PhD scholarships in superorbital radiating flows.

Travel to the planets is characterised by very high speeds, prescribed by the laws of gravity and the large masses and distances associated with the major bodies of the solar system. Atmospheric entry is required as the terminating or intermediate phase of many missions, the flight speeds of which may range from around 6 km/s for a low-speed Titan entry, to 50 km/s for direct entry to Jupiter. An understanding of aerodynamics of spacecraft at these very high speeds is critical for management of the heating, inertial and viscous loads, and for overall dynamic and static control.

The rapid early success in space travel was driven by sound capsule designs, such as the Soyuz, Gemini and Apollo aeroshells, and simple sphere-cone geometries for exploration of other planets. These configurations were chosen because they could be built with a high degree of confidence, and success at any price was considered more important than the testing of advanced and innovative concepts.

This approach places severe restrictions on the scope and value of the missions which can be performed. Entry into the atmospheres of the gas giants gives an example of this. The Galileo Jupiter entry probe was designed using a sphere-cone heat shield, with excess ablative material provided to account for the unknown level of heat transfer. Telemetry received during the entry of the probe indicated that the shield was substantially over sized near the stagnation point, but marginal near the periphery due to unexpectedly high heating on the flanks. The successful mission was an Engineering triumph in the face of many physical unknowns. However, the extra mass reduced the amount of fuel which could be carried on the orbiting mothercraft. In September 2003, the orbiter was caused to crash into the Jovian atmosphere because it had run out of fuel and could no longer retain the orientation required for communication with Earth.

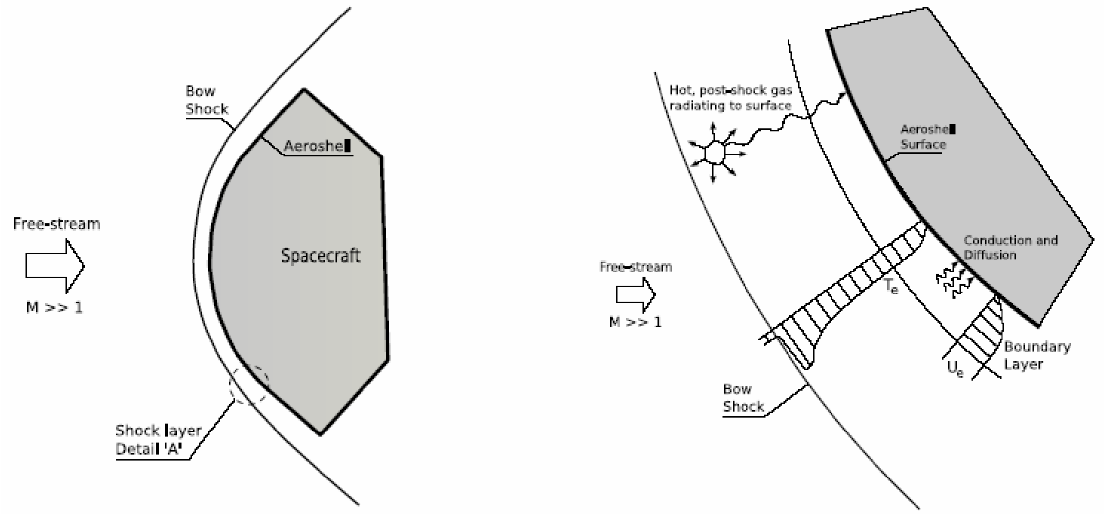

Figure 1: A planetary exploration vehicle during atmospheric entry. This particular shape is for the MUSES-C aeroshell. Detail A (right) shows the modes of heat transfer to the aeroshell surface.

Thus, the scientific returns from one of the most successful space missions ever performed could possibly have been improved, and it could have been run at lower risk, by an optimized design driven by better understanding of the aerothermodynamic effects of very high speed atmospheric entry.

The shock layer that envelopes the vehicle provides the aerodynamic force to decelerate the vehicle. It also contains hot gas that heats the aeroshell surface through convection and radiation (Fig. 1). At high flight speeds, such as those occurring on moon return missions, visits to other planets and the asteroids, the transfer from kinetic energy to chemical enthalpy dissociates and ionises some of the gas constituents. These effects involve significant transfers of energy that can alter important flight characteristics. Ionisation leads to the generation of a significant concentration of free electrons which, because of their long mean free path, can change the transport properties of the flow. In addition, ionized flows are strongly radiative and, above 11 km/s in air, radiation becomes a significant means of heat transfer. These processes are poorly understood and, in the design of superorbital vehicles, engineering safety factors as large as 450% have to be used to account for the unknowns. This presents difficulties for the designers of current superorbital spacecraft (primarily high speed aerobrakes for reentry after interplanetary or lunar missions), and limits the development of future concepts such as aero-gravity assist vehicles and deployable ballute aerocapture.

The University of Queensland (UQ) and the University of Southern Queensland (USQ) are pursuing an ARC funded research program into the effects of radiation in superorbiatal flows, in collaboration with the NASA Langley Research center. This program is based on experiments to be performed in the UQ superorbital expansion tubes and non-reflected shock tunnels, and is intended to develop a fundamental understanding of the aerothermodynamic processes involved in non-equilibrium radiating flows.

