QUEENSLAND HYPERSONIC TESTING FACILITY

2015 ANNUAL REPORT

1 JANUARY 2015 - 31 DECEMBER 2015

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

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THE CENTRE AT A GLANCE

Hypersonic aerodynamics has been a major research activity at The University of Queensland over the last 35 years.

Our researchers continue to be active internationally, and are involved in collaborative research programs with approximately 40 universities and research organisations around the world.

OUR OBJECTIVES ARE TO:

- Provide visible international leadership in the Centre's areas of expertise in hypersonics
- Maintain a high level of activity in both fundamental and applied research
- Provide graduate and undergraduate training opportunities of the highest international standards
- Play a pivotal role as collaborators in major international projects.

OUR EXPERTISE:

- Development of hypervelocity test facilities
- Scramjet propulsion (experiment in the laboratory and in flight, analysis and design)
- Rocket flight testing
- Aerothermodynamic experimentation and analysis
- Advanced instrumentation for aerodynamic measurements
- Computational fluid dynamic analysis of hypervelocity flows
- Optical diagnostics for hypervelocity superorbital flows
- Study of radiating and ablating flows

KPI 1: FEE FOR SERVICE ACTIVITIES

COMMERCIALISATION

The research program in the Centre for Hypersonics has been very successful and all-encompassing of our time, and has precluded us having the time to pursue commercial activities.

i. Establishment of operational procedures for the management of QHTF's fee for service activities within three (3) years of the Commencement Date.

   There were no fee for service activities in 2015.

ii. Establishment of material promoting QHTF's fee for service activities internally and outside UQ within three (3) years of the Commencement Date.

   There were no fee for service activities in 2015.

iii. Regular review of operating procedures and promotional opportunities for QHTF's fee for service activities

   There were no fee for service activities in 2015.

iv. Sale of Rockets

   There were no commercial sales in 2015. There is strong interest in the further development of larger rockets, and the establishment of a more extensive test facility off campus.

v. Testing Services

   As the inherent value of this research to the State exceeds the fees for commercial testing which could be raised instead, it was recommend in 2012 that this item be removed permanently, so that the best support can be given to developing the research capability of the State.

vi. Consulting Services

   There were no consulting services activities in 2015.

KPI 2: EMPLOYMENT OF PROFESSIONAL STAFF

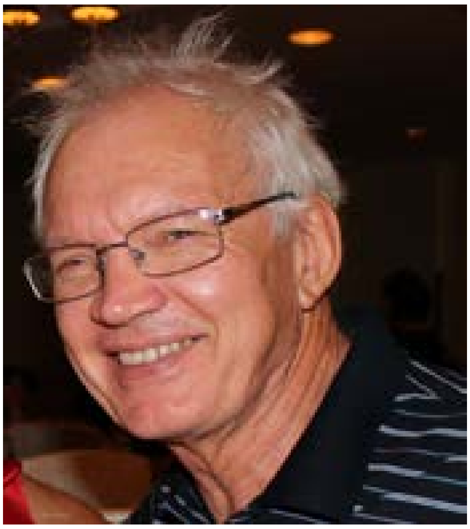
PERSONNEL

Nine UQ Teaching and Research (T&R) Staff, three Research Focused (RF) staff, and five technical staff were employed in the area of hypersonics at the Centre for Hypersonics. There are also 12 staff members with adjunct or honorary appointments.

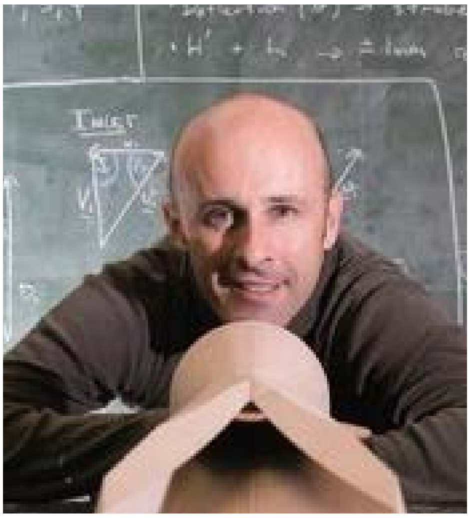
The Defence Science Technology Group (DST Group) Brisbane employs six staff in hypersonics, and has between one and five resident visitors at all times. Teakle Composites employs four staff working in related technology.

LEADERSHIP TEAM

RICHARD MORGAN
DIRECTOR
CENTRE FOR HYPERSONICS



Professor Richard Morgan is the founding Director of the Centre for Hypersonics, and he lectures in mechanical and aerospace engineering within the School of Mechanical and Mining Engineering. He has a strong research record in the development of hypervelocity impulsive facilities on which the UQ Centre for Hypersonics research program is based; this includes the 'X' series of superorbital expansion tubes. Richard has extensive experience in hypersonic aero-thermo-dynamics and scramjet propulsion. Richard has been developing superorbital ground based facilities for many years, and has collaborative research programs with NASA, ESA, Oxford University, Ecolé Centrale (Paris) and AOARD in radiating flows. Professor Morgan has had continuing ARC support in this area since 1990, including two current ARC Discovery grants in partnership with European and American partners. He was involved as a flight team member in the 2010 airborne observation of the Japanese 'Hayabusa' asteroid sample return mission, for which he was a co-recipient of the NASA Ames 'honour' award for 2010. He regularly gives invited talks in international meetings, and gave a plenary presentation to the American Institute of Aeronautics and Astronautics (AIAA) Hypersonic Spaceplanes Conference in San Francisco in April 2011. In 2014, Richard gave the 'Cullpepper' plenary lecture at the AIAA Aerospaceplanes conference in memorial to Professor Ray Stalker, the pioneering Australian Researcher from UQ who passed away in February 2014. Professor Morgan was also one of three UQ advisors awarded a 2012 Excellence in Research Higher Degree Supervision award for encouraging student development through international student exchanges with overseas collaborators, whilst engendering internal cooperation within the study body.

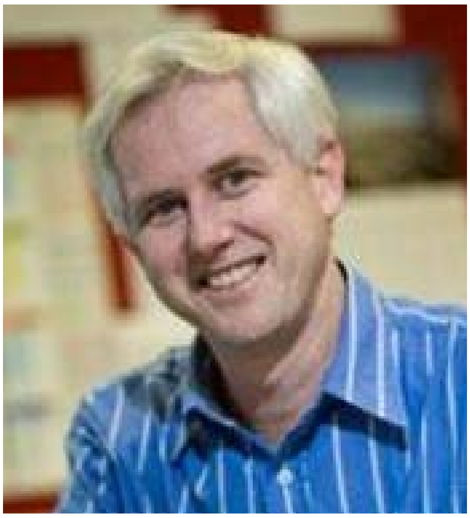


MICHAEL SMART
PROFESSOR
AIR-BREATHING PROPULSION

Professor Michael Smart's research interests are in hypersonic aerodynamics, scramjets and compressible fluid flow. Professor Smart graduated with a Bachelor of Engineering (Hons) from UQ in 1985. He completed a Master of Engineering Science at UQ in 1987, and completed a PhD at the Polytechnic University, Brooklyn, New York, in 1995. He was appointed as an Associate Professor in the Centre for Hypersonics in 2005 after spending ten years as a research scientist at NASA's Langley Research Centre in Virginia.

