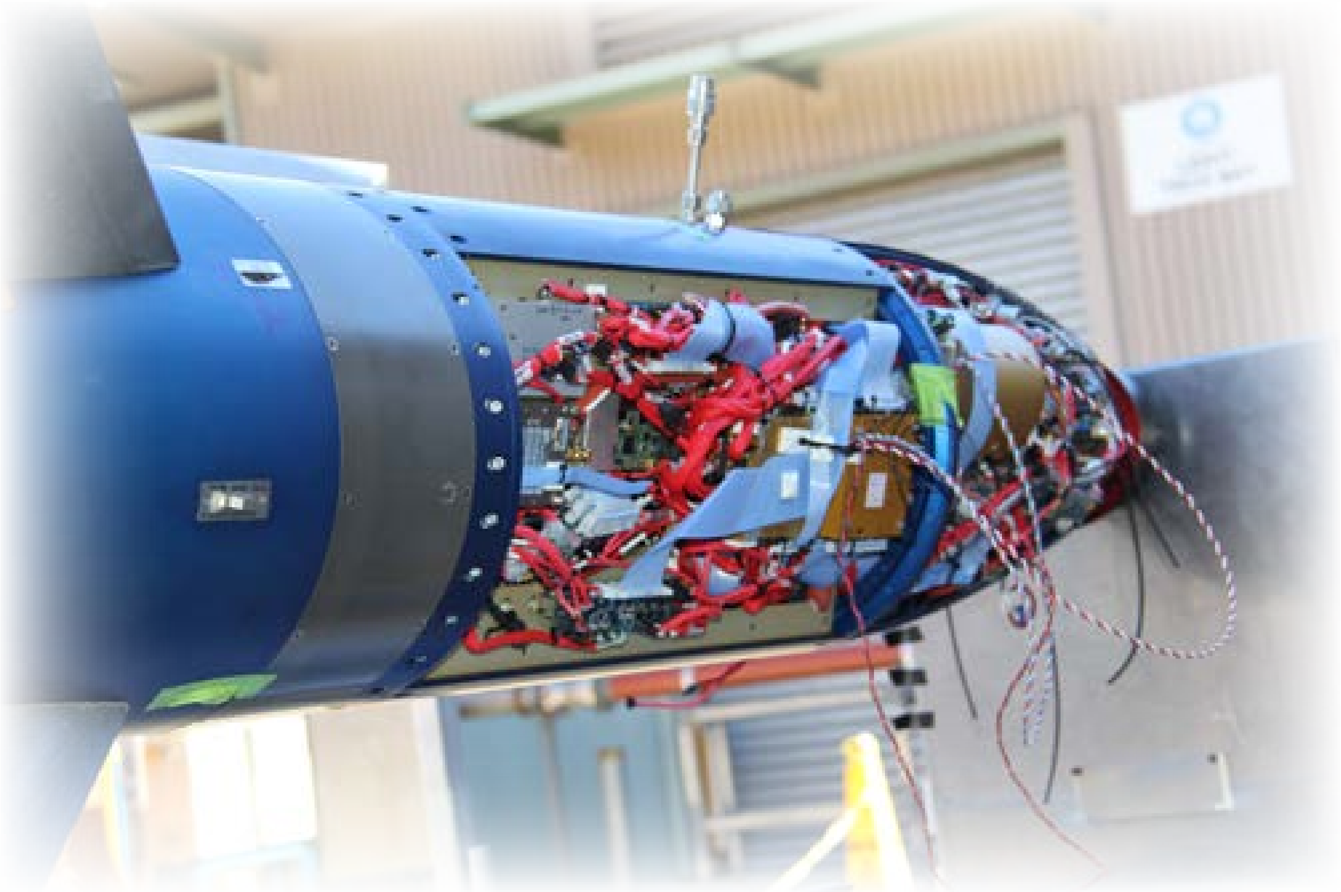
QUEENSLAND HYPERSONIC TESTING FACILITY



2014 ANNUAL REPORT

1 JANUARY 2014 - 31 DECEMBER 2014

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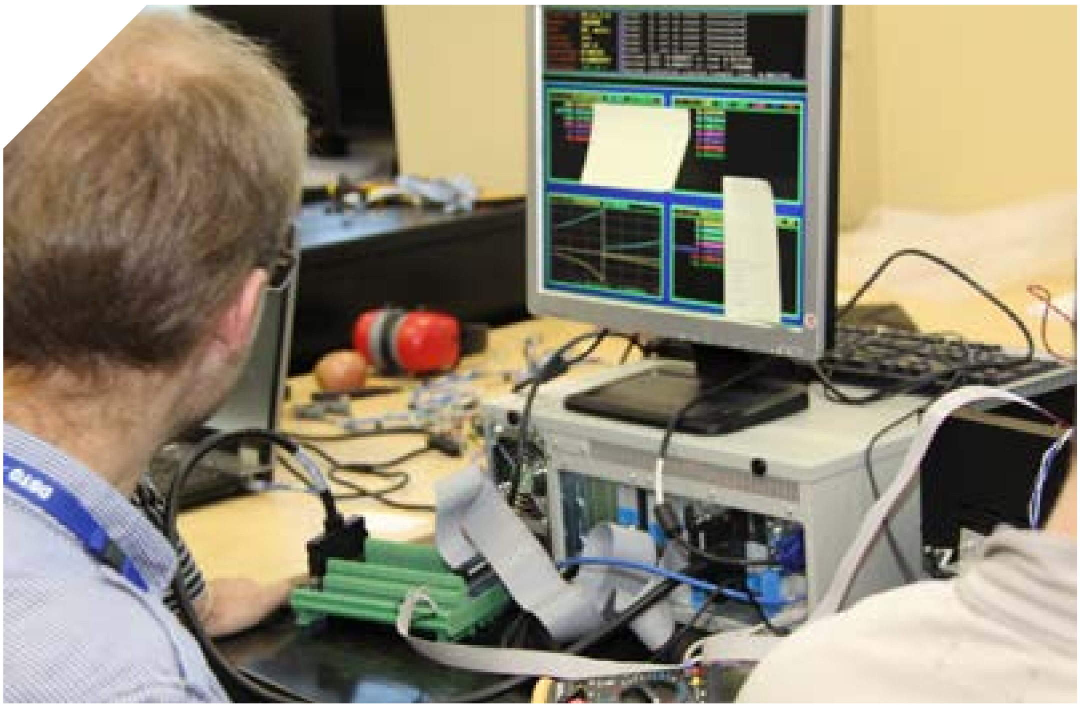
THE CENTRE AT A GLANCE



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

Our researchers have been active internationally during that period, and have been involved in collaborative research programs with approximately 40 universities and research organisations around the world.

OUR OBJECTIVES:

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

OUR EXPERTISE:

- development of hypervelocity test facilities
- SCRAMjet propulsion (experiment in the labratory 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.

   n/a

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

   n/a

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

   n/a

iv. Sale of Rockets

   There have been no commercial sales to date. 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 by far 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

   n/a

KPI 2: EMPLOYMENT OF PROFESSIONAL STAFF

PERSONNEL

Several Teaching and Research (T&R) Staff, Research Focussed (RF) staff, and technical staff are employed in the area of hypersonics at the Centre for Hypersonics. There are also several staff members with adjunct or honorary appointments. Further details

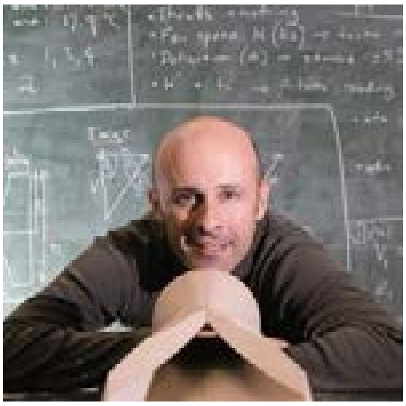
DSTO Brisbane employs six staff in hypersonics, and has between one and five resident visitors at all times. Teakle Composites employs a number of staff working in related technology.