Radiation is important for many reentry missions, as is evidenced by the dramatic “fireballs" which may be seen surrounding spacecraft and meteorites, and which may lead to burn-up if uncontrolled. In different situations, different effects dominate, such as nonequilibrium chemical composition, nonequilibrium thermal properties, altitude and ionisation. There is a common core of thermophysical phenomena involved in all situations which, if understood, would allow us to analyse any atmosphere, given the appropriate gas dependant parameters.

Air entry is an important case because of the regularity of low earth orbit (LEO) to Earth returns, crew exploration vehicle (CEV) plans and current funding priorities. (The CEV is a proposed NASA vehicle to replace the Space Shuttle, and act as a platform for moon exploration). Also, good flight data exists from the FIRE projects for comparison (the FIRE project involved 2 pre-Apollo reentry flights of a heavily instrumented capsule testing the heat shields which were to protect the astronauts on return from the moon. Extensive radiative and convective heating measurements were made, and it is still the best data available for code validation). However, air creates a very complex radiating situation, and contains energy in the hard ultraviolet spectrum which is difficult to measure accurately.

Saturn's moon Titan is also of great interest. The atmosphere consists primarily of molecular nitrogen (N2), with a small percentage (0.5 to 3%) of methane (CH4). Behind the bow shock the high temperatures rapidly cause the CH4 to dissociate to C and H atoms, with the C then reacting with the N2 to form cyanogen (CN) radicals, which are strong radiators (as are many 'C' species, as evidenced by the yellow light given off by hydrocarbon flames). The velocities associated with Titan entry are typically of the order of 6 km/sec, and although this is a speed which would not create radiation in air, the presence of the CN means that radiation is expected to be the dominant heat transfer mechanism. It makes an excellent case study because of NASA plans for aerocapture, the relatively low speeds involved, and the relative simplicity of the CN radiation mechanism.

In addition, we have some shock tunnel data for CH4-N2 mixtures and have developed test conditions in the UQ expansion tubes, and demonstrated the importance of the methane content through comparative shots with pure N2. (Without the methane, no radiation is detected.) The Titan high altitude ballute application (featuring the Ball Aerospace clamped ballute concept) is a NASA proposal to increase aero-braking capacity by attaching a large scale inflatable and disposable drag surface to reentry craft. The large capture area means that deceleration can be achieved at very high altitudes and low densities where the heating rates are much lower, and no heat shield is needed. Dubbed "building space craft from plastic bags" by NASA, it is a revolutionary concept which promises to significantly reduce the cost of high speed atmospheric entry. However, this adds another order of magnitude to the rarefaction of the flow, and makes radiation the only significant heat transfer source. This is an extreme example of a radiating flow, and an application which will be impossible to realize without the sort of information and understanding which this proposal is targeting.

Scholarships Available

Applications are called from suitably qualified science and engineering graduates for PhD scholarships to work in this program of study. The awards will be at the Australian Postgraduate Award (APA) level, currently $19,616 in 2007. Selection will be based on academic merit, and technical suitability for the field of study. Graduates from the fields of Mechanical and Aerospace Engineering, Physics, mathematics and chemistry are appropriate, though others may be considered if appropriate knowledge can be demonstrated. Applications will be considered from any Nationality.

Candidates must possess advanced ability for analytical modeling of physical processes. They must be able to develop and validate the details of new research concepts whilst working under supervision which provides directional guidance and technical support, but which requires that students take personal responsibility for the detailed planning and execution of their work. This is the stage of education where students are expected to overtake their teachers in a focused area of technical expertise, and so they must have the ability for independent thought, and the persistence and methodology to maintain motivation over a three year project. It is fundamentally different to undergraduate study, as there is not just a preexisting body of knowledge to learn, the analysis has to be original. It is an opportunity for suitable students to develop an area of unique expertise in an advanced technology field, and to learn research and self management skills.

Projects are available in the following topics:

- ***Facility development:*** non-reflected shock tunnels and expansion tubes for simulating superorbital radiating flows, Ludweig tube for long duration flows.

- ***Optical diagnostics and instrumentation:*** spectrometry, bulk radiation and surface heat transfer measurement, laser visualisation and velocimetry, quantitative species measurement
- ***CFD:*** non equilibrium radiation modeling, facility modeling, blunt body flows, rarefied gas dynamics
- ***Aerothermodynamics:*** Expansion tube testing of reentry capsules, scale modeling, use of various simulated atmospheres.

These projects will be based at UQ or USQ depending on the project and selected supervisor. Both groups work closely together, and with NASA Langley. Projects may include components from several of the above listed topics, and students are likely to overlap within these areas of study. The group works in a collaborative manner, as researchers are continually developing new concepts and techniques which are useful to their colleagues. The Centre for Hypersonics runs a well equipped laboratory with unique high speed impulse facilities. It has a long record of successful grants awards from many sources, and has highly experienced staff who collaborate with many leading groups worldwide. There is a large body of graduate students, and it forms a motivating and supportive environment for research by higher degree.

Please send inquiries to
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Include a full cv, with academic transcripts, and describe which aspects of the program you are interested to be involved with.