Michael is the chief investigator on the five-year National and International Research Alliances partnership collaboration between UQ, the Queensland Government, Boeing, USAF and DST Group to conduct scramjet-related flight tests as part of the Hypersonic International Flight Research Experimentation (HIFiRE) program. As head of UQ's HyShot Group, Professor Smart leads scramjet related research within the Centre for Hypersonics, with particular emphasis on flight applications. He is heavily involved in the HIFiRE series of scramjet launches, which are using the T4 shock tunnel for validation of flight hardware. He received the 2012 International Congress for Aeronautics (ICAS) Von Karman Award for International Co-operation in Aeronautics.

DAVID MEE
PROFESSOR
HEAD OF SCHOOL



Professor David Mee's research interests are in Hypersonic and Supersonic Flow. David Mee is the Head of the School of Mechanical and Mining Engineering. After completing his PhD at UQ, he spent five years as a Research Fellow in the turbomachinery research group at Oxford University in the U.K. He returned to UQ as an ARC Queen Elizabeth II Research Fellow in 1991 and joined the academic staff of the Department of Mechanical Engineering in 1993. He became Head of the Division of Mechanical Engineering in 2007 and served as acting Head of the School of Engineering from January to July 2009 until he took on his current role.

David has a strong research record in the field of hypersonics aerothermodynamics. He is recognised worldwide for his work on rapid response force balances, which are essential technology for categorising the performance of scramjet engines in transient facilities, such as our shock tubes. He was a member of the team that conducted the first known wind-tunnel test in which a scramjet vehicle produced net thrust. He has pioneered the use of stress wave force balances for measurement of multiple components of force on scramjet-powered vehicles and the techniques are in use around the world.

STAFF

The following personnel participated in research, education and training activities (all staff listed are part of the School of Mechanical and Mining Engineering at UQ unless otherwise specified):

Name	Position
Dr Hans Alesi	*Research Fellow (DST Group, HyShot)*
Dr Daryl Bond	*Research Fellow*
Dr Aaron Brandis	*Adjunct Research Fellow (NASA, Ames)*
Dr Stefan Brieschenk	*Adjunct Research Fellow (Rocket Lab, New Zealand)*
Professor David Buttsworth	*Honorary Professor (University of Southern Queensland)*
Dr Bianca Capra	*Honorary Research Fellow (Queensland University of Technology)*
Dr Wilson Chan	*Adjunct Fellow (University of Southern California)*
Dr Troy Eichmann	*Adjunct Fellow (DLR, German Aerospace Agency)*
Mr Myles Frost	*Research Assistant (DST Group, HyShot)*
Mr Donald Fry	*Adjunct Professor (NQEA)*
Dr David Gildfind	*Lecturer*
Dr Rowan Gollan	*Lecturer (currently on ARC DECRA award)*
Dr Peter Jacobs	*Associate Professor*
Dr Ingo Jahn	*Lecturer*
Dr Michael Macrossan	*Honorary Research Consultant*
Dr Matthew McGilvray	*Honorary Senior Fellow (Oxford University)*
Dr Tim McIntyre	*Associate Professor, School of Mathematics and Physics (UQ)*
Professor David Mee	*Professor and Head of School*
Dr Neil Mudford	*Honorary Senior Fellow*
Dr Judith Odam	*Research Fellow (DST Group, HyShot)*
Professor Allan Paull	*Program Leader (DST Group, HyShot) and UQ Adjunct Professor*
Dr Ross Paull	*Research Fellow (DST Group, HyShot)*
Ms Hadas Porat	*Research Officer (DST Group)*
Dr Sarah Razzaqi	*Postdoctoral Research Fellow*
Professor Halina Rubinsztein-Dunlop	*Professor, School of Mathematics and Physics (UQ)*
Dr Todd Silvester	*Adjunct Fellow (DST Group, HyShot)*
Dr Phillip Teakle	*Research Consultant, Teakle Composites, and Adjunct Associate Adjunct Associate Professor*
Dr Sandy Tirtey	*Adjunct Lecturer (Rocket Lab, New Zealand)*
Dr Anand Veeraragavan	*Lecturer*
Dr Vince Wheatley	*Senior Lecturer*
Dr Fabien Zander	*Adjunct Fellow (University of Stuttgart)*

TECHNICAL STAFF

Name	Speciality
Mr Barry Allsop	Electronics
Mr Frans De Beurs	X3 expansion tube upgraded driver installation
Mr Neil Duncan	X3 shock tunnel
Mr Samuel Grieve	T4 shock tunnel facility
Mr Keith Hitchcock	T4 shock tunnel facility

KPI 3: ENCOURAGE INVOLVEMENT OF RESEARCH HIGHER DEGREE STUDENTS

EDUCATION

STATISTICS

The group had four research higher degree (RHD) students commence in 2015, creating a cohort of 24. There were also eight PhD and MPhil graduations in 2015, bringing the number of RHD graduations from the Centre for Hypersonics at UQ to 58 for the period 2005 to 2015 (52 PhDs and six Master of Philosophy [MPhil]).

In addition, research students participated in several national and international conferences, and presented the results of their research in person, with further details of these engagements below.

PhD graduates again found employment in respected Institutions overseas including the California Institute of Technology (Caltech), the University of Illinois, Loughborough University and Rocket Lab (NZ). Rocket Lab is pioneering the development of innovative space propulsion systems, indicating the value and relevance of the experience they gained at UQ to state of the art in this field. Other 2015 graduates took up positions in consulting engineering firms and in the financial industry.

See Appendix 2 for a list of current RHD students, and Appendix 3 for a list of 2015 publications.

RHD ENGAGEMENT

Many RHD students enriched their studies through periods overseas with our collaborators.

Christopher James spent 12 months in 2014/2015 working with École Centrale Paris (ECP) under the Cotutelle program whereby a student undertakes a joint PhD between UQ and a French University, receiving a degree from both institutions.

Ms Elise Fahy completed four weeks working with the Interdisciplinary Aerodynamics Group (IAG) at École Polytechnique Fédérale de Lausanne in the Swiss Federal Institute of Technology during her PhD studies. Ms Fahy working on a collaborative project with multiple research partners from the European Space Agency, IRS Stuttgart and CIRA (the Italian Space Agency).

Mr Guerric De Crombrugghe de Looringhe spent a year of his PhD student at the Institut für Raumfahrtsysteme (IRS) at Stuttgart University, Germany and the von Karmen Institute, Brussels. Access to the European facility provides complimentary capabilities to those at UQ and strengthens the Centre's ties with this important European research group at IRS. This collaboration was well timed to capitalise on the recent appointment of a UQ postdoctoral fellow to IRS, and used the Go8-DAAD funding we have received for 2014 and 2015 jointly with IRS.

Ms Tamara Sopek spent time at Stanford University, working with the pioneering Professor Ron Hanson on optical diagnostics.

Mr Andreas Adrianatos and Mr Sangdi Gu spent a month at IRS working with collaborators. Their visit was funded by Go8-DAAD.

UNDERGRADUATE EDUCATION

Undergraduate students continued to undertake final year thesis projects with the group, and again, several students awarded summer or winter research scholarships were hosted in the Centre. The UQ Summer/Winter Research Program provides students with an opportunity to gain research experience working alongside some of the University's leading academics and researchers. By participating, they are able to extend their knowledge of an area of interest and develop their analytical, critical thinking, and communication skills.

MASSIVELY OPEN ON-LINE COURSE (MOOC)

EdX is a not-for-profit online education venture founded by Harvard University and the Massachusetts Institute of Technology (MIT) that is committed to making high-quality educational experiences more widely available. By joining edX, The University of Queensland (UQ) has partnered with a consortium of "X-University" institutions including the University of California, Berkeley, the University of Texas System, Georgetown University, McGill University, École Polytechnique Fédérale de Lausanne, University of Toronto, and Australian National University.

