Queensland Hypersonic Testing Facility

2010 Annual Report

Covering the period

1 January 2010 to 31 December 2010

Contents

1. Summary of activities

This has been a very busy year for hypersonics in Queensland, research has been at a very high level and much new funding has been secured. The Federally funded 'Scramspace' project commenced, and a highlight of the year was participation in the Japanese 'Hayabusa' asteroid sample return mission at Woomera in June. The HyShot and HiFire activities are proceeding well. The focus on fundamental research has meant that profit making activities were not pursued. Activity has focused on a number of areas including

- ARC Discovery program continued at UQ, and a new grant for radiating flows commenced in January 2010.
- In radiating and ablating flows, research contracts were completed for NASA Langley Research Center, ESA and AOARD
- USQ and UQ Centre for Hypersonics participated in the highly successful radiation observations of the hypervelocity return of the Japanese 'Hayabusa' asteroid sample return mission over Woomera in June 2010.
- The collaborative activities of the HiFire flight program, involving DSTO, various universities in Australia and DARPA and Boeing through the Smart State schemes.
- The 'Scramspace' collaborative project for an international scramjet flight and ground testing program for space access purposes (successful funding was announced in March 2010)
- The rocket fabrication plant at Pinjarra Hills continues to be developed, plans for a static test facility have been completed, and two rocket motoer configurations have been developed and await static testing.
-

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

HiFire Activities

The 'HiFire zero' flight was successfully launched by DSTO in May 2009, and the HiFire 1 was successfully flown in. Progress continues to be made on the ground testing of payloads for the follow on flights in UQ's T4 facility.

Equipment.

All of the equipment funded under the award has been purchased, installed and commissioned in accordance with the research objectives of the QHTF, except for the following items still in progress:

- The rocket test facility has been designed and indicative prices have been obtained from a suitable building contractor that specialises in explosives storage and testing facilities. Propellant processing equipment has been installed and commissioned in the QHTF. A licence has been obtained for the manufacture of rocket propellant and the propellant composition has been authorised by the QLD Explosives Inspectorate. It is anticipated that these items will be completed in 2011, administrative delays prevented the completion in 2010.

The supercomputer cluster, which has been operational since July 2004, has been a very successful acquisition, and computational time to the value of $50,000 per month (average usage) has been performed by members of the Centre for Hypersonics. This represents extremely good value for the initial acquisition, and the facility has been the cornerstone for our numerical analysis until 2010. It is now obsolete, and its use has been discontinued. It was closed down in 2010, and UQ now provides equivalent (in fact much

better, considering progress in computer technology since the SSRFF cluster was acquired) for the group through centralised resourses.

All equipment purchased under the scheme was heavily used in 2010.

RHD Training
The group had 30 higher degree students in 2010, and graduated four PhD's. This brings the number of Research Higher Degree (RHD) graduations from the Centre for Hypersonics at UQ to a total of 26 for the period 2005 to 2019 (22 PhDs and four MPhils). In 2010, one PhD student finished a year of her PhD at Ecole Centrale Paris under the 'co-tutelle' scheme for International collaboration.

In addition, RHD students participated in several international conferences, and presented the results of their research in person Educational activities extend beyond postgraduate student activities to include undergraduate students who are heavily included in the research program through final year thesis and design projects, and the small sounding rocket campaigns run by ASRI from Woomera.

Participation in international exchanges and training activities have also been developed at appropriate and complementary levels to QHTF research and education activities. This underscores the value of the education and research being supported by the SSRFF scheme.

Statement on progress of ARC Discovery Project DP1094560 (2010-12):

2010 was an extremely busy year for the grant. 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. The follow on workshop for the Hayabusa re-entry is being held at UQ in March 2010, giving good exposure of the results of our ARC research to the world leaders in this field.

Two new PhD students started on the project in 2010, working on radiation in air and Titan atmosphere, and another has submitted his thesis for review, and two more are in the final stages of completion. Carolyn Jacobs completed her year as a co-tutelle student in Ecole Centrale, Paris (EC) who are a leading group for the modelling of radiating processes. This has led to follow on grant applications with this group, and the likelihood of further collaborative work. Another PhD student working on the grant, Umar Sheik, has also been offered a co-tutelle position at EC for 2012. All three of these near-graduates are already being head hunted for post doctoral positions in radiating flows, indicating the relevance and timeliness of this work. We were invited to participate in 2 new ESA calls for tenders involving radiating flows, and a tender to build a European expansion tube for studying radiation based on the concepts we have developed for this study has been foreshadowed. We are partners on another recently submitted bid to ESA (with EPFL, Lausanne as the lead Institution) for a E$400k grant to investigate radiation

coupling in ablating flows. The invitation to participate in this project arose directly from the ARC radiation grants we have received. CI1 Morgan spent a six month SSP on the project in 2010, working with collaborators in EC, 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 labs in November and December, to work with the other investigators and students.