LEADERSHIP TEAM

RICHARD MORGAN
DIRECTOR
CENTRE FOR HYPERSONICS

Professor 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, including the 'X' series of super-orbital expansion tubes, and 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 program with NASA, ESA, Oxford University, Ecole Centrale (Paris) and AOARD in radiating flows, as well as 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 he 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 Richard 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, compressible fluid flow. Professor Smart graduated with a Bachelor of Engineering (Hons) at UQ in 1985 and Master of Engineering Science at UQ in 1987, and was awarded a PhD at the Polytechnic University, Brooklyn, New York, in 1995. He was appointed an Associate Professor in the Centre for Hypersonics in 2005 after spending 10 years as a research scientist at NASA's Langley Research Center in Virginia.

He is the chief investigator on the five-year National and International Research Alliances partnership collaboration between UQ, the Queensland Government, Boeing, USAF and DSTO to conduct scramjet-related flight tests as part of the 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 recently received the 2012 International Congress for Aeronautics (ICAS) Von Karman Award for International Co-operation in Aeronautics.

DAVID MEE
PROFESSOR

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 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.

IN MEMORIUM

RAY STALKER AO (1930-2014) PROFESSOR

As Australia's first Professor of Space Engineering and pioneer of the world's fastest jet engine, the Scramjet, Professor Raymond Stalker is remembered as a pioneer within the field of Hypersonics. Establishing UQ's research in Hypersonics and having invented the free-piston shock tunnel (known as the Stalker tunnel), Professor Stalker is also renowned for designing the first scramjet that was demonstrated to produce more thrust than drag. Professor Ray Stalker received a plethora of accolades and honours during his career including the Order of Australia, and was the only Australian Fellow of the American Institute of Aeronautics and Astronautics (AIAA).

Even after retirement Ray continued to be involved with his research group and contribute to realising his vision of an affordable Australian space program. Ray's life work laid the foundations for a respected Australian presence in hypersonic aerodynamics. After a valiant and determined struggle with Parkinson's Disease and the after-effects of his stroke in 1992, Ray passed away on the 9th of February 2014.

Due to the tireless dedication and work of Professor Ray Stalker, The University of Queensland has been able to firmly cement it's hypersonic research capabilities on an international stage. Professor Stalker's life work and research will continue as the University furthers it's hypersonic portfolio in the coming years.

A portrait of Ray has been hung in the foyer of the Mansergh Shaw Building. His contribution to Hypersonics at UQ is outlined towards the end of this report in "History of Hypersonics at UQ".

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 (DSTO, HyShot)
Dr. Stefan Brieschenk	Research Fellow
Professor David Buttsworth	Research Consultant (University of Southern Queensland)
Dr. Bianca Capra	Research Consultant (now at Queensland University of Technology)
Mr Myles Frost	Research Assistant (DSTO, HyShot)
Dr. David Gildfind	Research Fellow, then Lecturer since May 2014
Dr. Rowan Gollan	Research Fellow, then Lecturer since May 2014
Dr. Peter Jacobs	Reader
Dr. Ingo Jahn	Lecturer
Dr. Michael Macrossan	Research Consultant
Dr. Tim McIntyre	Senior Lecturer, UQ School of Mathematics and Physics
Dr. Judith Odam	Research Fellow (DSTO, HyShot)
Professor Allan Paull	Program Leader (DSTO, HyShot) and UQ Adjunct Professor
Dr. Ross Paull	Research Fellow (DSTO, HyShot)
Dr. Neil Mudford	Adjunct Researcher
Dr Sarah Razzaqi	Research Fellow
Professor Halina Rubinsztein-Dunlop	Head of School, UQ School of Mathematics and Physics
Dr. Todd Silvester	Research Fellow (DSTO, HyShot)
Dr. Phillip Teakle	Research Consultant, Teakle Composites, and Adjunct Associate Professor
Dr. Sandy Tirtey	Adjunct Research Fellow
Dr. Vince Wheatley	Senior Lecturer
Professor David Mee	Head of School, UQ School of Mechanical and Mining Engineering
Professor Richard Morgan	Director of the Centre for Hypersonics
Professor Michael Smart	Professor Air Breathing Propulsion
Dr. Anand Veeraragavan	Lecturer

TECHNICAL STAFF

Name	Speciality
Barry Allsop	Electronics
Frans De Bur	X3 expansion tube upgraded driver installation
Keith Hitchcock	T4 shock tunnel facility
Wayne Jenkins	X3 expansion tunnel facility

KPI 3: ENCOURAGE INVOLVEMENT OF RESEARCH HIGHER DEGREE STUDENTS

EDUCATION

STATISTICS

The group had eight research higher degree students commence in 2014, creating a cohort of 32. There were also nine PhD and MPhil graduations in 2014, bringing the number of Research Higher Degree (RHD) graduations from the Centre for Hypersonics at UQ to a total of 49 for the period 2005 to 2014 (43 PhDs and six MPhils).

In addition, research students participated in several national and international conferences, and presented the results of their research in person.

PhD graduates in 2014 found employment in respected institutions overseas including Ecole Polytechnique Federale de Lausanne (EPFL), Reaction Engines (UK) and Rocket Lab (NZ). The last two companies are 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.

See Appendix 2 for a list of current research higher degree students and Appendix 3 for a list of publications from 2014.

RHD ENGAGEMENT

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

Christopher James is spending 12 months in 2014/2015 working with Ecole Centrale Paris (ECP) under the Cotutelle de Thèse (Joint Supervision of Theses) program whereby a student undertakes a joint PhD between UQ and a French University, receiving a degree from both institutions.

Mr Wouter Mostert completed six weeks of his PhD study at the California Institute of Technology, USA in 2014 under an ARC Discovery Project strengthening the group's simulation capabilities for future research.

In 2014, Ms Elise Fahy completed four weeks working with the Interdisciplinary Aerodynamics Group (IAG) at Ecole Polytechnique Federale de Lausanne in the Swiss Federal Institute of Technology as part of her PhD studies. Ms Fahy worked 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 five weeks of his PhD study 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 the 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.

In addition, Mr Steven Lewis also spent seven weeks of his PhD at the Institut für Raumfahrtsysteme (IRS) at Stuttgart University, Germany. Following this, Mr Lewis spent time at the Ecole Centrale, Paris collaborating with Professor Christophe Laux in their world-class plasma torch facility. This visit was funded by the Australian-German G08-DAAD scheme to encourage the careers of young professionals and students.

Tamara Sopek (PhD student in Hypersonics) is currently on a placement at Stanford University, working with the pioneering Professor Ron Hanson on optical diagnostics.

UNDERGRADUATE EDUCATION

Many undergraduate students did their final year thesis projects with the group, and several students on 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 participated in the MOOC program 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 was very successful with very good reviews received from the inaugural class. It is being offered again in 2015.

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 course coordinated by Professor David Mee can be found online:

http://www.uqx.uq.edu.au/hypersonics

KPI 4: COLLABORATION

ENGAGEMENT AND COLLABORATION

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

A large number of visitors were received in connection with the HIFiRE and ARC research programs, and the G08-DAAD award we hold with IRS (Institute of Space Systems) Stuttgart.

Tobias Hermann, PhD student from IRS Stuttgart, spent a month working in the expansion tube laboratory under the G08-DAAD scheme on ablative thermal protection systems.