The Centre has been invited to participate in the MOOC program pioneered by MIT, Harvard and Stanford Universities by offering a hypersonics course, the first to be offered in that field. The MOOC is titled, "Hypersonics – from Shock Waves to Scramjets", and its first offering in 2014 was very successful with very good reviews received from the inaugural class. A total of 8693 students from 127 countries enrolled in the course. It was offered again in 2015 and 6651 students from 125 countries enrolled. The course is being offered again in 2016.

Some details of the MOOC courses available worldwide are contained in these links:

http://web.mit.edu/newsoffice/topic/massive-open-online-courses-moocs.html
http://edf.stanford.edu/tags/mooc
https://www.edx.org/

The UQ Hypersonics MOOC coordinated by Professor David Mee can be found online:

https://www.edx.org/course/hypersonics-shock-waves-scramjets-uqx-hypers301x-1

KPI 4: COLLABORATION

ENGAGEMENT AND COLLABORATION

As previously noted, the Centre for Hypersonics and QHTF have served as the focus point for numerous funding grants and collaborative research projects. These research collaborations are outlined under Research Summary (KPI 5).

The Centre hosted a number of visitors in connection with the HIFiRE, the ARC research programs, and the G08-DAAD award we hold with IRS (Institute of Space Systems) Stuttgart.
Following on from the successful Asia Pacific International Symposium on Aerospace Technology (APISAT) in Cairns in November 2015, UQ hosted a series of lectures in Aerothermodynamics. The meeting was chaired by Richard Morgan and was attended with invited speakers from Japan, Germany, China, Korea and Australia.

VISTING ACADEMICS

The Centre hosted three visiting academics in 2015.
Associate Professor Con Doolon from UNSW to discuss the application of aeroacoustic methods to hypersonic flows. A joint ARC Discovery grant was submitted as a result.
Assistant Professor Stuart Laurence of the University of Maryland visited to collaborate on the optical tracking of free-flying bodies in shock tunnels
Dr Dale Pullin from the California Institute of Technology in the USA continued his collaboration with Dr Vince Wheatley.

In addition, the Centre sponsored a seminar on 30 November – 1 December 2015. The theme of the seminar was “aerothermodynamics” and “diagnostics”. Presentations were on the following topics:

- Hypersonic gas/surface interaction and radiation
- Characterisation of plasma wind tunnel Mars entry flow
- Re-entry testing in HIEST
- Radiation modelling of shock layers in eilmer3
- High enthalpy flow diagnostics group at IRS (Stuttgart)
- Superorbital re-entry shock layers: flight and laboratory comparisons
- Radiation in hydrogen containing atmospheres
- Carbon nanotube heat transfer gauges
- Abel inversion approximations
- Emission spectrometry and calibration
- Laser based diagnostics at UQ

The seminar was attended by Centre staff as well as visiting academics from KAIST (South Korea), JAXA (Japan), IRS (Stuttgart), and Tsinghua University (China). UQ presentations included seven RHD students presenting their work.

OCCUPATIONAL TRAINEES

A number of Occupational Trainees worked in the Centre during 2015. These students are typically RHD or coursework masters students from other countries who undertake an internship overseas as part of the degree requirements from their home institution. The interns are generally from European countries and attending a university with which the Centre collaborates. In 2015, three interns worked in the Centre: two from France and one from Switzerland.

Research topics included:

- Experiments in the X2 expansion tube with heated carbon phenolic models
- Use of planar laser induced fluorescences (PLIF)
- Research related to non-equilibrium recombination processes in high enthalpy flows.

KPI 5: RESEARCH AND DEVELOPMENT EXCELLENCE

RESEARCH SUMMARY

A large variety of small and large projects were undertaken in the Centre for Hypersonics in 2014. A summary of the larger projects follows.

HIFiRE

The Hypersonic International Flight Research Experimentation (HIFiRE) program continued its investigation of the fundamental science of hypersonics technology and its potential for next generation aeronautical systems and will involve up to ten flights. HIFiRE is jointly established by DST Group and the US Air Force Research Laboratory (AFRL). The HIFiRE 7 scramjet was launched from Andoya, Norway on 31 March 2015. It was boosted successfully to a Mach 7 re-entry. The HIFiRE 7 payload entered the atmosphere at the correct orientation and the scramjet engine started. However, telemetry was lost on the vehicle at an altitude of 63 km, which was before fuel was turned on. The telemetry failure was traced to overheating of electronics in the telemetry power system. A repeat flight is scheduled in late 2017.

UNIVERSITY OF SOUTHERN QUEENSLAND (USQ)

Hot carbon. An axisymmetric model with forward and aft electrodes sandwiching a cylindrical graphite sample has been developed for experiments on heat shield ablation and chemistry in the hypersonic flow produced by TUSQ. Experiments using a slightly modified version of this model have also been performed to investigate the possibility of hydrogen combustion against hot carbon surfaces in hypersonic flows.

Free Flight Experiments. Internally-funded, free-flying experiments on a model of the HEXAFLY-INT hypersonic glider were performed at USQ in collaboration with colleagues from UNSW Canberra. USQ, The University of New South Wales (UNSW) and University of Sydney form the Australian arm of the EU-funded consortium working towards flight testing of the glider configuration in 2018. 3D printed models were assembled with an instrumentation package consisting of a 6-axis gyro board, microcontroller, battery and blue tooth for data download. Models were lead-ballasted to achieve the correct centre of mass. Measurements of moment coefficients were achieved and future work with additional instrumentation including pressure sensitive paints, IR surface temperature detection, and two axis Schlieren visualisation are planned for 2016. Following the success of the free flight work with the HEXAFLY-INT configuration, a program of free flight experiments sponsored by the DST Group on the HIFiRE-4 glider configuration are being performed in 2016.

Fluid-structure interaction. High quality experimental data on hypersonic fluid-structure interactions does not currently exist but is necessary for validation of both CFD models and reduced-order modelling of hypersonic fluid-structure interactions. Recent work in the TUSQ facility is targeting the development of such data. Experiments on a cantilevered plate in the Mach 6 hypersonic flow were performed in collaboration with colleagues from UNSW. The cantilevered plated was instrumented with pressure transducers and pressure sensitive paint was also used. Schlieren flow visualisation was also used to identify flow structures and the dynamics of the plate deformation. Experiments were also performed on a wing structure in collaboration with colleagues from UQ. The wing was free to oscillate about its ¼ chord location, and was initially set at 15 degrees prior to flow onset. The step-like flow establishment process initiated periodic wing oscillations about the zero angle of attack and analysis of Schlieren images revealed hysteresis in flow structures that developed.

Hypersonic control. A pivoted wing with a hinged elevator was tested in TUSQ as a hypersonic control capability demonstration. The wing was pivoted at the ¼ chord location and the elevator occupied approximately 15 % of the chord length of the wing. The wind was 3D printed with an internal cavity that allowed a gyro plus level shifting electronics, and servos for the elevator to be installed. A simple feedback control arrangement was implemented and successfully demonstrated that it was possible to either damp out or amplify the wing oscillations, depending on the phasing of the actuation of the elevator relative to the gyro signal. We anticipate hypersonic aerodynamic control work forming an important part of the TUSQ portfolio in the near future.

