Queensland Hypersonic Testing Facility

2012 Annual Report

1 January 2012 to 31 December 2012
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Images on cover:
September 13th, HIFiRE 3 launch
Scramjet testing in T4 shock tunnel. (Brieschenk and Loraine 2012)
SCRAMSPACE payload begins construction
Acronyms

AIAA American Institute of Aeronautics and Astronautics
AOARD Asian Office of Aerospace Research and Development
ARC Australian Research Council
DAAD German academic exchange service
DARPA Defence Advanced Research Projects Agency
DLR German Aerospace centre
DSTO Defence Science and Technology Organisation
EC Ecole Centrale (Paris)
ESA European Space Agency
Hayabusa Japanese asteroid sample return mission
HIFiRE Hypersonic International Flight Research Experimentation
HyShot UQ led hypersonic scramjet flight program
QHTF Queensland Hypersonic Testing Facility
RHD Research by higher degree students
SCRAMSPACE Scramjet-based Access-to-Space Systems. The Australian Government has invested $5m in SCRAMSPACE through the Australian Space Research Program (ASRP). Led by UQ
T4 Reflected shock tunnel at UQ
TUSQ Hypersonic facility based at USQ
X2 Superorbital expansion tube at UQ
1. **Executive Summary**

2012 was a highly successful year for the Centre, with a wide range of laboratory and flight testing activities all making good progress.

A highlight of the year was the 28th ICAS Congress in Brisbane, where the *ICAS von Kármán Award for International Cooperation in Aeronautics* and was presented to Adjunct Professor Allan Paull and Professor Michael Smart of the Centre for Hypersonics, Dr Kevin Bowcutt from Boeing, and Mr Douglas Dolvin from the US Air Force Research Laboratory (AFRL). This award was for the HiFire scramjet flight program, which is a long running collaboration in hypersonics between the Centre and a large number of leading Australian and overseas researchers. The Congress was preceded by the HiFIRE 3 flight on 13th September by DSTO/UQ in Andoya, and the HiFIRE 2 flight on 15th May in Hawaii by our American collaborators.

The preparation for the SCRAMSPACE and HiFIRE 4 flights in 2013 went very well, and the payloads are in an advanced stage of preparation for the launches. A full program of laboratory testing was performed in the laboratories on both scramjet and re-entry related projects. Staff members and students attended a wide range of international conferences during the year and published in the archival literature, as per the attached list. Three new ARC funded projects started in 2012, and a new Discovery grant was awarded for 2013. Two new DECRA fellowships were also awarded to members of the Centre and the first test firings of solid fuel rockets were made in the static test facility at Pinjarra Hills.
2. **Summary of grant activity**

2.1 **New ARC grants and fellowships**

*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 Tirty

**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.

2.2 **Progress reports on existing grants and fellowships**

*The general Richtmyer-Meshkov instability in magnetohydrodynamics* (DE120102942)

**Total** $375,000 (2012-2014)

First named Chief Investigator: Dr Vincent Wheatley

**Project Summary**

Fluid dynamic instabilities limit the chance of inertial confinement fusion, a carbon-free process, achieving net energy production. In highly idealised circumstances it has been shown that one of these instabilities can be suppressed by a magnetic field, a phenomenon that this project will investigate in the general case.

**Progress**

Overall, the project is proceeding on schedule. High quality research assistants have been recruited and excellent progress has been made:

A new linear model has been developed for the Magnetohydrodynamic (MHD) Richtmyer-Meshkov instability (RMI) in the presence of a transverse magnetic field. Nonlinear simulations were carried out for comparison to model predictions. The oscillatory motion of the interface was well predicted by the model and the physical mechanism responsible for the suppression of the instability was found to be completely different from that proposed in previous studies of the transverse field
case. Initial findings were presented at the 18th Australasian Fluid Mechanics Conference and a more detailed journal paper on the topic is in preparation.

A model has also been developed for the oblique field MHD RMI, where the field can be at any angle to the interface. This will allow the suppression of the instability to be estimated for any location within an inertial confinement fusion experiment. Initial nonlinear simulations, for comparison, have also been carried out for a series of magnetic field angles. These initial results have been accepted for presentation at the 29th International Shock Waves Symposium.

Progress has also been made on implementing an MHD simulation capability in a computational framework that already has the capability of simulating non-equilibrium thermo-chemistry and radiation transport. So far, an ideal MHD simulation capability has been implemented. Dr Daniel Potter of the DLR, Germany, was invited to conduct a highly successful training course on the theoretical basis and use of the radiation transport aspect of the framework.

Design optimisation and physical behaviour of fuel injection and mixing for innovative scramjet concepts (DE120102277)

Total $375,000 (2012-2014)

First named Chief Investigator: Dr Hideaki Ogawa

Project Summary

Scramjets are a potential game changer for satellite launch and high speed flight. The phenomena that will make or break them are complex, and achieving optimal designs is hugely challenging. This project combines advanced optimisation techniques and flow simulations to find, and understand, optimal fuel injection for innovative scramjet designs.