Hannes Fulge PhD student from IRS Stuttgart, spent a month working on instrumentation development in the expansion tube laboratory under the G08-DAAD scheme. As a follow on from that exchange, UQ PhD Student Brad Wheatley will spend a month at IRS in April 2015.

QUEENSLAND-INDIA FRIENDSHIP SCHOLARSHIPS PROGRAM

Mr Mohammed Ibrahim Sugano from the Indian Institute of Science (IISc) was selected to undertake the Queensland-India Friendship Scholarships Program at The University of Queensland.

Mr Sugarno worked in the expansion tube laboratory at The University of Queensland under the supervision of Professor Richard Morgan.

Mr Sugarno undertook this program from 16 March 2014 for a period of 18 weeks. Due to unforseen mechanical issues with our Shock Tunnel the School extended Mr Sugarno's program for an additional two weeks, and he finished on 30 June 2014.

He was involved in a series of experiments investigating 2D shear layers in hypersonic radiating flows in the super-orbital expansion tube X2. He designed a simple model with an axi-symmetrical compression ramp to create a Mach disc and a shear layer containing two adjacent and parallel regions of radiating flows, and use emission spectrometry and high speed video to investigate the growth of the radiating mixing layer under such conditions. The project involved exposure to analytical design techniques, experience in expansion tube operation, heat transfer analysis and optical instrumentation.

The program of study and research related closely to his PhD topic in hypersonic aerothermodyanmaics, and the exposure to experiments in an alternative facility type to the one he has been using at IISc Bangalore will be a useful learning experience to the student.

INDIAN-AUSTRALIAN WORKSHOP ON HYPERSONICS

An Indian-Australian workshop on Hypersonics was held at The University of Queensland on the 4th and 5th of December 2014. The invited group was:

- Prof. K P J Reddy (Department of Aerospace Engineering, Indian Institute of Science)
- Prof. G. Jagadeesh (Department of Aerospace Engineering, Indian Institute of Science)
- Dr. M. Annadurai (Programme Director, IRS & SSS, ISRO Satellite Centre)
- Dr. V. Jayaram (Solid State Structural Chemistry Unit, Indian Institute of Science)

"JUGEND FORSCHT" PLACEMENT -SAVERIO NOBBE

In September 2014, 18 year old Mr Saverio Nobbe visited the Centre for a two week laboratory placement. Mr Nobbe was one of the winners of Germany's largest youth science competition "Jugend Forscht", and part of the prize was gaining exposure to a university research environment.

Mr Nobbe is interested in ammonium nitrate based solid rocket fuels, and further details about his prize winning entry can be found here:

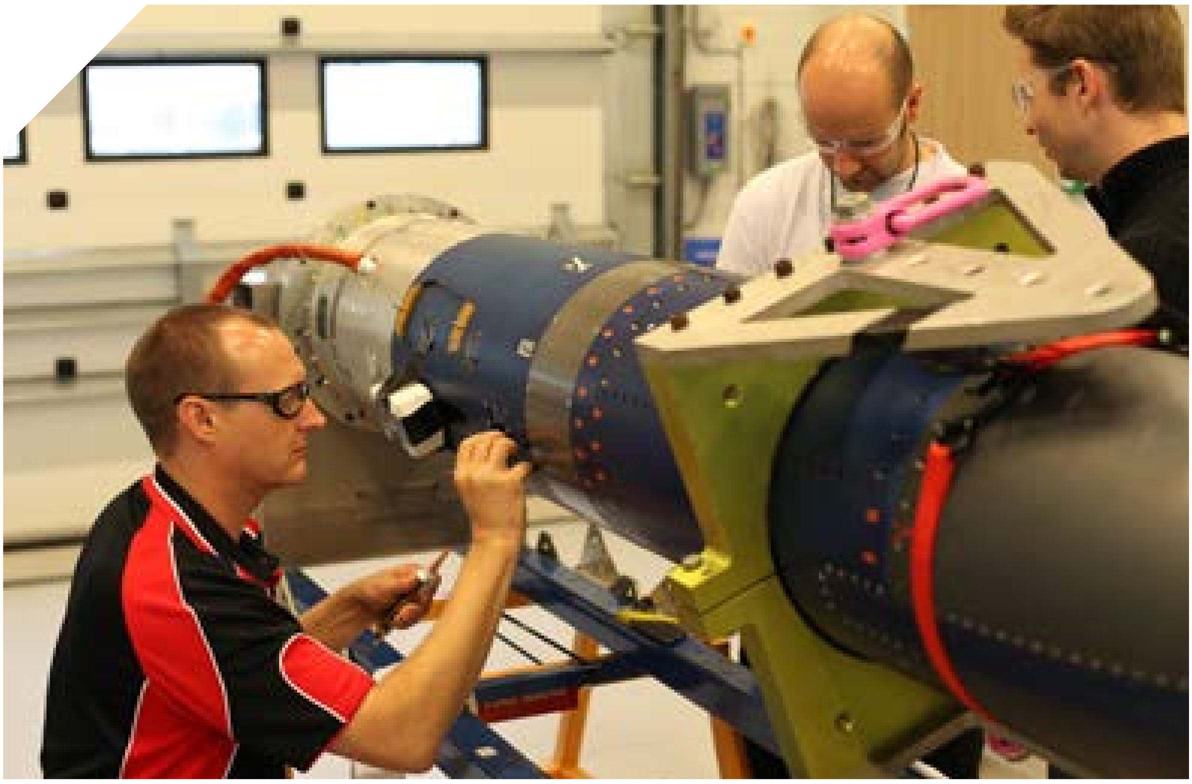
http://www.tagesspiegel.de/berlin/schule/sieger-aus-berlin-bei-jugend-forscht-schueler-erfindet-raketentreibstoff-aus-duenger/10052126.html.

PLASMA TORCH AEROSPACE TEST FACILITY ECOLE CENTRALE (PARIS)

Professor Christophe Laux from Ecole Centrale (Paris) held a formal inauguration of his plasma torch aerospace test facility in November 2014. The Centre participated through the presence of Cotutelle de Thèse (Joint Supervision of Theses) student Chris James from UQ who is doing his placement there. We have had an ongoing collaboration with his group for about 10 years, through PhD student placements, post doc exchanges, sabbatical visits, and collaboration on ARC and ESA grants.

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.

MAJOR PROJECTS

a. SCRAMSPACE

Designed and built in Brisbane, this is a $14 million, three-year research project to collect valuable data from an 8600km/h (Mach 8) high-speed test flight of a hypersonic scramjet.

SCRAMSPACE is the first and largest project funded by the Australian Space Research Program (ASRP). It builds on Australia's world-class hypersonics heritage, and its core objective is to build capacity and capability, in particular a talent pool, for the Australian space and aerospace industry.

This is achieved partly by means of the Mach 8 flight experiment, for which a team of exceptional young scientists and engineers has been assembled, and partly through extensive ground-based research involving many PhD students at UQ and partner universities.

By addressing key scientific and technological questions, the consortium is conducting ground-tests at up to Mach 14 and a flight-test of a free-flying scramjet at Mach 8.

Unfortunately, the scramjet payload was not delivered to the correct altitude and speed during the flight test on 18 September 2013 due to a problem with the first-stage rocket motor.