PROGRESSIVE REPORTS ON GRANTS AND FELLOWSHIPS

Progress reports on currently held grants and fellowships include –

Ablative thermal protection systems ARC Discovery Project (DP120102663)

Project Summary
The project will study ablative re-entry heat shields by experiments simulating hypervelocity atmospheric flight. The results will enable the design of the advanced spacecraft which are needed to extend man's exploration of the universe. Data will be validated by comparison with flights such as the Japanese Hayabusa asteroid sample return mission.

Progress
Work continued on the project in 2015, although the ARC funding ended in 2014. It was a very productive year, with 7 Journal and 11 conference papers accepted. Ten UQ and overseas students PhD did experiments relating to the grant in the UQ facilities. Collaboration between the partner institutions was strong, with eight student exchanges and 2 Chief Investigator (CI) visits taking place between the partners in 2015, with related experiments being performed in four of the collaborating laboratories (UQ, USQ, IRS and ECP). A UQ PhD student completed a Cotutelle exchange at ECP, on gas giant radiation, extending the capability of the ECP Plasma Torch and modelling software to include gas giant atmospheres. Three of our recent postdoctoral fellows are now employed at respected

institutions in Europe, including IRS Stuttgart, EPFL Lausanne and DLR Goetingen. Fabian Zander worked on the grant as a student, and is now at IRS Stuttgart, further strengthening our ties, and nine staff and student exchanges occurred in 2015. Ms Elise Fahy from UQ spent a year of her PhD at EPFL working on related aspects of both the ESA and ARC grants; she was instrumental in integrating the numerical modelling techniques used by all the partners. IRS and ECP also developed new instrumentation for heat transfer measurements in the ECP plasma torch.

Flow physics of porous wall fuel injection for scramjet combustion and drag reduction ARC Discovery Project (DP120101009)

Progress

Overall progress of the project has been good after some delays. The middle sections of the project were delayed due to the postdoctoral fellow, Dr Bianca Capra, taking up a T&R academic position at QUT; she has remained active in the project, albeit at a reduced level of involvement. In addition, the first-named CI on the project moved to UNSW in 2014 and in 2015 Mee became the first-named CI. A request to extend the project into a fourth year (2015) was approved. PhD scholar, Mr Kevin Basore, has been making good progress and is scheduled to submit his PhD in mid-2016.

Computational modelling of the performance enhancements of porous injection over porthole injection in a 2D radical farming scramjet was completed in year 2. Three-dimensional CFD modelling of the experimental configuration for the fundamental T4 experiments was completed in 2014. This was used to identify the quality of the flow on the test surface of the experiments.

The T4 test section was modified in 2013 to allow for optical diagnostics (PLIF) measurements and model mounting from the bottom of the test section. The campaign to undertake the tunnel testing to identify the fundamental flow physics was started in 2014 and completed in 2015. The wind tunnel model (a heavily instrumented flat plate with porous injection and interchangeable leading edges) was designed and manufactured in 2014. The testing involved injecting hydrogen (the fuel) through one of the porous injectors supplied by the PI from Stuttgart. The schlieren flow visualisation of the injection indicated that there were some discreet jets within the porous injection. It was decided not to push further with the testing program until that issue was resolved. An analysis of the wind-tunnel results also indicated that the quality of the flow over the plate was poorer than required due to the blockage to the flow under the test plate. A major re-design of the test plate was undertaken in 2015 and thermocouple heat transfer gauges were replaced with higher-sensitivity nickel thin-film heat transfer gauges. In order to ensure a successful outcome of the project, the mounting of the porous injector was altered. Also, two additional porous inserts were designed and manufactured in case the non-uniformities in the porous injector identified in the first tests precluded an appropriate injection being achieved.

An OH&S issue with the laser diagnostic system for the T4 shock tunnel in 2015 delayed the commencement of the final series of experiments in T4 for this project. Tests commenced in late 2015 and are currently being completed. The results are showing that the quality of the flow over the plate has been significantly improved by the modifications and the new instrumentation.

The science of scramjet propulsion ARC Discovery Project (DP130102617)

Project Summary

We will produce laboratory test conditions that simulate the highest speeds at which scramjets might eventually fly, and develop the underlying scientific knowledge required to reach the ultimate limits of the viable flight envelope. The significance of the work lies in the family of advanced flight vehicles which will be enabled by the knowledge and experimental validation which will be gained, and the reinforcement of Australia's world leading position in hypersonics. The primary outcomes will be fundamental technical understanding of how the mixing, ignition and combustion processes occur and can be controlled at high Mach numbers, and an extensive database of experimental data at conditions not previously obtainable.

Progress

Experiments were performed in reflected shock tunnel and expansion tube facilities, and good progress has been made in the design and operation of scramjet combustors at high Mach numbers, and in creating very high total pressures in the laboratory. We have made major strides towards a viable Mach 12 engine. Simulations of a Mach 12 REST inlet with inlet injection revealed a significant source of well-mixed fuel, heat, thermal compression, and radicals to enhance combustion downstream, while increasing inlet drag by less than 5%. Full-engine RANS simulations were then used to tailor combustor fuel injector locations to take advantage of favourable interactions with flow structures generated in the inlet. This dramatically increased the simulated combustion efficiency from the previously reported mark of 60% up to 85%, exceeding the requirements for access-to-space systems. The engine research conducted under the grant culminated in the REST engine model tested in UQ's T4 Shock Tunnel becoming the first scramjet to demonstrate experimentally robust supersonic combustion at Mach 12 flight conditions, with the measured pressures validating the predicted combustion efficiency. Recent numerical studies on the exploitation of the stream-wise vortices that occur in scramjet engines showed that they play a major role in fuel transport and mixing, as postulated in the original proposal. Simulations have shown that selective placement of the fuel jet in relation to the vortices can enhance fuel mixing by more than a factor of two. This success is a critical step in making access-to-space scramjets a reality.

An improved inlet injection strategy, which manipulates the flow field so that fuel-air mixing and combustion efficiency can be enhanced, is being investigated for the Mach 12 REST engine using the NCI computing facility at ANU. Once the best injector configuration is identified, this will be implemented in the engine and tested in the shock tunnels in follow-on research arising from the grant. Full flowpath testing (forebody/inlet/combustor/nozzle) was conducted in the T4 shock tunnel at simulated Mach 12 flight conditions for the first time. Results of the tests, which involved a 3-D REST engine using hydrogen fuel, showed robust combustion over a range of fuelling conditions. A key aspect of the work was the ability to trip the bodyside boundary layer, as a laminar boundary layer cannot sustain the pressure rise generated in the engine. This is a key milestone reached in demonstrating the critical technologies that will be required for an accelerating scramjet trajectory that can be used as a stage of a transformational access to space launch system.

In the X3 expansion tunnel, new flow conditions have been developed with total pressures up to one GPa, representative of higher Mach number flight on an accelerating corridor. The tests used a Mach 10 nozzle, although the pressures achieved exceeded flight levels at that speed. A 2D generic scramjet model was tested in these new conditions, and steady combustion was demonstrated for flow durations up to one millisecond. The

X3 tests reproduced the data from the other facilities for the conditions where they overlapped, and gave new information pertaining to the extended envelope conditions. To use the enhanced capabilities at a more realistic free stream Mach number, a Mach 12 nozzle has been designed, which will enable testing of a full inlet-combustor configuration at the correct free stream Mach number, enthalpy and total pressure. The facility will then act as the testing platform for more advanced scramjet configurations, such as those discussed above, and to explore the ultimate operating envelope limits for scramjet propulsion. No other facility type is currently available that can do this. TDLAS instrumentation was been developed for detecting water in combusting systems, and was tested in the X3 2D scramjet, and three other facilities. This promises to be a very powerful diagnostic for future engine studies. Four PhD students completed their studies under work partially supported by the grant, and have found immediate employment in the aerospace industry in Europe and Australasia in propulsion and aerospace related jobs. The outcomes of the research have been disseminated through 4 PhD theses, 10 Journal papers, 1 book chapter, and 13 workshop and conference presentations.