Progress

This project is undertaken to investigate the flow physics and explore the optimum design for fuel injection and mixing by various methods including transverse injection, hypermixers (streamwise vortices) and porous injection, aiming at the application to scramjet intakes. Multi-objective design optimisation based on surrogate-assisted evolutionary algorithms has been performed for transverse injection through various portholes, resulting in physical insight into underlying fluid mechanism and useful knowledge into key design factors. Overall three journal articles (including the AIAA Journal and Journal of Propulsion and Power) and five conference papers (AIAA Aerospace Sciences and Meeting, AIAA Space Planes and Hypersonics Conference, and ICAS Congress) were published by Dr Ogawa in 2012. These articles and papers were a result of this ARC DEcRA project as well as the design optimisation and inlet starting studies for scramjet engines as a continuation from the preceding research on the UQ Postdoctoral Research Fellowship.
**The converging shock driven Richtmyer-Meshkov instability in magnetohydrodynamics**  
(DP120102378)  
Total $120,000 (2012-2014)  
First named Chief Investigator: Dr Vince Wheatley

**Project Summary**  
Fluid dynamic instabilities limit the chance of inertial confinement fusion, a carbon-free process, achieving net energy production. The project will investigate the effectiveness and consequences of suppressing one of these instabilities with a magnetic field.

**Progress**  
Overall, the project is proceeding on schedule. An exceptional PhD candidate has been recruited and excellent progress has been made:

During his funded visit to UQ, Associate Professor Ravi Samtaney from King Abdullah University of Science and Technology (KAUST) created a new version of his MHD solver tailored to the geometries considered in this project, trained the PhD candidate in the use of the solver, and, in collaboration with the candidate and Chief Investigator, made a number of improvements to the initialization, flux solver, boundary and output routines. He also carried out simulations of the planar, transverse field MHD RMI, the results of which were presented 18th Australasian Fluid Mechanics Conference.

Using the code developed during Samtaney’s visit, the flow physics of cylindrical and spherical converging MHD Riemann problems were investigated for three canonical field geometries. These will form the base flows for the simulation of converging shock driven MHD RMI simulations in subsequent phases of the project. These simulations showed a complex wave structure in most cases, with nonlinear wave interactions playing a key role. The results for the uniform field, cylindrical case were presented at the 18th Australasian Fluid Mechanics Conference. The results of all three cylindrical cases have been accepted for presentation at 29th International Shock Waves Symposium. A journal paper detailing the results for both cylindrical and spherical cases is in preparation.

Preliminary simulations of the cylindrically converging RMI in the presence of a uniform field have been carried out. These indicate significant suppression of the RMI by the magnetic field leading to lower growth of the subsequent Rayleigh-Taylor instability, which is very promising. Preliminary simulations of perturbed cylindrically converging MHD shocks have also been carried out. These indicate that the shocks do not suffer from any severe instabilities.
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
The project has had a very good first year, with excellent progress in experimental and analytical work. "Flow physics of porous wall fuel injection for scramjet combustion and drag reduction" - this project has come about as a direct result of the relationship between UQ and DLR that has expanded due to the SCRAMSPACE program. The first year of the project has seen excellent progress on both the experimental and numerical fronts. Dr Bianca Capra, a postdoctoral research fellow in the Centre for Hypersonics working on the SCRAMSPACE project, has come onto the ARC project on a part-time basis. Employing an existing generic two-dimensional scramjet being used in SCRAMSPACE ground testing, Dr Capra has successfully upgraded the test article with fuel injection modules that utilise advanced high temperature porous ceramic (carbon-carbon silicon carbide, or C-C SiC) walls designed and manufactured by DLR Stuttgart for the project. The scramjet has been tested in the T4 shock tunnel, and has generated porous injection scramjet combustion results that are currently being reconstructed using sophisticated computationally intensive numerical simulations of the flowfields. Alongside this, a new PhD student, Kevin Basore, is developing a new porous injection test model which can be used to directly study the injection flow physics using the CfH's advanced optical diagnostics capability that has stemmed from the activities of the Chief Investigators position as Chair for Hypersonics.

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 man's exploration of the universe. Data will be validated by comparison with flights such as the Japanese Hayabusa asteroid sample return mission.

Progress
Good progress has been made in the first year, with archival publication of the first results from hot wall ablation tests in shock tubes, and the development of a new
configuration using a Mach disc generator for studying radiating flows. The work has directly led to our involvement in a new ESA ablation and ablation study in 2013, and the ‘Rastas Spear’ ablation project, which is intended to validate new European re-entry protections systems. The first experiments in vacuum ultra violet (VUV) radiation ever done in an expansion tube have been completed. This radiation is critical to the operation of earth return heat shields, but is very hard to observe as it is strongly absorbed by atomic oxygen, and can only be measured through specially designed high vacuum light tubes. The success of these experiments have led to requests for the UQ designed and fabricated apparatus to be shipped to Europe in 2013 for use on the Plasma Wind Tunnels PWT(SCIROCCO) at CIRA, (the Italian Aerospace Research Centre), and at the Institute of Space Systems (IRS); University of Stuttgart, and on the plasma torch at Ecole Centrale, Paris.