While the final stage of the project, the flight test, did not deliver hypersonic flight data, the ground testing and modelling and analysis components of the project delivered many important research results that will be published in papers and theses in the coming years.

b. HiFiRE

The Hypersonic International Flight Research Experimentation (HIFiRE) program is investigating the fundamental science of hypersonics technology and its potential for next generation aeronautical systems and will involve up to ten flights. HIFiRE has been jointly established by Defence Science and Technology Organisaton (DSTO) and the US Air Force Research Laboratory (AFRL). The HiFiRE 7 scramjet is ready for flight, and scheduled to be launched from Andoya, Norway in March 2015.

c. USQ ACTIVITIES

ASRP-funded (SCRAMSPACE) dominated the activities of the University of Southern Queensland (USQ) hypersonic wind tunnel (TUSQ) facility during 2013. A fast door opening scramjet inlet model was developed at USQ to provide benchmarking data for the PhD program of Alex Grainger, a UQ student. Door opening speeds of the order of 1 millisecond were achieved using a pneumatically actuated pull-ram and carbon fibre doors. Pressure measurements within the scramjet inlet were obtained and high speed schlieren imaging of the flow establishment process were taken. The results from time-resolved computational simulations of the door actuation process within the Mach 6 hypersonic flow are currently being analysed in conjunction with the TUSQ experimental results and submission of Alex Grainger's dissertation is expected to occur in 2014.

Internally-funded, free-flying experiments on a model of the SCRAMSPACE vehicle were performed by a USQ final year project student, Rod Ennis using the TUSQ facility. The model included the geometric detail of the inlet starting doors-open flow path and the external vehicle profile. The motion of the vehicle was tracked using high speed cameras, and internally-mounted accelerometers and gyroscopes with wireless serial port data acquisition to a computer external to the test section. The results are yet to be fully-analysed, but further free-flying work is anticipated in the near future.

Internally-funded testing by UQ engineering students was also performed in the TUSQ facility using the Mach 2 nozzle as part of their design course under the supervision of Dr Vince Wheatley. Two days of testing on separate occasions occurred during the year and for the first time in the TUSQ student scramjet testing program, a visual signature of combustion was detected.

GRANTS -
PROGRESS REPORTS ON GRANTS AND FELLOWSHIPS

COMPARISON BETWEEN HYDROGEN AND METHANE FUELS IN A 3-D SCRAMJET AT MACH 8 (ASIAN OFFICE OF AEROSPACE RESEARCH AND DEVELOPMENT)

Total: $116,185.09 (2013-2014)
Chief Investigators: Professor Michael Smart, Dr Vincent Wheatley

Project Summary

Gaseous hydrogen has typically been the fuel of choice for scramjets operating at speeds greater then Mach 7. This is because of its high scientific energy content, as well as its fast reaction characteristics in air. The disadvantage of hydrogen is its low density, which is a particular problem for small vehicles with significant internal volume constraints. The current study will investigate the use of gaseous methane as a fuel for a Mach 8 scramjet. This will involve experiments with a 3-D scramjet using a cavity based flame holder in the T4 shock tunnel at UQ as well as a companion fundamental CFD study. The performance of methane will be compared with hydrogen to establish the importance of its lower specific energy content and slower reaction characteristics. In addition, a scoping study will be performed to determine the capability for direct connect testing in the T4 shock tunnel.

Progress

We have assembled a strong UQ team for the research, including Dr Anand Veeraragavan (combustion), Dr Stefan Brieschenk (ignition systems) and Zachary Denman (PhD student), as well as Dr Vince Wheatley (computations) and Professor Smart (overall research lead). A circumferential cavity has been designed and added to the existing REST flowpath; design work on the wind tunnel model is progressing well. A spark plug based ignition system will also be added for the experiments that were performed in May 2014. We have also conducted a significant amount of fundamental computations to compare the reaction and ignition lengths of hydrogen, ethylene and methane. I have included a few snippets of the research for your interest.

Snippet 1: Cavity Design Methodology

The combustor of the Mach 8 REST scramjet engine will be modified to include a modular cavity. The entire engine with the modified combustor is shown in Figure 1. The initial dimensions of the cavity that have been selected for testing are L/D = 4.0, D = 10.9 mm and aft wall angle = 22.5 degrees. The cavity is designed such that the robust combustion of ethylene should occur without an external ignition source. The L/D ratio and aft wall angle selected have been tested by the Air Force Research Laboratory with success. The depth of the cavity was determined using the correlations developed by Davis and Bowersox (for cavity depth) and Colket and Spadaccini (for residence time). These expressions are shown in Equations 1 and 2 respectively. The cavity depth expression estimates the required depth of a cavity, given a freestream velocity, and the required residence time, of the cavity.

$$D = \frac{\tau_r U_\infty}{100} \qquad (1)$$

$$\tau_{ign} = A \exp\left(\frac{E}{RT}\right) [O_2]^a [C_x H_y]^b \qquad (2)$$

The residence time required was approximated using the ignition delay correlations for ethylene. Axisymmetric simulations of the cavity flow were completed using Eilmer3 [4]. These simulations were completed to estimate the temperature in the cavity so that the ignition delay correlations could be utilised. Figure 2 shows both the cavity depth correlation and the ignition delay times for ethylene and hydrogen. A cavity depth of 10.9 mm is required for the autoignition of ethylene without an external ignition source.

Snippet 2: Premixed Combustor Simulations

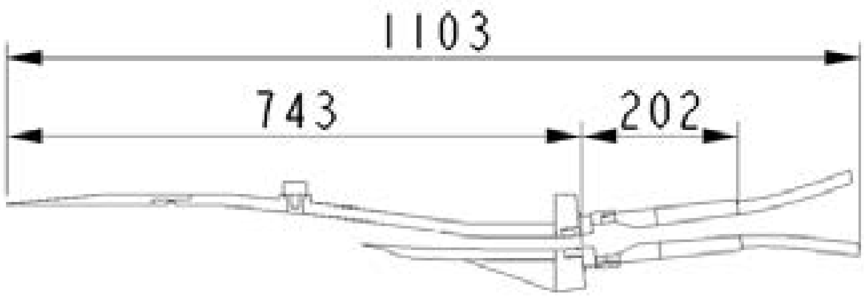


Figure 1: A cross-section of the flow path in the Mach 8 REST engine with modular cavity (dimensions in mm).

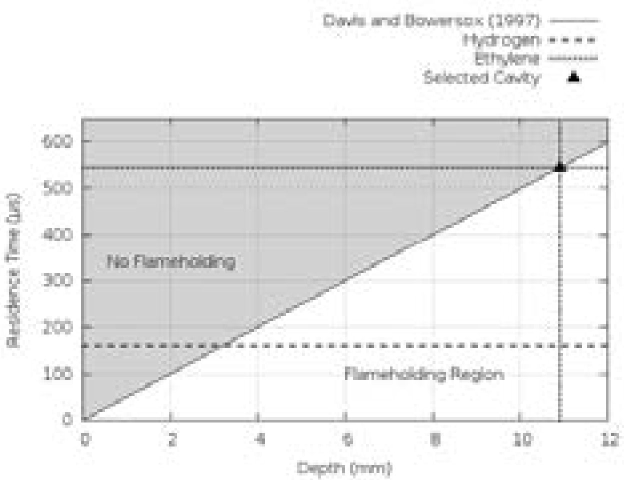


Figure 2: Depth of cavity based on Davis and Bowersox perfectly stirred reactor model, coupled with Colket and Spadaccini's ignition delay correlations for hydrogen and ethylene with $\phi = 0.8$ and $T = 1500K$.