Radiation and Ablation in Rapidly Expanding Flows (DP150100631)

Project Summary
The aim of the proposal is to record the spectra of radiation from a region of rapidly expanding flow representative of the passage of the shock layer on a re-entry capsule from the windward to the leeward surfaces. The project addresses a critical area of spacecraft where the uncertainties of our design techniques are of the order of 300% in terms of surface heat transfer, and current vehicles have to use large safety factors to ensure survivability. The outcomes from the project will be a database of radiative parameters which will enable accurate models of the flow to be developed, and will facilitate the design of advanced spacecraft with greater safety and reliability, with lower structural mass.

Progress
Very good progress was made in 2015. Six PhD students and three undergraduates are now working on topics related to the projects, including recombination processes in air, and in carbon dioxide, representative of entry into the atmospheres of Mars and Venus. They are following up on the preliminary 'proof of concept' tests we did before the grant application which provided the experimental justification for our approach. The more detailed experimental programs now in place are extending the range and spectral resolution of the early experiments. We also have a French graduate working in the UQ laboratories who will be starting a PhD on the grant at École Central Paris (ECP, now known as Centrale-Superlec) in April 2016, co-supervised by PI Laux from ECP and Rowan Gollan from UQ.

Interaction between the Investigators has been good, with PI Brandis (NASA Ames) and PI Laux (ECP) both visiting the UQ laboratories, and CI Morgan visiting NASA Langley. The PIs are playing a useful role in mentoring the HDR students, and Langley are doing numerical analysis on the UQ flow conditions.

This project originally grew from a 'white paper' proposal by CI Morgan to Airbus at a workshop in Bordeaux in 2013. Airbus have maintained a strong interest in its progress, with financial support for the associated ECP operations, and the sponsoring with the French Embassy of a Franco-Australian Symposium at UQ in February 2016. CI Morgan gave four presentations on the project to AFOSR, NATO, NASA and the American Society of Engineering Science meetings in 2015, and the methodology and experimental platform attracted widespread interest and acclaim. Subsequently, we have been invited to prepare a grant submission to AFOSR on an extension of the project, jointly with Texas A&M University and the Air Force Institute of Technology, and Airbus are actively investigating further ways in which they can support further activities within the distributed Hypersonics community in Australia.

The experimental program went well, with measurements in air extended to the vacuum ultra violet range of the spectrum, and measurements in simulated Mars entry expanding to the start of the mid infrared region, which is critical for diagnostics on recombining CO2 flows. A new operating configuration for the X2 expansion tube was commissioned using a cold Helium driver, which gave very good representation of flight in the 3 to 4 km/sec range. New diagnostic techniques were developed in 2015, including surface thermography performed through a radiating shock layer, and from the outside of an infrared transparent wall, internally blackened with a thin film optical coating.

Other developments in related ongoing work include increasing the surface temperatures of our test models to above 3300K, the temperature at which graphitic sublimation takes place. This will now allow us to study recombining flows that have been seeded by the diffusion of sublimated products from very hot heat shield surfaces. This is a very important but poorly understood phenomenon that takes on very high performance heat shields, dominated by surface radiation from extreme temperatures, and the very high enthalpy of sublimation of carbon.

Four Journal papers relating to the work were published, three more are under review and three related conference papers were presented in 2015.

Shock Tunnel Development

Project Summary
In 2014 we received a collaborative Grant from Oxford University, funded by the UK National Wind Tunnel Facility Scheme NWTF for $454,710 to develop what will be the fastest shock tunnel in the UK.

Progress
The structural and functional design of the facility was completed by Richard Morgan and David Gildfind, working with the team from Oxford University. Richard Morgan spent 3 months at the Rolls Royce technology Centre at Oxford University in 2015 working on the project. Progress has been good, and commissioning is scheduled for 2016. During this time collaborative links between Oxford and UQ were strengthened, with two Bachelor of Engineering/Master of Engineering students on placement and a UQ PhD student on exchange in the Oxford laboratory. New grant proposals were developed for ARC and EPSRC projects, and Richard Morgan participated in the annual ‘Luddock day’ festivities, giving a presentation on the long-term links between UQ and OUEL.

http://www.eng.ox.ac.uk/about/news/the-41st-maurice-lubbock-memorial-lecture-the-departments-biggest-event

Development of computer-based optimisation to improve hypersonic aerodynamic design ARC DECRA Award (DE140101546)

Project Summary

Next-generation launch vehicles using high-speed jet engines will make it cheaper and more reliable for humankind to engage in activities in space. This project will contribute to the technology of high-speed jet engines by developing optimised air intake systems. The research aims to advance the use of computational engineering and apply this to improve the design of air intake systems. The outcomes of this project will advance the technology of high-speed jet engines with the goal of replacing existing rocket systems.

Progress

The project on using computer-based optimisation for the design of hypersonic inlets has been underway for 24 months. The project work has been progressing largely according to the planned schedule: there have been no interruptions or delays at this stage; however, there have been some unexpected developments.

During the initial stages of the project, it became clear that the flow solver infrastructure would need to be upgraded significantly in order to undertake the flow optimisation work. This portion of the work has been completed. The new flow solver has been implemented in the D programming language. The use of the D programming language is a novel approach to building large-scale high-performance simulation codes. This novel approach was communicated to the research community at the Australian Conference on Computational Mechanics. This work will appear as an archival journal paper in a special issue of the Advances of Computational Mechanics in Australia. This was an unexpected development in the project plan. The newly implemented flow solver infrastructure allowed for other modelling developments that were not originally planned. Chief amongst these was the development of a conjugate wall model. This will give a more realistic boundary condition for scramjet inlet studies than what was originally proposed in the project. The work on implementing and verifying the conjugate wall model was reported in the Journal of Computational Physics.

The project is entering the final phase. In that part, the coupling of the flow solver and optimisation method will be implemented and tested. The final part of the project involves application of the developed method to the optimisation of a hypersonic inlet. Work has already been completed on developing a baseline inlet for the optimisation study. The baseline inlet was developed as a timely response to contribute towards a larger project at the University of Queensland to develop a scramjet-powered demonstrator vehicle.

Ablation radiation coupling

Project Summary

This project involved the generation of peak convective and peak radiative conditions in the X2 facility, modelling flow over the Phoebus and Hayabusa vehicles entering Earth`s atmosphere. Spectroscopic measurements were taken of the gas flow over the front of the model focussing on the vacuum ultraviolet region of the spectrum. Two model configurations were studied – a flat face cold (room temperature) model and a hemi-cylindrical strip. The latter can be used to simulate the ablative processes that occur on the front of the re-entry vehicle due to the high temperature of the flow.

Progress

All measurements for the project have now been completed. For all experiments, three test conditions were developed simulating a range of entry conditions. For the flat-faced model, spectra were recorded both across the front of the model as well as through the model (using a window mounted flush with the model surface). For the graphite strip, spectra were recorded across the front of the strip in three different model configurations: a steel strip at room temperature, a graphite strip at room temperature and a graphite strip heated to simulate ablation from the surface.