**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**
This program is now nearly complete, and has been very successful.

Final report on the Discovery Grant DP1094560, Hypervelocity Reentry. 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 three 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 Chief Investigator 1 Professor Richard Morgan spent a six month Special Studies Program (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 UQ to work with the other investigators and students. The group received the inaugural UQ award for ‘Internationalisation’ in 2010, and the 2012 award for Excellence in RHD supervision. Two of the PhD students enrolled for their degrees under the 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 130nm 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.

Work on the grant has been extended to 1 April 2013, and a formal ARC online final report will be made at that time.
3. **HIFiRE Activities**

HIFiRE activities have been very intense this year, with the HiFIRE 3 flight, and preparation for the HiFIRE 7 flight well under way and scheduled for September 2013 from Andoya. The associated program of shock tunnel testing which runs in parallel with and supports the flight program has also produced very effective and widely published results. At the 28th ICAS Congress in Brisbane, the ICAS von Kármán Award for International Cooperation in Aeronautics was presented to Adjunct Professor Allan Paull and Professor Michael Smart of the Centre for Hypersonics, and their collaborators Dr Kevin Bowcutt from Boeing, and Mr Douglas Dolvin from the US Air Force Research Laboratory (AFRL). This award was for the HiFIRE scramjet flight program, which is a long running collaboration in hypersonics between the Centre and a large number of leading Australian and overseas researchers. The Congress was preceded by the HiFIRE 3 flight on 13th September by DSTO/UQ in Andoya, and the HiFIRE 2 flight on 15th May by in Hawaii flown our American collaborators.

The following is the abstract from the paper the team presented at the 28th ICAS before receiving their award:

**HIFIRE: AN INTERNATIONAL COLLABORATION TO ADVANCE THE SCIENCE AND TECHNOLOGY OF HYPERSONIC FLIGHT**

The Hypersonic International Flight Research and Experimentation (HIFiRE) program was created to perform hypersonic flight tests intended to quickly and affordably gather fundamental scientific data that are difficult or impossible to obtain via ground testing alone. The program is being executed jointly by the United States Air Force Research Laboratory (AFRL) and the Australian Defence Science and Technology Organisation (DSTO), with significant support from partners Boeing in the U.S. and the University of Queensland in Australia. Intellectual, financial, and physical resources from the four partners have been combined to achieve these essential objectives with the overarching goal of advancing the art and science of hypersonic flight.

This extract from the summary of the same paper indicates the important role this project will play in the future of aerospace research:

The potential rewards of routine and efficient hypersonic flight are many. But several challenges remain before the full value of hypersonic flight can be realized. In fact, addressing technical challenges is itself challenging because of the high flow energy and extreme thermal environment encountered in hypersonic flight, which are difficult to exactly replicate in ground test facilities. To address some of the challenges facing hypersonics, the HIFiRE program was created to increase the knowledge base for critical hypersonic phenomena and mature technologies enabling to hypersonic flight. The program plan consists of nine focused research projects that each culminate in a flight experiment. Each project addresses one or more technical challenges in propulsion, aerodynamics, propulsion-airframe integration, aerothermodynamics, flight control, high temperature materials and structures, thermal management, and/or instrumentation and sensors.
A primary objective of the HIFiRE program is conducting flight experiments faster and at lower cost than has traditionally been achieved. This is possible in part because of the overall philosophy and approach employed in program execution, such as using low-cost sounding rockets to boost experimental payloads to hypersonic test conditions and accepting greater technical risk in performing the flight experiments.

Nine flight experiments are a key element of the program plan, four of which have already been flown. The completed flights have verified critical flight systems and instruments, gathered unique boundary layer transition data that shows behavior different from what has been previously observed, and demonstrated in flight for the first time scramjet engine mode transition from dual-mode transonic combustion to pure supersonic combustion.

To achieve the above and all that remains in the HIFiRE program plan, the resources of a very diverse and capable international team were assembled from government, industry, and academic institutions in the United States, Australia, and Germany. In no small part the capabilities, dedication, and hard work of this expert team have lead to a high level of mission success and will likely lead to many more significant accomplishments and findings in the remainder of the HIFiRE program and beyond.

4. SCRAMSPACE Activities

DSTO funded a Chair for Hypersonics at UQ in 2007, and Professor Boyce is the appointee. This has been a highly successful ongoing collaboration, and in this role Professor Boyce has greatly expanded the impact of and increased the activities in the Centre for Hypersonics, including participants from around Australia and the world. These activities have continued to consolidating a research team and research capability throughout recent years. The focal point of his activity has been the SCRAMSPACE (Scramjet-based Access-to-Space Systems) project described below. In addition to SCRAMSPACE Professor Boyce, Chair for Hypersonics, has continued to develop research across a broad range of topics relevant to hypersonic flight, and currently leads a team of 25 postdoctoral research fellows, engineers and PhD students, most of whom appear in the recent photograph below. Publications in the past 12 months total 5 journal (with a further 3 under review and 5 nearing submission) and 19 international conference papers.
The ultimate aim of SCRAMSPACE has been to build human capacity and capability for Australia’s aerospace (especially space) sector and it has been highly successful in doing so. SCRAMSPACE has directly employed 14 post-doctoral fellows and engineers and supported the research of 13 PhD students, at four universities across the country – UQ, UNSW, USQ, UA. Including UQ-funded post-doctoral fellows, the total across all universities is 29 with the UQ total being 20. This is a considerable return on investment by the Australian Space Research Program.