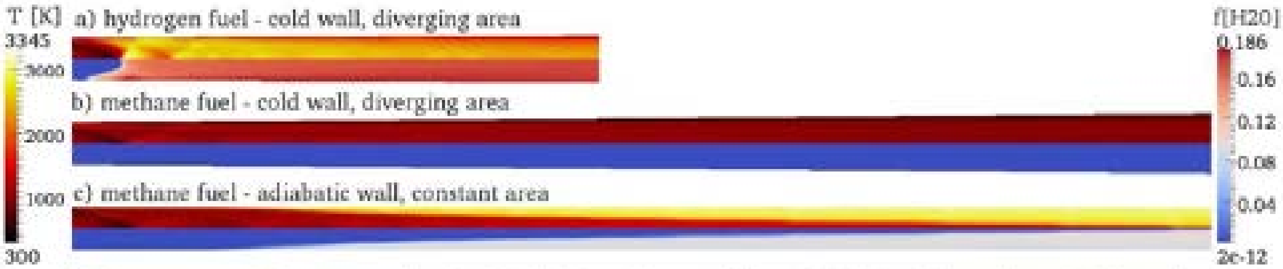


Figure 3: Temperature and water mass fraction distributions from turbulent URANS simulations of premixed combustion in axisymmetric scramjet combustors. a) Hydrogen fuelled, $\phi = 0.73$, 300 K wall temperature, inflow from triple ramp inlet, diverging geometry. b) Methane fuelled, $\phi = 0.88$, 300 K wall temperature, inflow from triple ramp inlet, diverging geometry. c) Methane fuelled, $\phi = 1$, adiabatic wall, inflow from triple ramp inlet, constant area.

In order to establish the combustion characteristics of methane at the scale and conditions present in the combustor of the Mach 8 REST engine, a number of premixed axisymmetric URANS simulations have been carried out. These simulations were conducted with UQ's in-house hypersonic flow solver Eilmer3 using the k-w turbulence model.

Finite rate methane chemistry is modelled using the 19 species, 84 reaction reduced version of GRI-Mech. For comparison, hydrogen combustion was also simulated using the Rogers and Schexnayder mechanism. In both cases, the fuel equivalence ratio (Ø) was set to have the equivalent potential heat release of a Ø = 0.8 ethylene-air mixture. The most informative simulations were run in diverging combustors with the cold walls characteristic of testing in impulse facilities. The inflow to the simulations was extracted from a separate simulation of a triple ramp axisymmetric inlet with approximately the same compression as the REST inlet. The high local temperatures produced through the interaction of the inlet shock train with the turbulent combustor boundary layer govern the ignition process.

Figure 3(a) shows that hydrogen burns robustly at these conditions. The premixed hydrogen combustion process is unsteady and eventually results in the formation of a detonation, a process that does not occur in the experimental engine to the combustion being mixing limited. On the other hand, Figure 3(b) demonstrates that unforced ignition of the methane-air mixture does not occur at the conditions present in our scramjets, even for a combustor extended to over 1 m in length. This justifies the inclusion of a cavity flameholder and forced ignition system in the experimental model. The potential for methane combustion to occur out our conditions once the flow is ignited is demonstrated in figure 3(c). This shows the results of a stoiciometric simulation with adiabatic walls and a constant combustor area. The elevated temperatures in the boundary layer lead to ignition, after which the flame front propagates towards the centerline, reaching it at a combustor length of approximately 1.08 m and resulting in a combustion efficiency of 77%.

THE SCIENCE OF SCRAMJET PROPULSION (DP130102617)

Total: $560,000 (2013-2015)
Chief Investigators: Professor Richard Morgan, Dr Tim McIntyre, Professor Michael Smart, Dr Anand Veeraragavan, Dr Ingo Jahn, Dr Sandy Tirtey

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 data base of experimental data at conditions not previously obtainable.

Progress

2014 was a very busy year for the grant, with experiments performed in both the reflected shock tunnel and expansion tube facilities, and good progress made in the design and operation of scramjet combustors at high Mach numbers, and in creating very high (GPa) 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 experimentally demonstrate 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 2. 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 by an RHD student for the Mach 12 REST engine using the NCI computing facility at Australian National University. Once the best injector configuration is identified, this will be implemented in the engine and tested in the shock tunnels. 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 gaseous 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 to achieve an accelerating scramjet trajectory that can be used as a stage of a high performance access to space launch system.

In the X3 expansion tunnel, new flow conditions have been developed with total pressures up to 1 GPa, representative of higher Mach number flight on an accelerating corridor. The tests were performed using a Mach 10 nozzle, although the pressure levels achieved exceeded those that would be expected in flight at that speed. A 2D generic scramjet model, previously used on the T4 and X2 facilities at lower total pressures, was tested in these new conditions, and steady combustion was demonstrated for flow durations up to 1 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 make use of the enhanced capabilities at a more realistic free stream Mach number, a Mach 12 truncated nozzle has been designed and is under fabrication. This is important, as it 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.

Three PhD students completed their studies in 2014, and have found immediate employment in the aerospace industry in Europe and Australasia in propulsion related jobs. The outcomes of the research have been disseminated through 4 Journal papers, 1 book chapter, 8 workshop and conference presentations. An additional journal paper is under review.

THE GENERAL RICHTMYER-MESHKOV INSTABILITY IN MAGNETOHYDRODYNAMICS (DE120102942)

Total: $375,000 (2012-2014)
First Named Chief Investigator: Dr Vincent Wheatley

Project Summary

This project is to examine and understand the effects of magnetic fields of arbitrary orientation and strength on the Richtmyer-Meshkov instability (RMI) in magnetohydrodynamics (MHD), along with non-ideal effects. This instability is detrimental to inertial confinement fusion, thus its suppression is desirable.

Progress

An analytical model was developed for the transverse field MHD RMI, where the initial magnetic field is parallel to the mean interface location. Its prediction of purely oscillatory interface behaviour was verified by comparing to the results of non-linear compressible simulations. These simulations revealed the suppression mechanism for the instability to be the transport of vorticity on finite amplitude Alfvén wave that travel parallel and to the magnetic field, never leaving the vicinity of the interface. The transverse field model integrates across these waves and does not resolve their structure. The interface oscillates as these waves periodically reconstruct with alternating phase as they propagate, whereas an earlier paper attributed this solely to field line tension. The waves appeared to behave as solitons for the conditions first studied, but our study over a broader range of parameters revealed, that these waves split into transmitted and reflected waves when interacting with a high density ratio interface. A for more complex analytical model for the MHD RMI was then developed for the case where the initial magnetic field can have arbitrary orientation. Again the interface behaviour is dominated by vorticity transport on MHD waves parallel and anti-parallel to the magnetic field. The interface-parallel transport of vorticity, due to the tangential field, continuously alters the phase of the induced velocities with respect to the interface, causing the growth rate to oscillate. Simultaneously, the induced velocities at the interface, and hence the growth rate, decay as vorticity is transported normally due to the normal component of the magnetic field. In the limit of the magnetic field becoming transverse, the waves do not vanish, thus the oblique field model resolves the structure that was integrated across in the transverse field model. It also confirms that the model by other authors, that relies on field line tension only, is not a natural limit as the magnetic field becomes parallel to the interface.

With Research Assistant (RA) Pavaman Bilgi, we have automated and generalized a 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. These fundamental findings were presented at the 19th Australasian Fluid Mechanics Conference. Together with RA James Barth, 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. A paper fully documenting these findings is in preparation. Implementation of MHD capability in our in-house compressible Navier-Stokes solver, eilmer3, is in progress. Ideal MHD capability including hyperbolic divergence cleaning has been validated while resistive terms are currently being formulated appropriately.

The role of the RMI in another context, mixing and combustion enhancement in scramjets, was also investigated. Wall-Modelled Large-Eddy Simulations of axisymmetric and planar inlet-injected scramjets demonstrated that inlet injection allows the interaction of turbulent fuel plumes with primary compression shocks at the combustor entrance, triggering the Richtmyer-Meshkov instability, which has a transformational effect on the mixing process. The mixing rate is more than doubled due to this. We also demonstrated this effect in a complex 3D scramjet.