The laboratory test program continues to be active, incorporating non reflected shock tube and expansion tube experiments. New data from the large bore Aluminium non reflected shock tube has given calibrated information for radiating flows in simulated Titan atmospheres at lower pressures (equivalent to flight at higher altitudes) than has been possible before. Numerical modelling has been a strong feature of the work, and CFD of the facility operation, and the coupling of radiation with the flow fields was the main focus of the recently submitted Potter PhD thesis.

The Centre for Hypersonics received the inaugural UQ award for 'Internationalisation', and the work arising from this grant and its ARC predecessors contributed greatly towards this Institutional recognition.

DSTO Chair for Hypersonics

Under the Memorandum of Agreement between DSTO and UQ for hypersonics research, Professor Russell Boyce was appointed to the DSTO Chair for Hypersonics at UQ in December 2007. The mandate is four-fold :

- To conduct strategic fundamental research in the fields of hypersonic aerothermodynamics and hypersonic airbreathing propulsion, in areas relevant to the needs of both UQ and DSTO.
- To provide focused research and/or analysis to help answer practical engineering questions and to solve specific needs of DSTO's applied hypersonics HIFiRE flight experiment program.
- To organise Australian hypersonics at a fundamental level, to ensure that the universities in particular are working cohesively and efficiently and the fundamental work being conducted is complementary and creates outcomes greater than the sum of the individual parts.
- To maintain, strengthen and seek new strategic international partnerships for Australian hypersonics in general and UQ in particular.

Concerning fundamental research and engineering support activities, Professor Boyce has been actively pursuing the following programs throughout 2008 and 2009, assisted by a team of postdoctoral research fellows and PhD students that he supervises at UQ :

- **Supersonic and hypersonic transverse jet interactions.** The HIFiRE flight experiment trajectories require controlled descent from high altitude, and for much of that descent, control surfaces will be ineffective. Side-jet thrusters are thus required. Almost nothing is known of jet interaction behaviour when the boundary layer is transitional, except that there is evidence to suggest that turbulent spot development may result in very complex interaction structures. HIFiRE will pass through the

transitional regime, and so to support HIFiRE Professor Boyce has initiated a research program to study supersonic and hypersonic transitional jet interactions. The ground testing is being conducted by a PhD student (Freebairn). Experiments with fully turbulent boundary layers and boundary layers with turbulent wedges tripped by posts, interacting with transverse jets, have been performed in the T4 shock tunnel at UQ. Excellent new results showing the complex behaviour of such flows have been generated.

- **Upstream injection / shock induced combustion / radical farming scramjet ignition processes.** Following from the original work at UQ by Dr Allan Paull and Dr Tony Gardner in upstream injection / shock induced combustion, in which observed surface pressure measurements in the combustion chamber led to the proposal of the radical farming scramjet ignition concept, Professor Boyce initiated a PhD research program at UNSW@ADFA to investigate this with a coupled experimental/CFD approach. The outcomes were extremely significant. Upstream injection and radical farming is a technology that will form a key part of certain HIFiRE scramjet flights, and is regarded in Australia as one of the technologies likely to lead to viable scramjet propulsion. The fundamental understanding generated in radical farming research that Prof Boyce supervised is needed in order to successfully apply the technology, and continues under his supervision at UQ. He supervises one of DSTO's hypersonics engineers, Mr Dillon Hunt, who is developing a radical farming flight experiment for HIFiRE flight 3 as his PhD research. The work is also being continued by a new PhD student (Schloegel) employing OH-PLIF with USAF AOARD funding, and is the focus of a large ARC Discovery Project application for 2010-2012.
- **Experimental, CFD and finite element analysis of the HIFiRE 3 scramjet flight experiment**. The scramjet configuration proposed for HIFiRE 3 is an innovative and extremely promising axisymmetric inlet-injection, shock-induced-combustion concept that is delivering high performance in our shock tunnels. The majority of the work being performed by Professor Boyce's team of postdoctoral research fellows and PhD students at UQ is employing experimental and CFD investigations of the fundamental science that underpins this concept, as well as finite element analysis of the thermal and structural loads that will be experienced by the vehicle's inlet and combustion chamber during flight.
- **Hypersonic shape optimization.** To develop optimal hypersonic vehicle designs, it is necessary to couple multidisciplinary design optimization (MDO) to computational fluid dynamics (CFD). To this end, Prof Boyce has instigated a research program with Dr Tapabrata Ray, a world-class MDO specialist at UNSW@ADFA, with the long term goal of developing a sophisticated Australian hypersonic vehicle design optimization capability. The initial research focused on the optimization of the HyShot ascent nose cone for minimum drag, and employed the concept of surrogate approximations to the dependence of drag on shape to reduce the number of CFD calculations required in the evolutionary algorithm shape optimization. Current work is optimising the HIFiRE 3 thrust nozzle and external contour. Further work will focus on the problem of representing complete 3D flow structures with a surrogate vector approximation, so that complex hypersonic shape optimization becomes realistic. This is an important development for Australia's long term hypersonics objectives.