The SCRAMSPACE hypersonic flight experiment team is now a fully capable, balanced team able to couple hypersonic flight science with aerospace, mechanical and electronic engineering to take hypersonic concepts and science from the laboratory to the sky.

Within the team, key leadership has been provided by Dr Sandy Tirtey (Technical Lead and Flight Experiment Project Manager) and Dr Melrose Brown (who has played a significant role in the scientific development of the flight). Both will be very important to UQ’s effort to analyse, reconstruct and gain full leverage from the results to come from the flight experiment.

All other flight team members have also done an outstanding job so far – Dr Michael Creagh, Dr Bianca Capra, Mr Paul Van Staden, Mr Igor Dimitrijevic, Mr Brad Sharp, Ms Amy Dedman, with occasional assistance from Flight Lieutenant Adrian Pudsey.

Value-adding by the team to Australia’s hypersonic flight test capability includes approaches to applying high fidelity numerical modeling (aeropropulsive balance, stability, thermal-structural loads), certain electronics, high temperature carbon-phenolic thrust nozzle, pneumatic control of inlet starting doors, reaction control system and associated algorithms, on-board camera viewing temperature-sensitive paints on the back side of the combustor.

The SCRAMSPACE flight experiment passed its Critical Design Review in May 2012, and is currently near the end of the manufacturing stage and part-way through the assembly, instrumentation and testing phase. The team is working hard toward having the payload ready for flight in June 2013, with the launch campaign set for September 2013.

Beyond the flight experiment, SCRAMSPACE has included research on the fundamental behaviour of supersonic combustion, fuel injection and mixing, oxygen enrichment of the fuel, porous wall drag reduction, and inlet starting. To do this, it has employed
experimental, analytical and numerical approaches, including massively parallel supercomputing involving RANS and Detached Eddy Simulation CFD.

SCRAMSPACE has also involved advances in multi-disciplinary design optimisation approaches, flight dynamics and stability, and adaptive control.

The recent AIAA International Spaceplanes and Hypersonic Systems and Technologies Conference in France, September 2012, was an extremely successful demonstration of Australian leadership in the field. One sixth of the 161 papers were from Australia, with one eighth related directly to SCRAMSPACE.

SCRAMSPACE also made the front cover of the world’s leading magazine for the aerospace sector, Aviation Week and Space Technology, November 26 2012.

Optical diagnostics: following the renegotiation of and increased funding for the UQ/DSTO Chair Agreement, a $1M (over 5 years) grant of internal UQ funds was awarded for equipping the Centre for Hypersonics and in particular the T4 shock tunnel laboratory, with advanced optical diagnostic capabilities. This has enabled Professor Boyce to employ Dr Stefan Brieschenk, a hypersonics optical diagnostics expert, to purchase the necessary equipment and establish the capability, and in turn has led to additional PhD projects. The optics capability, although not fully established, has now reached an exciting level of quality that is enabling scramjet combustion flowfields to be directly probed with very high resolution for the nature of the flow structures and the presence of particular combustion species.
In summary, SCRAMSPACE has been running for almost 3 years, and has been extremely successful from both the research outcome and the human capability point of view. In particular, UQ now has a hypersonic flight experiment team well able to take our fundamental science from the laboratory to the sky.

5. **Equipment**

All of the equipment funded under the award has been purchased, installed and commissioned in accordance with the research objectives of the QHTF.

All equipment purchased under the scheme, apart from the supercomputer cluster that was commissioned in 2004 and decommissioned in 2010, was heavily used in 2012.

**Teakle Composites**

Teakle Composites specialises in product development using fibre composite materials, and was a direct result of the support from the SSRFF scheme for the fabrication of advanced composite rockets. It is helping to meet the KPI’s of the SSRFF scheme through employing high technology workers in Queensland, and in helping to introduce advanced techniques to industry, as for example, light weight fibre wound drilling rods.