THE CONVERGING SHOCK DRIVEN RICHTMYER-MESHKOV INSTABILITY IN MAGNETOHYDRODYNAMICS (DP120102378)

Total: $120,000 (2012-2014)
First named Chief Investigator: Dr Vince Wheatley

Project Summary

This project is to understand the effect of various geometry magnetic fields on the cylindrical and spherical converging shock driven Richtmyer-Meshkov instability (RMI) in magnetohydrodynamics (MHD). This instability is detrimental to inertial confinement fusion, thus its suppression is desirable. Excellent progress has been made to date.

Progress

Woueter Mostert continues his PhD in this project. During his first funded visit to UQ in 2012, PI Samtaney created a custom mapped grid version of his MHD code to study the problem at hand, and trained Woueter Mostert in its use. He also conducted simulations of the transverse field RMI for comparison to the analytical model developed by CI Wheatley as part of his DECRA project. It was found that the instability could be suppressed by an entirely different mechanism to that reported in the literature. The first stage of our investigations of the converging instability was to study the behaviour of the implosions that drive them. We initialise these implosions using Riemann problems, and the behaviour of the resulting flows in the presence of a magnetic field was unknown. We first studied a cylindrical implosion in the presence of a uniform magnetic field. The field was found to have major effect on the implosion, with the multiple shocks generated rapidly developing kinks and hence reflected shocks. The wave system then interacted non-linearly resulting in a rich and interesting flow structure.

During PI Pullin's funded visit to UQ in 2013, he extended an analytical technique known as shock dynamics to MHD for converging cylindrical shocks the presence of a singular magnetic field generated by a current along the axis of the cylinder. Remarkably, the shock Mach number weakens to zero as it converges, making this field a very poor candidate for fusion experiments, despite having been proposed in the literature. During PI Pullin's 2014 visit to UQ and Mostert's subsequent visit to Caltech, this work was extended to the case of a time varying current, producing a wealth of interesting results: for a decaying current the shock Mach number can tend to either zero or infinity at convergence depending on problem parameters. A paper documenting these findings is in preparation.

During PI Samtaney's visit to UQ in 2013, he installed an adaptive version of his MHD solver and trained Mostert in its use, enabling more efficient simulations of 3D implosions. Cylindrical implosions were studied for azimuthal and saddle geometry fields, with the latter having a more complex flow structure than for the uniform field case, but a much more symmetric implosion. These results were published and presented at the International Symposium on Shock Waves, for which Woueter Mostert won the prize for best student presentation. Together with RA Gehre, PI Samtaney also conducted simulations of the planar RMI at arbitrary field angles for comparison to Wheatley's new analytical model developed as part of his DECRA project. It was found that the analytical model reasonably predicted the flow behaviour for any field angle.

We completed our simulations of 3D implosions over a wide range of field strengths, allowing us to plot the effect of field strength on implosion symmetry. From this we have determined that the saddle geometry field is most promising for suppressing the RMI while maintaining implosion symmetry. PI Samtaney and CI Wheatley have examined the converging shock driven RMI for a radial magnetic field over a broad range of parameters using a 1D linearized solver, verified by multi-dimensional simulations. Both the RMI and subsequent Rayleigh-Taylor instability are found to be suppressed for all wave-numbers for sufficiently strong fields. These results were presented at the 2013 and 2014 APS Division of Fluid Dynamics Meetings. Mostert has also completed simulations of the cylindrical converging RMI for uniform and saddle fields. We find that interestingly, the saddle topology seed field is more effective in suppressing the RMI while also maintaining greater implosion symmetry. Simulations of the spherical version of the instability have also been completed and analysed, with similar conclusions. A paper documenting the investigation is in preparation.

FLOW PHYSICS OF POROUS WALL FUEL INJECTION FOR SCRAMJET COMBUSTION AND DRAG REDUCTION (DP120101009)

Total: $320,000 (2012-2014)
First Named Chief Investigator: Professor Russell Boyce

Project Summary

This project combines world-class Australian scramjet science with German advanced high temperature materials, exploring potentially transformational technology for satellite launch. Australia's credentials in the international space arena will strengthen, contributing to assured access to the space-based applications upon which we heavily depend.

Progress

Overall progress of the project has been good with many steps achieved. There have been some delays to the project 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) and some unexpected issues in obtaining a good quality porous flow in the T4 shock tunnel tests. Arequest has been made to extend the project into 2015. PhD scholar, Mr Kevin Basore, has completed his mid-term review and scheduled to complete his PhD at the end of 2014.

<u>Computational Modelling</u>

Computational modeling of the performance enhancements of porous injection over porthole injection in a 2D radical farming scramjet was completed in year two. Two journal papers (see below) from this work were published in 2014. Three-dimensional CFD modelling of the experimental configuration for the fundamental T4 experiments has been completed. This was used to identify the quality of the flow on the test surface of the experiments. Modeling of the injection through the porous injector for those experiments is about to start.

<u>Experimental Campaign</u>

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. A new wind tunnel model (a heavily instrumented flat plate with porous injection and interchangeable leading edges was designed and manufactured in 2014. The system of mounting the model from the floor of the test section worked well. 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 may have been some discreet jets within the porous injection. It was decided not to push further with the testing program until that issue was resolved. Therefore, it was proposed that the final series of experiments in T4 be performed in mid-2015. The PLIF testing was delayed until the 2015 campaign.

ABLATIVE THERMAL PROTECTION SYSTEMS (DP120102663)

Total: $540,000 (2012-2014)
First Named Chief Investigator: Professor Richard Morgan

Project Summary

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

Progress

2014 has been a very productive year for the grant, with three students graduating with their PhD's, and two new PhD's starting. Eight UQ PhD students are currently working under the grant, at various stages of completion. Collaboration between the partner institutions was strong, with 10 student exchanges and 4 CI visits taking place between the partners in 2014. A UQ PhD student is undertaking a Cotutelle de Thèse (Joint Supervision of Theses) exchange at ECP, on gas giant radiation, extending the capability of the ECP Plasma Torch to include gas giant atmospheres. Three of our recent postdocs 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 international ties. Researchers from AFIT made a second visit to UQ in 2014 for experiments on X2 and a joint paper won a best paper award at the 39th AIAA Aerospace Sciences Symposium. In 2013 we got funding from the Go8-DAAD scheme to support further personnel exchange related to the project, with special emphasis on students and early career researchers, and this has helped with the good progress made in 2014, continuing into 2015. During a UQ SSP trip to Paris in 2013, the group was also involved in experiments on the ESA funded 'Rastas-Spears' re-entry project using the ECP plasma torch facility, and the ESA Ablation-radiation coupling project led by EPFL, Lausanne. IRS and UQ worked closely together on this project to set up the required VUV instrumentation, which called heavily on the lessons learned under this grant. IRS and ECP also developed new instrumentation for heat transfer measurements in the ECP plasma torch. A full experimental program was undertaken in 2014, with 15 test campaigns performed on the UQ X2 expansion tube, and the TUSQ facility at USQ. The plasma torch at ECP and the arc driven facilities at IRS have also been very active. In addition, a series of related experiments were performed at the Von Karmen Institute (VKI Brussels) by a UQ exchange student on a short placement. This visit was not funded by the grant, but it was a useful follow-on opportunity enabling the comparison of data from different facilities. As a result of this interaction, the student is returning to spend a year of his PhD at VKI.

The heated graphite technique pioneered by this group to simulate ablating surfaces in flight was extended to temperatures above 3000K, where sublimation of the surface into gaseous forms of carbon occurs. This is of great importance to the design of heat shields at very high speeds, and the preliminary results indicate that we have a useful testing procedure for examining this mechanism of ablation. New flow conditions for Earth, Mars, Venus, Titan and the gas giants were developed, and progress in instrumentation included pyrometry and the use of filters on our ICCD cameras to give 2D images of selected spectral features. Good progress was made on the computational and analysis side in quantifying our flow conditions more accurately, and in comparing the experimental spectra with numerical analysis.

