could meet NASA's goal, for instance, to move beyond some of these smaller vehicles into larger vehicles or assist the Air Force with their needs. We must have a much better understanding of the heat fluxes in different regimes of the flow of the vehicle. With a larger vehicle, there's a potential for what's called transition of the boundary layer. The boundary layer is the flow right near the vehicle. It transitions to a turbulent boundary layer, which has a higher heat flux. So we need to be able to predict the transition better in order not to pay a prohibitive penalty in terms of the protection system.



Schlieren image of high-enthalpy $CO_2$ flow over Mars Science Laboratory geometry.

Another experiment we have been working on is direct measurements of gas species that occur at high temperatures to help develop models for the chemical and thermal molecular exchanges. Understanding these gas and gas-surface reactions is critical for predicting the flow around the vehicle. We are working on applying optical diagnostics techniques to achieve both temporally and spatially resolved measurements of the species and their temperatures in high-enthalpy hypersonic flows. It's exciting that we are now able to probe the species directly and move beyond inferring what is happening in the molecular interactions from much more indirect measurements.

My interests in reactive, compressible flows also spans a broader range of applications beyond hypervelocity flight and planetary entry, including supersonic combustion and detonation, bubble dynamics, and explosive geological events. For instance, our work on voids or bubbles collapsing under dynamic loading waves such as shocks or stress waves is motivated by predicting the significant damage caused to the surrounding material. This work has very diverse applications, from explosives to underwater propulsion to biomedicine. Our experiments are designed to illuminate the hydrodynamic processes of collapsing void interactions for eventual input into device-scale models where, while their impact on surrounding material is critical, the void dynamics cannot be individually resolved. We use a gas gun to generate a loading wave through our sample in which we locate a void or array of voids. We can then use high-speed optical diagnostics to examine the collapse process of the void and the damage mechanisms in the surrounding material. The capability for accurate prediction of damage to the surrounding tissue, for example, has a profound impact on treatment options across a broad range of biomedical applications, including extracorporeal shock-wave lithotripsy, laser-induced plasma surgery, and ultrasound.

Looking to the future, my students' excitement about this research makes overcoming the logistical and other challenges especially rewarding. I always make sure to point out that these are very difficult experiments, but the students respond to that and see that their work makes an impact. They are enthused about working on these types of problems in spite of the challenges! Interacting with my research group is really one of the most rewarding aspects of my career thus far. ENG

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