The experimental data has since been analysed and a final report for the project is in preparation for submission to the granting agency in the middle of the year. This will mark the end of the project.

Development of X3R, an advanced Scramjet testing Shock Tunnel (MYIP#5828)

Project Summary

In response to the clear need for enhanced ground testing capability in Australia for the Mach 5 to 8 speed range, with extended test times and larger physical dimensions than can be achieved in any existing facilities, UQ is collaborating with the DST Group Applied Hypersonics branch to develop a new reflected shock tunnel, X3R. The facility is based on the existing X3 superorbital expansion tube platform, and uses the same driver and the first driven tube configured as a reflected shock tunnel. The facility will give test times in the range from 10 to 20 milliseconds, and is predicted to have useful core flows of the order of 600 mm diameter. The primary role anticipated for the facility will be for the testing of flight scale scramjet combustors for use with hydrocarbon fuels.

Progress

Progress has been good in 2015, with the design details nearing completion. The project has been extended with phase two funding in 2016, when commissioning is expected. Contracts for some of the major structural components have been signed, and the remaining parts will be under construction soon. The laboratory layout to enable the ergonomic use of X3 in all its configurations (superorbital expansion tube, non reflected shock tube, and now reflected shock tunnel) is in the process of being established. Three postdoctoral researchers are currently working on the project, which is being led by Richard Morgan and David Gildfind.

Experimental Analysis of High Speed Earth Re-entry

Project Summary

This project is a DAAD collaborative program between the UQ Centre for Hypersonics and IRS, Stuttgart. It is based around experimental measurements in radiating and ablating flows in UQ's superorbital expansion tube facilities, and the plasma based facilities at IRS.

Progress

Work under the grant was extremely active in 2015, with 4 UQ students spending periods of up to 2 months in Stuttgart, and three students, postdoctoral fellows and academics from IRS visiting UQ. The IRS visitors also participated in the UQ lecture series on Aerothermdynamics in November/December 2015.

Mach 6-8 scramjet combustion experiments using hydrocarbon fuel (Asian Office of Aerospace Research and Development)

Project Summary

The T4 shock tunnel is a facility designed for generation of true scramjet flight conditions (matching Mach number, velocity and altitude) between Mach 6 and 12. This research involves experiments with a relatively large scale (45mm/1.8in. diameter) axisymmetric isolator/combustor in the Mach 6-8 flight regime using hydrocarbon fuels. Experiments in the first year (2015-16) will be with gaseous hydrocarbons, with experiments in the second year utilizing a liquid hydrocarbon fuel system supplied by DSTO. As well as high frequency surface pressure and heat transfer measurements, PLIF visualisations will be made in the exhaust plume downstream of the combustor. This experimental set-up is ideal for fundamental studies of scramjet ignition, flame-holding and combustion.

HiFiRE Postdoctoral Research Fellow A8

Project Summary

The effect of increasing wall temperature on the combustion process in a scramjets operating at Mach 7 will be investigated. Wall temperatures up to 2000K will be considered in a CFD analysis, and the overall combustion efficiency and combustor length will be of primary importance. The fuel will be both hydrogen and hydrocarbons.

HiFiRE Postdoctoral Research Fellow A6

Project Summary

The project aims to determine the effectiveness of a priority material to emit electrons when heated. Effectiveness will be in reference to a heated combustor as well as aerodynamic heating of leading edges of a hypersonic vehicle. It will involve bench testing of the material to temperatures of 2000K and determining the electron emissions as a function of temperature between 1000K and 2000K. Estimates of drag reductions will then be made. In addition, if the material is shown to be successful, engineering methods for integration into an operational system will be investigated.

HiFiRE 8 Ground Testing (2014/1099642/1)

Project Summary

This research involved shock-tunnel testing of an approximately half-scale HIFiRE 8 scramjet engine in combustor/nozzle configuration B at Mach 7. The tests were conducted with the model at angles-of-attack of -2, 0, and+2, at total enthalpies ranging from 2.2 MJ/kg to 2.45 MJ/kg (which correspond to equivalent flight Mach numbers ranging from 6.7 to 7.0), at different flight altitudes ranging from 25km to 28.5km (computed assuming Reynolds number scaling), and with different fuelling schemes. Hydrogen was used as the fuel for the engine in these tests. The key finding from these tests was that robust dual-mode combustion can be obtained at all the angles-of-attack tested. The static pressure and surface heat-transfer levels in the combustor and nozzle when dual-mode combustion occurs were generally three times higher than those for the fuel-off and combustion-suppressed tests.

Magnetic suppression of instabilities in shock driven converging flows (King Abdullah University of Science and Technology)

Project Summary

Hydrodynamic instabilities such as shock-driven Richtmyer-Meshkov (RM) and Rayleigh-Taylor (RT) have inhibited ignition and fusion of heavy hydrogen isotopes in inertial confinement fusion (ICF). It was shown that the RM instability is suppressed in the presence of a magnetic field. We propose to investigate the suppression of shock-driven hydrodynamic instabilities in converging cylindrical and spherical geometries relevant to ICF. We propose: (a) investigations of cylindrical and spherical Riemann problems to determine symmetry preserving or asymmetry minimizing initial seed magnetic field configurations, (b) linear and nonlinear simulations of single and double interface RM instability investigations modelled using equations of ideal magnetohydrodynamics (MHD), (c) stability of converging MHD fast shocks, and (d) investigations into the detailed patterns of MHD shock refraction at density interfaces using a self-similar formulation of the MHD equations. These investigations will enhance the knowledge base of the plasma physics discipline. Successful suppression of hydrodynamic instabilities in ICF will have a tremendous impact and potentially pave the way to make fusion energy a reality.

Progress

Our investigation of the converging shock driven RMI commenced by simulating the cylindrical converging case for uniform and saddle fields. The RMI was found to be suppressed; however, the extent of that suppression is non-uniform and highly dependent on local magnetic field orientation. We find that interestingly, the saddle topology seed field is more effective in suppressing the RMI while also maintaining greater implosion symmetry. After extending the study to a wide variety of field strengths and perturbation wavenumbers, it was determined that both the RMI and subsequent Rayleigh-Taylor instability are found to be suppressed for all wave-numbers for sufficiently strong fields. Simulations of the spherical version of the instability have also been completed and analysed, with similar conclusions. These results are reported in Mostert, Wheatley, Samtaney & Pullin (2015).

We have demonstrated that seed magnetic fields can certainly be effective in suppressing the RMI and RTI in fusion implosions. Care must be taken, however, to minimise the impact of the field on implosion symmetry. Our results indicate that this can be achieved by maximising the planes of symmetry of the initial field. To further investigate the effect of field geometry, we have extended our investigations to an octahedrally symmetric seed magnetic field. This was found to achieve both greater instability suppression and a more symmetric implosion than the saddle field. These preliminary results were presented at the 2015 APS Division of Fluid Dynamics (DFD) Meeting.

We have also furthered our investigations of shock refraction in MHD, having automated and generalized an analytical solver for the MHD shock refraction problem. This was used to map out solutions over a wide parameter space. The limit of regular refraction was identified and irregular refraction solutions were numerically generated. Irregular MHD shock refraction has been simulated over a broad range of parameters. The structure is more complex than originally understood, and sensitive to problem parameters. Critically, the shock refraction process always leaves the density interface vorticity free, which is the underlying mechanism for the suppression of the RMI. The extended findings were presented at the 2015 APS DFD meeting and a paper fully documenting them is in preparation.