The UQ static rocket static test facility was completed in 2011, and the live first tests were performed in 2012. They suffered some damage due to a casing failure on the second test campaign, which will be repaired. The rocket motor will be able to be adapted to use as a high performance scientific rocket for low-cost hypersonic and space science experiments.
### 6. Participants

#### 6.1. 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):

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
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<tbody>
<tr>
<td>Professor Richard Morgan</td>
<td>Professor of Hypersonics, Director Centre for Hypersonics</td>
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<tr>
<td>Emeritus Professor Ray Stalker</td>
<td>Research Consultant</td>
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<tr>
<td>Dr. Hans Alesi</td>
<td>Research Fellow</td>
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<td>DSTO, HyShot</td>
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<tr>
<td>Professor Russell Boyce</td>
<td>Research Consultant</td>
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<tr>
<td>Dr. Stefan Brieschenk</td>
<td>Research Fellow</td>
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<tr>
<td>Dr. Melrose Brown</td>
<td>Research Fellow</td>
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<tr>
<td>Professor David Buttsworth</td>
<td>USQ Research Consultant</td>
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<tr>
<td>Dr. Bianca Capra</td>
<td>Research Fellow</td>
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<tr>
<td>Dr. Michael Creagh</td>
<td>Research Fellow</td>
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<tr>
<td>Mr Igor Dimitrijevic</td>
<td>Electronics Engineer</td>
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<tr>
<td>Mr Myles Frost</td>
<td>Research Assistant</td>
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<td></td>
<td>DSTO, HyShot</td>
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<tr>
<td>Dr. David Gildfind</td>
<td>Research Fellow</td>
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<td>Dr. Peter Jacobs</td>
<td>Reader</td>
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<td>Dr. Ingo Jahn</td>
<td>Lecturer</td>
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<tr>
<td>Dr. Michael Macrossan</td>
<td>Research Consultant</td>
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<tr>
<td>Dr. Tim McIntyre</td>
<td>Senior Lecturer, School of Mathematics and Physics</td>
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<tr>
<td>Professor David Mee</td>
<td>Head of School</td>
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<tr>
<td>Dr. Judith Odam</td>
<td>Research Fellow</td>
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<td>DSTO, HyShot</td>
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<tr>
<td>Dr. Hideaki Ogawa</td>
<td>Research Fellow</td>
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<tr>
<td>Professor Allan Paull</td>
<td>Program Leader, DSTO, HyShot, Adjunct Professor.</td>
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<tr>
<td>Dr. Ross Paull</td>
<td>Research Fellow</td>
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<td>DSTO, HyShot</td>
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<tr>
<td>Dr. Neil Mudford</td>
<td>Adjunct Researcher</td>
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<tr>
<td>Dr Sarah Razzaqi</td>
<td>Research Fellow</td>
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<tr>
<td>Professor Halina Rubinsztein-Dunlop</td>
<td>Head of School, School of Mathematics and Physics</td>
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<tr>
<td>Dr. Todd Silvester</td>
<td>Research Fellow</td>
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<td>DSTO, HyShot</td>
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<tr>
<td>Professor Michael Smart</td>
<td>Professor of Air-Breathing Propulsion</td>
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<tr>
<td>Dr. Phillip Teakle</td>
<td>Research Consultant, Teakle Composites, Adjunct Associate Professor</td>
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<tr>
<td>Dr. Sandy Tirtey</td>
<td>Research Fellow</td>
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<tr>
<td>Dr. Vince Wheatley</td>
<td>Lecturer</td>
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6.2 Research Higher Degree Students
The group had eight research higher degree students commence in 2012, creating a cohort of 40. There were five PhD and one MPhil graduations in 2012, bringing the number of Research Higher Degree (RHD) graduations from the Centre for Hypersonics at UQ to a total of 37 for the period 2005 to 2012 (32 PhDs and five MPPhils).

In 2012 a major milestone was achieved when the Centre for Hypersonics graduated it’s 100th research higher degree student.

Professor Richard Morgan (Mechanical Engineering / Director of the Centre for Hypersonics) was awarded a UQ Award for Excellence in Research Higher Degree Supervision in 2012. The UQ Awards for Excellence in Research Higher Degree Supervision honours the advisers who lead and inspire UQ research higher degree candidates. Professor Morgan was commended for encouraging student development through international student exchanges with overseas collaborators, whilst engendering internal cooperation within the study body.

An example of this is Professors Morgan’s collaboration with Ecole Centrale (Paris). Dr Aaron Brandis spent a year of his PhD at Ecole Centrale (Paris), world leaders in the modelling of radiating flows. His resulting paper, combining experimental data from UQ and a theoretical model developed during the collaboration won the best paper award at the 2008 AIAA Thermophysics Conference. Aaron is now at NASA and the University of California, working on modelling of re-entry capsules. The success of this collaboration led to two further students (Umar Sheik and Carolyn Jacobs) undertaking a year of their PhD studies with Ecole Centrale (EC) in Paris. Both were awarded the prestigious ‘Eiffel’ scholarship, with Umar Sheik being the only Australian to receive this scholarship in 2012 and in fact, the only one Ecole Centrale (Paris) received in 2012. The recipient in 2009, Dr Carolyn Jacobs, has now received a postdoctoral fellowship with Ecole Centrale and will continue with the institution in this capacity. Her shared thesis with UQ and EC received the highest award ‘tres honourable’ available at EC, indicating that the quality of the work is truly of highest international standard.

In addition, research students participated in several national and international conferences, and presented the results of their research in person. See Appendix 1 for a list of current research higher degree students, and Appendix 1 for a list of publications from 2012.