In February 2015 the era of the 1st generation European Automated Transfer Vehicle supply vehicle to the international Space Station ended with the return of last of the series, ‘Georges Lemaître’, on a self destructing trajectory. This was a rare opportunity to make scientific measurements of a disintegrating space craft under controlled conditions, and we were invited to participate in the multi-national observation mission. Payloads were prepared in our laboratories for the NASA DC 8 flying observatory, but due to a failure on the capsule itself, the mission had to be re-scheduled and the reentry was made before the observations could take place. However, the inclusion of so many members of our team on the mission, and the global coordination provided by Stefan Loehle reflects well on the work performed under this grant, and on the relevance of the study to current aerospace requirements.

Related work will continue, with a 2015 ARC Discovery grant awarded on rapidly expanding radiative flows, and with the group now including NASA’s AMES and Langley Research Centers. The outcomes of the project continue to be widely published, with 14 Journal papers accepted, 4 submitted and 27 international conference and workshop presentations delivered or accepted for presentation in 2014.

HYPERVELOCITY REENTRY (DP1094560)

Total: $249,000 (2010-2012)
First Named Chief Investigator: Professor Richard Morgan

Project Summary

During planetary entry from space, severe heating loads are created on the exposed surfaces of flight vehicles from the layer of plasma trapped behind the bow shock, many times hotter than the Sun. Design of the thermal protection systems is a major engineering challenge, and a limiting technology for space travel. Our aim is to do an experimental and analytical study of the associated radiating gases to gain the theoretical and practical knowledge needed to design a new generation of advanced spacecraft. Experimental data will be obtained from the unique Australian hypersonic ground facilities, and selected flight records, and the theoretical analysis will be performed in collaboration with NASA scientists.

Progress *(work on this grant finished in 2014 and extracts from our final report to ARC follows)*

The grant started well in 2010 as we were invited to participate in the airborne observation of the re-entry of the ‘Hayabusa’ asteroid sample return capsule, and also had 2 teams of students doing simultaneous ground based spectrometric measurements of the shock layer during re-entry and mothercraft break up. The shock tube instrumentation was adapted for use in flight in the form of a hand tracked UV spectrometer, and two ground based spectrometers were set up and operated by our students. One of the student packages used an automated tracking system, built as part of a parallel MPhil project in controls. The UQ participants in the air borne observation team on the NASA DC8 flying laboratory were also co-recipients of the 2010 NASA Ames ‘honour award’ with the rest of the flight team, and the 2011 NASA Group Achievement Award.

The follow on workshop for the Hayabusa re-entry was held at UQ in March 2011, giving good exposure of the results of our ARC research to the world leaders in this field. Eight PhD students have worked on the grant, and 3 of them have graduated during it. Many final year undergraduate projects have also worked on the project. We have had good interaction with our partner investigators, and CI1 Morgan spent a six month SSP on the project in 2010, working with collaborators in Ecole

Centrale Paris, NASA Langley and NASA Ames Research Centers, and installing the UQ flight package with Buttsworth on the DC8 at Dryden AFB. During this SSP, 14 invited talks were given to various Institutions on the research which is being well received by our peers. The work during the visit to NASA Langley focused on methods for getting more accurate measurements in equilibrium flows, and the results of this were presented by Dr Gnoffo (PI) at the 2011 Aerospace Sciences Conference. Dr McGilvray (PI on the grant from Oxford University) visited the UQ to work with the other investigators and students. The group received the inaugural UQ award for 'Internationalisation' in 2010, and the UQ 2012 award for HDR supervision. Two of the PhD students enrolled for their degrees under co-tutelle scheme with Ecole Centrale, and also received Eiffel scholarships to support their study.

From an educational point of view, it was a great success. Experiments were performed in the X2 facility examining radiation in flows relevant to Mars, Earth, Jupiter and Titan entry. Diagnostic measurements have focused on measuring the intensity of UV and visible radiation emitted by the flow. New measurements have been performed at higher simulated altitudes. We conducted preliminary tests on measuring the radiation incident on the surface of the test model using a periscope arrangement to transport the light through a window on the surface to an external camera, which is now forming the basis for an ESA grant we are working on. We have further developed a total radiation gauge capable of measuring the radiative heat transfer to the surface of the vehicle. In 2012 radiation measurements were extended into the vacuum ultraviolet. A spectrometer/camera system capable of operating at wavelengths down to 130 nm was obtained under extra UQ funding in support of the grant. A vacuum system for coupling the system to the expansion tube has been developed, and will also be used on the ESA program. A recent breakthrough made under the grant that positively influences the project is the development of an electrical preheating technique by our students to transiently raise the surface temperature of graphite containing samples to the order of 3000K. This matches flight values, and removes wall temperature as one of the parameters which we have previously been unable to match. Preliminary experiments using this technique have confirmed an enhanced rate of surface chemistry, characteristic of the high temperatures found in flight, and this system will be transported to Europe in May for further testing on facilities operated by our international partners. The work has been well published and presented at international meetings, including four keynote and plenary talks. It has created worldwide interest in the work, and the impact has exceeded our original expectations.

RADIATION AND ABLATION IN RAPIDLY EXPANDING FLOWS (DP150100631)

Total: $503,400 (2015 – 2017)
First Named Chief Investigator: Professor Richard Morgan

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 data base 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

In November 2014 we received a new ARC Discovery Grant for $503,400 involving collaborators from NASA, Ecole Centrale, USQ and QUT. This project is still in the very preliminary stages. Two PhD students are working on the project, one looking at recombination processes in air, and the other 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. Their more detailed experimental programs will start shortly, and they will be extending the range and spectral resolution of the early experiments. We expect to recruit a 3rd student to the project in the next UQ round of applications in May. We also have a French graduate who is very keen to enrol for a ‘co-tutelle’ PhD shared between UQ and Ecole Centrale Paris (ECP), who are partners on the grant.

Partner Investigator Christophe Laux from ECP has recently received funding from AIRBUS DS - Space Systems (International Partnerships Division) to perform parallel experiments in Paris on their plasma torch facility, and to support another PhD student to work on the grant.

SHOCK TUNNEL DEVELOPMENT (OXFORD UNIVERSITY)

Total: $454,710
Chief Investigator: Professor Richard Morgan

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 facility iunder development is required to withstand extreme pressures and temperatures (750 bar and 5000 degrees C), and create a recoil force peaking at nearly 1000 tonnes for several milliseconds. When complete, the facility will be capable of producing flows to test Earth re-entry vehicles from the Moon and beyond. This will allow Oxford and UK researchers to play an important role in exploration of the solar system by providing vital measurements about the heat transfer and ablation processes on spacecraft heat-shields, which protect the vehicle during re-entry.

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 signed off by the Head of School at UQ. Examples of the number of staff development opportunities are set out below. These examples are opportunities for teaching staff; however, through the Institute for Teaching and Learning Innovation (ITaLI), UQ offers a comprehensive staff development program for all staff.

Graduate Certificate in Higher Education

New academic staff are encouraged to complete the University's Graduate Certificate in Higher Education (GCHEd). This program is designed for university teachers and PhD students who seek to improve their educational practice. It introduces major conceptual issues, research directions, and innovative practices associated with higher education. It challenges and extends notions of learning, curriculum, pedagogy, assessment of student performance, and evaluation of teaching and courses within the higher education context. The University pays the tuition fees for eligible staff. One member completed this program in 2013, and another is enrolled in 2014.