With Daryl Bond, we have begun to examine the RMI in the far more general context of two-fluid MHD, where electrons and ions are simulated separately. We have established that for reasonable plasma parameters, vorticity is still effectively transported in the two-fluid system. These finding were presented at the 2015 APS DFD meeting.

KPI 6: PROFESSIONAL DEVELOPMENT

STAFF DEVELOPMENT AND PUBLICATIONS

The professional development needs of staff are normally identified as part of the annual performance appraisal, undertaken by supervisors, and approved by the Head of School. Examples of a number of staff development opportunities are set out below. These examples are opportunities for teaching staff; however, through the University’s staff development program, staff development activities are provided to all staff and RHD students.

Opportunities for staff development were available in 2015.

GRADUATE CERTIFICATE IN HIGHER EDUCATION

The School of Education at UQ offers a unique opportunity for professional development in a UQ accredited program for those teaching in the university context. New “Teaching and Research (T&R)” are encouraged to enrol in the Graduate Certificate in Higher Education (GCHEd) in their first two years of appointment. The program consists of four 2-unit courses generally taken part time over a two year period. The program includes learning modules on student learning, teaching methods, eLearning, and evaluation of teaching. The School of Mechanical and Mining Engineering pays the tuition fees for new T&R staff.

INSTITUTE FOR TEACHING AND LEARNING INNOVATION

The Institute for Teaching and Learning Innovation (ITaLI - formerly TEDI) provides practical support to faculties and schools to achieve and celebrate teaching excellence. ITaLI staff collect and interpret data about teaching practices to enhance learning and teaching practices and anticipate future impact and opportunities for the University. ITaLI also coordinates the student evaluation of courses and teaching (SECaT) surveys which are undertaken each semester and are used to help teaching staff improve their courses, teaching, and provision of feedback to students. Examples of projects undertaken by ITaLI include: “flipped classrooms”, tutor training, electronic marking of assignments, and a new program “Teaching@UQ” which is designed to provide technology enhanced professional development to new teaching staff.

STAFF DEVELOPEMENT PROGRAM

The University's staff development program is run at no cost to staff. Areas of staff development activities include: "managing people", "research skills development", "teaching, learning and assessment", and "OH&S and sustainability". Some courses are compulsory, including a number of managing people and OH&S courses.

SUPERVISORY SKILL DEVELOPMENT

All staff, including Research Focused (RF) staff, are encouraged to be active in research higher degree supervision (PhD and Master of Philosophy students), final year engineering undergraduate thesis supervision, and masters coursework student supervision. Staff who supervise RHD students are required to complete a program of professional development run by the University's Graduate School. Staff can enroll in a number of courses under the topic "Maximising your RHD Advisory Skills". In addition, in 2015, the University introduced a new policy "Eligibility and Role of Research Higher Degree Advisors". This policy sets out criteria for eligibility of principle advisors, associate advisors, and other members of the candidature team and is used as for quality assurance purposes. All principle advisors must be registered on the University's Principle Advisory Registry.

RESEARCH HIGHER DEGREE SKILL DEVELOPMENT

The majority of hypersonics students enrol through the School of Mechanical and Mining Engineering, with a small number enrolling through the School of Mathematics and Physics. They all have access to a free University wide Career Development Framework run by the UQ Graduate School.

Students are also encouraged to participate in the Faculty's annual Postgraduate Conference. This conference provides an opportunity for RHD students to present their research to academia and industry, improve presentation skills, and network with potential employers and research partners. The conference also provides a chance for attendees to interact and gain an overview of research across the different schools within the Faculty. Each year, the Centre for Hypersonics sponsors The Professor Raymond Stalker Prize for best presentation related to Mechanical and Aerospace engineering.

The University also participates in the annual 3 Minute Thesis (3MT) competition. The 3MT is a research communication competition that challenges PhD students to communicate the significance of their project without the use of props or industry jargon, in just three minutes. This exercise develops academic, presentation, and research communication as well as supports the development of a research student to quickly explain their research in a language appropriate to a non-specialist audience leaving them to want to learn more. The School strongly encourages all PhD students to participate at least once during their studies.

The University closely monitors RHD student progression through a three-step milestone attainment program. Milestones are reviewed at confirmation (one year into the program), mid-candidature review, and thesis review. Milestone meetings are designed to allow the student to articulate their progress and receive feedback and guidance throughout the candidature.

The Centre for Hypersonics also trains all RHD students supervised by Centre staff to act as operators for the X3 Expansion Tube and the T4 Free-piston driven shock tunnel.

CONFERENCE AND PUBLICATIONS

Conference attendance has been strong, with many staff and students given the chance for professional development by presenting their work to international audiences and visiting other research organisations overseas.

Refer to Appendix 3 for a list of conferences attended and publications.

APPENDIX 1:

HISTORY OF HYPERSONICS AT UQ

Hypersonics research at UQ commenced in 1980 when Professor Ray Stalker AO, pioneer of the free piston shock tube driver technique which powers some of the most advanced facilities for hypersonic flow simulation in the world (now universally known as 'Stalker tubes'), started Australia's first research program on scramjet propulsion. Rapid progress in the 1980's and early 1990's led to the introduction of the Mechanical and Space Engineering degree program in 1993, which was expanded in 2005 into the Mechanical and Aerospace program with broader aeronautical content. Hypersonics continues to be the core discipline supporting the Mechanical and Aerospace program, and the primary field of research for the aerospace staff in the School.

Related to this activity is a strong program of research higher degree (namely MPhil and PhD) in Hypersonics. Our 100th research higher degree student (Dr David Gildfind) graduated in 2012. UQ has the largest alumni of hypersonics graduates from any university, and they have been extremely successful, finding employment in varied institutions such as National Aeronautics and Space Administration (NASA), Stanford, Oxford, Loughborough and École Centrale (Paris) universities, Airbus, Defence Science and Technology Organisation (DSTO) and many Australian universities. Many opportunities for overseas study have arisen subsequent to or as part of the UQ hypersonics research program, including student placements at Oxford, Stanford, École Centrale (Paris), EPFL (Lausanne), IRS (Stuttgart University) Universities, and the Indian Institute of Science.

Subsequent to the successful scramjet tests in the early 1980's (which were performed in the 'T3' Stalker tube at the Australian National University), the need for a more powerful facility was evident. Ray Stalker designed the T4 shock tube at UQ, which was commissioned in 1987, and has performed more scramjet tests than any other facility in the world.

Following on from this, in the mid 1980's Ray Stalker and Allan Paull applied the free piston driver concept to the so called 'expansion tube' facilities. These 'expansion tubes' operate by means of a cascade of shock tubes in series, and have the capability of flow at much higher speeds and pressures than conventional shock tubes. This was an extremely successful proof of concept study, and identified fundamental flaws and performance limits in the way previous expansion tubes had been operated. The next stage of development was to push the limits of the expansion concept in 1990, by means of a compound driver system upstream of the shock tube cascade. Thus the 'super-orbital' expansion tube was developed at UQ, capable of simulating the hyperbolic flight conditions of reentry from outside the Earth's gravitational field. The family of 'X tube' facilities X1,X2 and X3 was then developed by Richard Morgan and many colleagues and students. These X tube's have formed the backbone of our research in re-entry capsules and radiating and ablating flows ever since. They are also used to simulate flight in the atmospheres of the planets, including Mars, Venus, Jupiter and the moon Titan.