6.3 Visitors
A large number of visitors were received in connection with the HIfiRE and ARC research programs. Visitors included:

- Dr Hao Zhu from the China Aerospace Aerodynamics Academe.  
  Dr Zhu was a visiting academic, working on expansion tube performance analysis.

- Mr Robin Schellhase from the University of the Federal Armed Forces in Munich.  
  Mr Schellhase was an occupational trainee, working on the scramjet project titled “Numerical investigations of flow processes in expansion tunnels”, applying the
computational fluid dynamics code CFD++ to time-accurate simulations of the flow processes in the acceleration tube and expansion nozzle of the X2 and X3 expansion tunnels that are being adapted for scramjet test purposes at UQ.

- Professor Sannu Molder from the School of Aerospace Engineering Ryerson Polytechnic University Toronto, Ontario, Canada. Professor Molder visited for 3 months working on a wide range of activities.

- Emilie Bette from University of Technology of Belfort-Montbeliard Ms Bette was an occupational trainee, working on project titled “Development of a forward facing imaging module for Hypersonics activities”, looking at the simulation aspect (heat and structural load, aerodynamic aspect etc).

6.4 Technical staff

- Brian Loughrey (X3 expansion tunnel facility)
- Keith Hitchcock (T4 shock tunnel facility)
- Frans De Bur (X3 expansion tube upgraded driver installation)
- Barry Allsop (electronics)

7. Publications

The group continued to publish in the archival literature and at international conferences. See Appendix 2.

8. Awards

The von Karman Award for International Cooperation in Aeronautics acknowledges programs that achieve substantial advancements and exceptional international collaboration in the field of aeronautics. It is awarded by the International Council of Aeronautical Sciences (ICAS), and in 2012 it was awarded to members of the Hypersonics International Flight Research Experimentation (HIFiRE) program.

The named recipients included two Centre for Hypersonics staff members (Paull and Smart), and two collaborators from the United States of America (Dolvin and Bowcutt).

ICAS – von Karman Award for International Cooperation in Aeronautics 2012

D. Dolvin  A. Paull  M. Smart  K. Bowcutt
The citation read, “In recognition of creating an international collaboration of Australian and US joint experiments to significantly advance knowledge and technology in the hypersonic flight regime”.

9. **Key Performance Indicators**

The Queensland Hypersonic Testing Facility (QHTF) has been able to achieve early success in a number of important areas and these are detailed below.

**KPI 1:**
*Regular review of operating procedures and promotional opportunities for QHTF’s fee for service activities*

Due to a very busy year in research activities, we have not been able to pursue commercial opportunities in the short term, and there are no commercial proceeds to report.

**KPI 1 (iv) - Sale of Rockets commencing 5 years after Commencement Date of 16 November 2006, income from rocket sales up to $500,000 per annum with 20% profit margin.**

Progress on the commercialisation of rockets has been delayed due to delays in commissioning of the static test facility. It is also apparent that a much longer period of testing and validation of the rockets than we initially anticipated is required before they can be marketed commercially.

We request that this item be removed from the KPI's till 2018.

**KPI 1 (v) - Testing Services commencing 5 years after Commencement Date of 16 November 2006, each year during first 10 years of operation, income from testing services up to $100,000 per annum with 20% profit margin.**

The unprecedented level of activity in the laboratories in recent years has precluded the use of the facilities for commercial testing, partly due to the great success of the infrastructure supported under this grant. They are in use full time, on major research programs in collaboration with leading aerospace partners from around the world, supporting the work of a large number of academics, post doctoral researcher and RHD students.

As the inherent value of this research to the State exceeds by far the fees for commercial testing which could be raised instead, we recommend that this item be removed permanently, so that the best support can be given to developing the research capability of the State.
KPI 1 (vi) - Consulting Services commencing 5 years after Commencement Date of 16 November 2006, engage QHTF to provide Consulting Services by 1 external entity, measured in five year intervals in arrears and averaged on a per annum basis

Like the facilities, the staff of the QHTF are involved full time pursuing leading edge research projects with a large number of collaborative partners. In addition, they are providing higher degree education of high value, and participating in the career development of a large group of post doctoral researchers and early career academic staff.

The engagement of staff in short term commercial research projects for personal gain would detract from that process, and we recommend that this item be removed permanently.

KPI 2: Employment of Professional Staff
Eight Teaching and Research (T&R) Staff, eight Research Only (RO) staff, one administrative support staff, and five technical staff were employed in the area of hypersonics at the Centre for Hypersonics. DTSO Brisbane employs 13 staff in hypersonics, and has between one and five resident visitors at all times. Teakle Composites employs four staff working in related technology.

KPI 3: Encourage involvement of Research Higher Degree students
Please refer to section 6.2.