Institute for Teaching and Learning Innovation (ITaLI)

ITaLI provides leadership, engagement and advocacy in educational innovation, teaching excellence and learning analytics and aims to transform and innovate teaching, learning and creativity at UQ. ITaLI is designed to respond to projects prioritised by a governance structure that connects School and Faculty teaching and learning needs with institutional strategic priorities.

Supervisory Skills Development

Research staff are encouraged to be active in research supervision (e.g. final year undergraduate thesis, masters thesis). They are required to complete a program of professional development run by the Graduate School in order to supervise PhD and MPhil students. However, as most research staff are on fixed term contracts that are shorter than the duration of a PhD candidature, the University does not permit them to serve as principle supervisors. Consequently, academic staff carry the principal supervisory load and a large proportion of the associate supervisory load.

Teaching Development

ResTeach is a UQ scheme funded centrally to pay up to 20% of the salary of research staff to allow them to engage in teaching programs in the schools. A 20% ResTeach appointment would be awarded to a staff member to coordinate and deliver one 2 unit course to a moderately sized class. A lower fraction would be for a correspondingly lower teaching involvement. The School of Mechanical and Mining Engineering has also established its own "Teaching Support Program (TSP)". This provides School funds to support additional teaching involvement from research staff in the School.

These programs have been very beneficial to the Centre in facilitating participation in teaching by research staff.

Research Higher Degree Student 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 Skills Training program run by the Graduate School.

Students are also encouraged to participate in the Engineering Postgraduate Conference. This conference provides an opportunity for engineering postgraduate 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 engineering schools. Each year, the Centre for Hypersonics sponsors The Professor Raymond Stalker Prize for best presentation related to Mechanical and Aerospace engineering.

The Centre also trains research higher degree students (PhD and MPhil) to act as operators for the X3 Expansion Tube and the T4 Free-piston driven shock tunnel.

Conferences 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 Ecole 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, Ecole 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, Ecole 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 reentry 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.
Sanchito Banerjee	Professor Russell Boyce	PhD	Nonlinear adaptive flight control for hypersonic vehicles.
Kevin Basore	Dr Vincent Wheatley	PhD	Flow physics of scramjet fuel injection through porous walls.
Daryl Bond	Dr Vincent Wheatley	PhD	Modelling and simulation of heat and mass transfer enhancement of micro-scales.
Mathew Bricalli	Professor Russell Boyce	PhD	Ignition processes in scramjet accelerators.
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.
Rolf Gehre	Dr Vincent Wheatley	PhD	Numerical investigation of the axisymmetric inlet-fuelled radical-farming scramjet with RANS and LES simulations of the injection, mixing and flow structure/ combustion coupling.
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.
Steven Lewis	Professor Richard Morgan	PhD	Melting Models of CO2, in re-entry flow conditions.

Name	Primary Supervisor	Program	Project Title
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.
Wouter Mostert	Dr Vincent Wheatley	PhD	The Converging Shock-Driven Richtmyer-Meshkov Instability in Magnetophydrodynamics.
Daniel Oberg	Professor Russell Boyce	PhD	Combustion scaling of an axisymmetric inlet-fuelled, radical farming scramjet engine.
David Petty	Dr Vincent Wheatley	PhD	Flow physics of hypervelocity scramjet combustion with oxygen enrichment.
Hadas Porat	Dr Timothy McIntyre and Professor Richard Morgan	PhD	Hypervelocity re-entry.
Dawid Preller	Professor Michael Smart	PhD	Heat transfer measurements of a hypersonic wing body junction.
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.
Jorge Sancho Ponce	Dr Timothy McIntyre and Professor Richard Morgan	PhD	Simulation of hypersonic radiation flow field coupling in expansion tubes.
Tamara Sopek	Dr Timothy McIntyre	PhD	Fuel injection/mixing studies in hypersonic flows using advanced optical diagnostic techniques.
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.
Brad Wheatley	Dr Timothy McIntyre	PhD	Physics boundary layer transition.
Dylan Wise	Professor Michael Smart	PhD	Experimental investigation of a 3D scramjet engine at hypervelocity conditions.

APPENDIX 3:

PUBLICATIONS

Conference Papers

Alba, C., Greendyke, R., Lewis, S., De Crombrugghe de Looringhe, G., Eichmann, T., and Morgan, R., Investigation of Surface Radiation in Earth Re-entry Flows with Graphite Ablation, 39th AIAA Dayton- Cincinnati Aerospace Science Symposium, Dayton, OH. March 2014.

Alba, C., Greendyke, R., Lewis, S., De Crombrugghe de Looringhe, G., Eichmann, T., and Morgan, R., Investigation of Surface Radiation in Earth Re-entry Flows with Graphite Ablation, 6th Ablation Workshop, 24th-28th November 2014, St Andrews, UK

Bailet, G., Bourgoing, A., Magin, T., and Laux, C.O., “Radiative and Ablative Studies for In-Flight Validation”, 5th PhD Symposium, VKI, Rhodes-Saint-Genèse, 12th March 2014, Belgium.

Bailet, G., Bourgoing, A., Magin, T., and Laux, C.O., “Reentry Platform for Radiation Studies”, 11th International Planetary Probe Workshop, 14-20 June 2014, Pasadena, Califormia, USA.

Banerjee, S., Creagh, M. & Boyce, R. (2014). An alternative attitude control strategy for SCRAMSPACE 1 experiment. In AIAA Guidance, Navigation, and Control Conference. AIAA Guidance, Navigation, and Control Conference 2014 - SciTech Forum and Exposition 2014, National Harbor, MD, United States, (1-17). 13-17 January 2014.

Banerjee, S., Creagh, M., Boyce, R., Wang, Z., Baur, B. & Holzapfel, F. (2014). L1 adaptive control augmentation configuration for a hypersonic glider in the presence of uncertainties. In AIAA Guidance, Navigation, and Control Conference. AIAA Guidance, Navigation, and Control Conference 2014 - SciTech Forum and Exposition 2014, National Harbor, MD, United States, (1-19). 13-17 January 2014.

Barth, J., Wheatley, V. & Smart, M. (2014). Inlet fuel injection in a mach 12 shape-transitioning scramjet. In 52nd AIAA Aerospace Sciences Meeting - AIAA Science and Technology Forum and Exposition, SciTech 2014. 52nd AIAA Aerospace Sciences Meeting, National Harbor, MD, United States, (1-26). 13-17 January 2014.

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Casses, C.J., Bertrand, P.J., Jacobs, C.M., MacDonald, M.E., and Laux, C.O., "Experimental characterization of ultraviolet radiation of air in a high enthalpy plasma torch facility," EUCASS, Vol. 7-603, Feb. 2015.

Chan, W., Razzaqi, S.Smart, M. & Wise, D. (2014). Freejet testing of the 75%-scale HIFiRE 7 REST scramjet engine. In 19th AIAA International Space Planes and Hypersonic Systems and Technologies Conference. 19th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, Atlanta, GA, United States. 16-20 June 2014.

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Alba, C. R., Greendyke, R. B., Lewis, S. W., Morgan, R. G., and McIntyre, T. J., “Numerical Modeling of Earth Re-entry Flow with Surface Ablation”. Journal of Spacecraft and Rockets.

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MacDonald, M.E., Jacobs, C.M., Laux, C.O., Zander, F., Morgan, R.G., “Measurements of Air Plasma/Ablator Interactions in an Inductively Coupled Plasma Torch,” Journal of Thermophysics and Heat Transfer, preprint 2014. doi: 10.2514/1.T4402.

MacDonald, M.E., Jacobs, C.M., Laux, C.O., “Interactions of Air Plasmas with Ablating Heat Shield Material,” IEEE Transactions on Plasma Science, Vol. 42, No. 10, pp. 2658-2659, Oct. 2014, DOI: 10.1109/TPS.2014.2307911.

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Book Chapter

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