By 1993, understanding of scramjet operation had progressed to the stage that a viable propulsion unit could be produced, and a system designed by Ray Stalker, Allan Paull and David Mee demonstrated in T4 the operation of a scramjet powered flight vehicle developing more thrust than drag. This was the first ever published data of such an achievement.

In 1997 an opportunity to demonstrate scramjet operation in flight arose, and Allan Paull started the HyShot program. This was a non-thrust producing scramjet combustor, flown on a sounding rocket from Woomera, configured to demonstrate that supersonic air breathing propulsion was possible in flight, and to validate the results of ground based shock tube testing. Despite the first flight crashing due to a rocket fin failure, the second was a complete success. It demonstrated supersonic combustion in flight for the first time ever, some months before the first successful flight of NASA's Hyper-X X43A scramjet in 2004. The success of the HyShot program led to the HFiRE program, a ten flight $54 million collaborative scramjet research and development project involving UQ, Defence Science and Technology Organisation, National Aeronautics and Space Administration, Defense Advanced Research Projects Agency, Boeing and other aerospace participants. The experiences of the HyShot campaign led to the formation of the Defence Science and Technology Organisation Brisbane Hypersonics Branch, founded and led by Allan Paull, to handle the payload preparation and flight testing component of our collaborative scramjet program. Allan still maintains an advisory position as an Adjunct Professor at the UQ Centre for Hypersonics, which was formally established in November 1997 jointly between the departments of Mechanical Engineering (now the School of Mechanical and Mining Engineering) and Physics (now the School of Mathematics and Physics).

In 2010 the Scramspace project started based on funding from the Federal Government initiative to develop space capability in Australia. This was led by Professor Russell Boyce, and was configured around a program of laboratory research on scramjet fundamentals, and a demonstration flight of a scramjet using a flowpath developed by Allan Paull and the DSTO group. In October 2013 the Scramspace rocket failed on lift off from Andoya, Norway, and the payload was lost. The Scramspace program ended in November 2013, and the research outcomes and knowledge gained were very positive despite the loss of the demonstrator.

The ongoing HIFiRE program is led by Professor Michael Smart, and is building up to a peak of activity with a further three flights, demonstrating the use of advanced intakes in flight, and sustained and controllable flight. Advanced intakes using efficient compression processes and self-starting capabilities were developed and pioneered by Michael during his 10 years with NASA. These are a critical feature required for using scramjet propulsion for practical engineering applications, and for breaking the Mach 10 speed barrier required for scramjets to be viable as part of an access to space system.

Since 2005 the group has also been involved in re-entry studies, with particular emphasis on the ablation and radiating processes occurring on thermal protection systems for spacecraft. In this area we have received five consecutive ARC Discovery grants, and many other awards from NASA, ESA and AOARD. We have developed strong collaborative links with leading researchers in the area, including NASA's AMES and Langley Research Centers, École Centrale Paris, Institute of Space Sciences (IRS) Stuttgart and the Indian Institute of Science (Bangalore). We have recently been invited to join the NATO working group on turbulence and transition, AVT-240, and this involvement has led to a new ARC Discovery grant application in partnership with JAXA (Japanese Aerospace Exploration Agency). The group participated in the 2010 return of the Japanese 'Hayabusa' re-entry vehicle, which recovered the first ever samples from an asteroid. Instrumentation developed on X2 was flown on the NASA observation flight monitoring the re-entry over Woomera. A Hayabusa 2 return is planned for 2020, and another observation campaign for 2014 of the Italian ATV 5 re-entry vehicle is anticipated over the South Pacific in December 2014.

To summarise, Hypersonics is a growing area of research in the School, and covers a broad multidisciplinary range of topics, including fundamental studies of radiation, combustion and heat transfer, the design of hypersonic flight vehicles, numerical modelling, facility development and flight testing.

APPENDIX 2:
RESEARCH HIGHER DEGREE STUDENTS

Name	Primary Supervisor	Program	Project Title
Andreas Adrianatos	Dr David Gildfind	PhD	Expansion tube study of radiation scaling from earth re-entry.
Kevin Basore	Dr Vincent Wheatley	PhD	Flow physics of scramjet fuel injection through porous walls.
Timothy Cullen	Professor Richard Morgan	PhD	Reentry shock layer thermography
Kyle Damm	Dr Rowan Gollan	PhD	Numerical estimation of blunt body heating using a macroscopic model for multi-temperature effects
Guerric De Crombrugghe de Looringhe	Professor Richard Morgan	PhD	Aerothermodynamics of super orbital radiating flows.
Zachary Denman	Dr Ananthanarayanan Veeraragavan	PhD	Optimisation of fuel-air mixing and burning in shape transitioning scramjet engines.
Elise Fahy	Professor Richard Morgan	PhD	Superorbital Re-entry Shock Layers, Flight and Laboratory Comparison.
Augusto Fontan Moura	Dr Ingo Jahn	PhD	Investigation and optimization of complex porthole injector arrangements in scramjet inlets.
Sholto Forbes-Spyratos	Dr Ingo Jahn	PhD	Control aspects for the fly-back of a supersonic reuseable rocket booster.
Nicholas Gibbons	Dr Vincent Wheatley	PhD	Dynamics and simulation of hypersonic combustion.
Alexander Grainger	Professor Russell Boyce	PhD	Mechanism for hypersonic scramjet inlet starting.
Sangdi Gu	Professor Richard Morgan	PhD	Ablative thermal protection systems for re-entry into Titan.
Christopher James	Professor Richard Morgan	MPhil	Radiation from Simulated Atmospheric Entry into the Gas Giants.
Jens Kunze	Professor Michael Smart	PhD	Effects of engine scaling on the combustion performance of 3D scramjets
Steven Lewis	Professor Richard Morgan	PhD	Melting Models of CO2, in re-entry flow conditions.
Juan Llobet Gomez	Dr Ingo Jahn	PhD	Vortex-fuel jet interactions to enhance mixing in scramjets.
Will Landsberg	Dr Anand Veeraragavan	PhD	Optimisation of inlet and combustor fuel injection in shape transitioning scramjet engines.

Name	Primary Supervisor	Program	Project Title
Sreekanth Raghunath	Professor David Mee	PhD	Boundary layer transition lengths in hypersonic flows.
Michael Roberts	Professor David Mee	PhD	Investigation of heated hydrocarbon fuelling in a radical farming scramjet engine.
Tamara Sopek	Dr Timothy McIntyre	PhD	Fuel injection/mixing studies in hypersonic flows using advanced optical diagnostic techniques.
Samuel Stennett	Dr David Gildfind	MPhil	Flow condition optimisation and characterisation for a new large scale reflected shock tunnel
Pierpaolo Toniato	Professor Richard Morgan	PhD	High Mach number Scramjet Testing in the X3 Expansion Tube.
Tristan Vanyai	Dr Timothy McIntyre and Professor Richard Morgan	PhD	Scramjet accelerators investigated using advanced optical diagnostic techniques.
Han Wei	Dr Timothy McIntyre and Professor Richard Morgan	PhD	Interaction between shock layer and ablative products from heat shields during atmospheric entry.

APPENDIX 3:

PUBLICATIONS

JOURNAL ARTICLES

Barth, James E, Wheatley, Vincent and Smart, Michael K (2015) Effects of Hydrogen Fuel Injection in a Mach 12 Scramjet Inlet. AIAA Journal, 53 10: 2907-2919. doi:10.2514/1.J053819

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