KPI 4: Collaboration
As previously noted, the Centre for Hypersonics and QHTF have served as the focus point for numerous funding grants and collaborative research projects. New collaborative projects started in 2012 include:

- Prof Pullen from Caltech (USA) on converging shock driven Richtmyer-Meshkov instability in magnetohydrodynamics
- Dr. H Hald from the German Aerospace Center (DLR) and Dr. Markus Kuhn from the University of Stuttgart on Flow physics of porous wall fuel injection for scramjet combustion and drag reduction
- Prof Laux from Ecole Central Paris, Dr. Greendyke from the Air Force Institute of Technology USA and Dr. Lohle from the University of Stuttgart on ablative thermal protection systems
- Many colleagues from our collaborators have visited UQ during the period of this report.
KPI 5:
Research and Development Excellence
Staff were involved in many collaborative research ventures with leading groups, indicating a high level of esteem and many research papers were published and presented at international meetings as listed in Appendix 1.

Please refer to the list of new research grants for 2012 in Section 1.
Please refer to Appendix 2 for a complete listing of publications for 2012.

KPI 6:
Professional Development
Conference attendance has been strong, with many staff and students given the chance for professional development through presenting their work to international audiences and visiting other research organisations overseas. Refer to Appendix 2 for a list of conferences attended.

10. Accounts
All funds have been spent, and the final claim has been settled. All items funded have been purchased or fabricated in house, and have been commissioned and are in regular use. The only exception to this is the ‘Black Hole’ supercomputer cluster which is now obsolete and has been retired. UQ have now commissioned a replacement machine ‘Barrine’ to which the Centre for Hypersonics gets unrestricted access. The effective computing capacity this represents far exceeds that of the original purchase. All contributions in kind and in cash from the participants have been made. UQ have continued to add to the infrastructure of the group, with a Major Equipment and Infrastructure grant of $260k being approved in late 2011 for 2012.

Proceeds of commercialisation
Just as research programs and activities are still at the early stage of implementation, development of IP with commercial value and commercialisation activities in general are consequently at a very early stage. All the facilities were too busy with our in-house programs to be made available to commercial users. No commercialisation of services occurred in 2012.

11. Collaboration
Refer to KPI 4 in section 9 for details of new collaborative projects initiated in 2012.

12. USQ Activities
Testing in the USQ TUSQ wind tunnel continued in 2012. One of the major projects was testing associated with the ASRP SCRAMSPACE project. TUSQ highlights include:
• PhD completion by Agung Widodo, "Temperature variations in a free piston compression wind tunnel"

• Visiting Masters Thesis student from University of Stuttgart (August 2012 - March 2013), Mr Benjamin Kraetzig: Successful demonstration of transient heat flux measurement using hot carbon surfaces and multi-parameter curve fitting to Hayabusa re-entry data leading to deduction of rotational and vibrational temperatures of CN and N2+.

• Article accepted for publication: Widodo, A. and Buttsworth, D., Stagnation Temperature in a Cold Hypersonic Flow Produced by a Light Free Piston Compression Facility, Experiments in Fluids, accepted for publication December 2012.

Further investment has been received for the construction of an Annex to the main wind tunnel laboratory for a student office an electronics/instrumentation room, plus an optics laboratory.
### Appendix 1. Research Higher Degree Students

<table>
<thead>
<tr>
<th>Name</th>
<th>Primary Supervisor</th>
<th>Program</th>
<th>Project Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanchito Banerjee</td>
<td>Professor Russell Boyce</td>
<td>PhD</td>
<td>Simulation of scramjet performance at access-to-space mach numbers</td>
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<tr>
<td>James Barth</td>
<td>Dr Vincent Wheatley</td>
<td>PhD</td>
<td>Simulation of scramjet performance at access-to-space mach numbers</td>
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<tr>
<td>Kevin Basore</td>
<td>Dr Vincent Wheatley</td>
<td>PhD</td>
<td>Flow physics of scramjet fuel injection through porous walls</td>
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<tr>
<td>Mark Bateup</td>
<td>Professor Allan Paul</td>
<td>PhD</td>
<td>Hydro-carbon supersonic combustion</td>
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<tr>
<td>Daryl Bond</td>
<td>Dr Michael Macrossan</td>
<td>PhD</td>
<td>Modelling and simulation of heat and mass transfer enhancement of micro-scales</td>
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<tr>
<td>Mathew Bricalli</td>
<td>Professor Russell Boyce</td>
<td>PhD</td>
<td>Ignition processes in scramjet accelerators</td>
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<tr>
<td>Luke Doherty</td>
<td>Professor Michael Smart</td>
<td>PhD</td>
<td>Investigation of thrust generation in 3D scramjets for access-to-space applications</td>
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<tr>
<td>Mary D'Souza</td>
<td>Dr Timothy McIntyre and Professor Richard Morgan</td>
<td>PhD</td>
<td>Spectrometry of radiation form a stimulated ablation layer</td>
</tr>
<tr>
<td>Elise Fahy</td>
<td>Richard Morgan</td>
<td>PhD</td>
<td>Superorbital Re-entry Shock Layers, Flight and Laboratory Comparison</td>
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<td>Rolf Gehre</td>
<td>Dr Vincent Wheatley</td>
<td>PhD</td>
<td>Numerical investigation of the axisymmetric inlet-fuelled radical-farming scramjet with RANS and LES simulations of the injection, mixing and flow structure/combustion coupling</td>
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<td>Alexander Grainger</td>
<td>Professor Russell Boyce</td>
<td>PhD</td>
<td>Mechanism for hypersonic scramjet inlet starting</td>
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<td>Dillon Hunt</td>
<td>Professor Russell Boyce</td>
<td>PhD</td>
<td>Radical farming in an Axisymmetric Scramjet</td>
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<td>Christopher James</td>
<td>Professor Richard Morgan</td>
<td>MPhil</td>
<td>Radiation from Simulated Atmospheric Entry into the Gas Giants</td>
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<tr>
<td>Philippe Lorrain</td>
<td>Professor Russell Boyce</td>
<td>PhD</td>
<td>Inlet-fuelled radical-farming scramjets at high flight mach number</td>
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<tr>
<td>Wouter Mostert</td>
<td>Dr Vincent Wheatley</td>
<td>PhD</td>
<td>The Converging Shock-Driven Richtmyer-Meshkov Instability in</td>
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<tr>
<td>Name</td>
<td>Supervisor(s)</td>
<td>Degree</td>
<td>Title</td>
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<tr>
<td>Daniel Oberg</td>
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<td>Combustion scaling of an axisymmetric inlet-fuelled, radical farming scramjet engine</td>
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<td>David Petty</td>
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<td>PhD</td>
<td>Flow physics of hypervelocity scramjet combustion with oxygen enrichment</td>
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<td>Hadas Porat</td>
<td>Dr Timothy McIntyre and Professor Richard Morgan</td>
<td>PhD</td>
<td>Hypervelocity re-entry</td>
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<td>David Preller</td>
<td>Professor Michael Smart</td>
<td>PhD</td>
<td>Heat transfer measurements of a hypersonic wing body junction</td>
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<td>Adrian Pudsey</td>
<td>Professor Russell Boyce</td>
<td>PhD</td>
<td>Hypersonic viscous drag reduction through multi-port injector arrays</td>
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<td>Andrew Ridings</td>
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<td>PhD</td>
<td>Scramjet experiments using divergent elliptical combustors</td>
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<td>Jorge Sancho Ponce</td>
<td>Dr Timothy McIntyre and Professor Richard Morgan</td>
<td>PhD</td>
<td>Simulation of hypersonic radiation flow field coupling in expansion tubes.</td>
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<td>Fabrice Schloegel</td>
<td>Professor Russell Boyce</td>
<td>PhD</td>
<td>The combustion scaling laws for radical farming scramjets</td>
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<td>Arman Schwarz</td>
<td>Professor Michael Smart</td>
<td>PhD</td>
<td>Optimisation of aerodynamic wing and fin root heating for hypersonic flight vehicles</td>
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<td>Umar Sheikh</td>
<td>Dr Timothy McIntyre and Professor Richard Morgan</td>
<td>PhD</td>
<td>Effects of radiation heating on hypersonic re-entry</td>
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<td>Ben Shoesmith</td>
<td>Professor Michael Smart</td>
<td>PhD</td>
<td>Computational and experimental assessment of the starting behaviour of hypersonic intakes</td>
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<tr>
<td>Rajinesh Singh</td>
<td>Dr Peter Jacobs</td>
<td>PhD</td>
<td>Exploring the dynamics and control issues of the supercritical carbon dioxide power loop</td>
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<tr>
<td>Tamara Sopek</td>
<td>Professor Russell Boyce</td>
<td>PhD</td>
<td>Fuel injection/mixing studies in hypersonic flows using advanced optical diagnostic techniques</td>
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<tr>
<td>Paul van Staden</td>
<td>Professor Russell Boyce</td>
<td>PhD</td>
<td>Scramjet drag reduction from porous combustion chamber wall fuel injection</td>
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<tr>
<td>Tristan Vanyai</td>
<td>Dr Timothy McIntyre and Professor Richard Morgan</td>
<td>PhD</td>
<td>Scramjet accelerators investigated using advanced optical diagnostic techniques</td>
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<tr>
<td>Name</td>
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<td>Degree</td>
<td>Research Project</td>
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<td>Han Wei</td>
<td>Dr Timothy McIntyre and Professor Richard Morgan</td>
<td>PhD</td>
<td>Interaction between shock layer and ablative products from heat shields during atmospheric entry</td>
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<td>Brad Wheatley</td>
<td>Tim McIntyre</td>
<td>PhD</td>
<td>Physics boundary layer transition</td>
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<td>Dylan Wise</td>
<td>Professor Michael Smart</td>
<td>PhD</td>
<td>Experimental investigation of a 3D scramjet engine at hypervelocity conditions</td>
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<tr>
<td>Fabian Zander</td>
<td>Professor Richard Morgan</td>
<td>PhD</td>
<td>Applications of advanced composites for hypersonic propulsion</td>
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</table>
Appendix 2. 2012 Publications

See attached document.