Concerning strategic domestic activities, Professor Boyce is reshaping Australian fundamental hypersonics into a university-led network, the Australian Hypersonics Network, making particular effort to expand and strengthen our capabilities from

aerothermodynamics and propulsion to design optimisation, robust control and materials. The first step in this involved holding the successful Australian Hypersonics Capabilities and Future Directions Workshop 2008 in Brisbane. Furthermore, he is leading negotiations for a DSTO/university-funded Australian Centre of Expertise in Hypersonics, is proposing linkages and work programs with and amongst Australian hypersonics industry players, and is actively involved in efforts to maintain and raise the profile of Australian hypersonics with state and federal politicians and their officials.

Concerning international partnerships, Professor Boyce is using his international network, as well as his influential role as Australian representative on the technical steering committee for the world's leading hypersonics forum (the AIAA International Spaceplanes conference series) to develop these. This includes negotiations to extend the DLR / UQ MOU for collaborative hypersonics research, development of a similar MOU with JAXA, and development with CIRA of a Statement of Intent between the Queensland and Campania governments for collaboration in aviation and aerospace, with UQ/CIRA collaboration in hypersonics as the initial focus. He is also working with Dr Jean Muylaert to involve UQ in ESA's proposed RADFLIGHT radiation flight experiment. He enabled and led UQ's participation in a consortium led by University of Maryland, short-listed for a US$10M 5-year USAF/NASA-funded National Hypersonics Research Center. Finally, he is working with the USAF AEDC towards scramjet ballistic range experiments - not only for scientific research, but to blaze a trail for Australia (for DSTO) to use AEDC's major Test and Evaluation facilities as Australia's hypersonics technology program expands.

TEAKLE COMPOSITES

Teakle Composites is a new company specialising 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 company has negotiated a contract with the Defence Materials Technology Centre for the testing of various high temperature materials in a rocket plume. This project will utilise the largest rocket motor capable of being manufactured at the facility – 2 meters long, 200 mm diameter and containing approximately 60 kg of propellant. This will be the first commercial application of the rocket test facility. The tests are planned in 2011, after the UQ static test facility is completed. 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.

The company also used the facility to manufacture a solid fuelled gas generator to support external burning scramjet experiments by students at the University of Adelaide in October 2010.

The company constructed a large fibreglass nozzle for the X3 expansion tube in 2009 and will shortly be commencing work on a lightweight piston for the same facility to further boost its performance.

The company also added to the facility's capabilities by designing and constructing at its own expense a large filament winding machine capable of manufacturing items up to 9 metres long and 900 mm diameter.

2. Staff and research performance

The following personnel participated in research, education and training activities:

- Professor Richard Morgan (Professor of Hypersonics, Director of the Centre for Hypersonics)
- Emeritus Professor Ray Stalker (retired, School of Mechanical and Mining Engineering)
- Professor Halina Rubinsztein-Dunlop (Head of School of Mathematics and Physics)
- Dr. Peter Jacobs (Senior Lecturer, School of Mechanical and Mining Engineering)
- Dr. Michael Macrossan (Senior Lecturer, School of Mechanical and Mining Engineering)
- Professor David Mee (Head of School of Mechanical and Mining Engineering)
- Dr. Tim McIntyre (Senior Lecturer, School of Mathematics and Physics)
- Professor Michael Smart (Professor of Hypersonic Air breathing Propulsion, School of Mechanical and Mining Engineering)
- Dr Vince Wheatley (Lecturer, School of Mechanical and Mining Engineering)
- Dr Andrew Dann (Post Doc, Centre for Hypersonics)
- Dr. James Turner (Post Doc, Centre for Hypersonics)
- Dr Sandy Tirty (Post Doc, Centre for Hypersonics)
- Professor Russell Boyce, DSTO Chair of Hypersonics
- Professor Allan Paull (Program Leader, DSTO, Adjunct Professor, Mechanical Engineering, HyShot)
- Dr. Hans Alesi (Research Fellow, DSTO, HyShot)
- Dr. Ross Paull (Research Fellow, DSTO, HyShot)
- Mr. Myles Frost (Research Assistant, DSTO, HyShot)
- Ms. Lisa Jensen (HyShot Flight Business Manager & Flight Safety Officer, DSTO)
- Dr. Phillip Teakle (Research Consultant – Teakle Composites)
- Assoc Prof David Buttsworth (USQ Research Consultant - hypersonics)
- Dr Bianca Capra (Research Fellow, UQ Scramspace team)
- Dr. Melrose Brown (Research Fellow, Division of Mechanical Engineering)
- Dr. Michael Creagh (Research Fellow, Division of Mechanical Engineering)
-

Postgraduate Students:

- Jason Hoogland (PhD, Mech. Eng.)
- Mark Bateup (PhD, Mech. Eng.)
- Anne Kovachevich (PhD, Mech. Eng.)
- Troy Eichmann (PhD, Physics)
- Dillon Hunt (PhD, Mech. Eng.)

- Katsuyoshi Tanimizu (PhD, Mech. Eng.)
- Samantha Coras (MPhil, Mech. Eng.)
- Aaron Brandis (PhD, Mech. Eng.)
- Andrew Dann (PhD, Mech. Eng.)
- James Turner (PhD, Mech. Eng.)
- Carolyn Jacobs (PhD, Mech. Eng.)
- Rainer Kirchhartz (PhD, Mech. Eng.)
- Dan Potter (PhD Hypersonics)
- Luke Doherty (PhD Hypersonics)
- Andrew Ridings (PhD, Mech. Eng.)
- Sarah Razzaqi (MPhil, Mech. Eng.)
- Fabian Zander (PhD)
- Michael Creagh (PhD)
- Mary D'Souza (PhD)
- David Gildfind (PhD)
- Wilson Chan (PhD)
- DJ Gangurde (M.E.)

- Tomas Jazzra (PhD Hypersonics)
- Fabrice Schloegel (PhD Hypersonics)
- Dylan Wise (PhD, Hypersonics)
- Dawid Preller (PhD, Hypersonics.)
- Hadas Porat (PhD, Hypersonics.)

- Umar Sheikh (PhD, Hypersonics David Petty (PhD, Mech Eng., Smart)
- Paul van Staden (PhD, Mech Eng, Boyce)
- Philippe Lorrain (PhD, Mech Eng, Boyce)
- David Petty (PhD, Mech Eng, Smart)
- Alex Grainger (PhD, Mech Eng, Boyce)
- Ben Shoesmith (PhD, Smart)
- Daniel Oberg (PhD, Boyce)
- James Barth (PhD, Wheatley)
- Rolf Gehre (PhD, Wheatley)

-

Visitors:

- A large number of visitors were received in connection with the HIFiRE and ARC research programs.

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)

3. Key Performance Indicators

It should be noted that the QHTF is still at an early operational stage and research projects are consequently at the initial phases of development and implementation, thus KPIs relating to research performance have little significance at this time. Further, many of the KPIs recognise that the QHTF will require at least five years to become fully functional. Of special note is that the group has been so heavily involved in leading research of a fundamental nature that we have not had time to pursue commercial activities.

Nonetheless, the 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,

KPI 2:
Employment of Professional Staff
A total of 12 researchers, 1 administrative support staff, and 4 technical staff are employed in the area of hypersonics at the Centre for Hypersonics. DTSO Brisbane employs 13 staff in hypersonics, and has between 1 and 5 resident visitors at all times. Teakle Composites employs 4 staff working in related technology.

KPI 3:
Encourage involvement of Research Higher Degree students

Currently, 26 RHD students are involved in projects at UQ Centre for Hypersonics. In addition, approximately 20 undergraduate students at UQ are doing final year project work in hypersonics. Five PhD's graduated from the Centre for Hypersonics in 2009. This brings the number of Research Higher Degree (RHD) graduations from the Centre for Hypersonics at UQ to a total of 22 for the period 2005 to 2009 (18 PhDs and four MPhils)..

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, among them:

- Increased capability of the X2 and X3 expansion tube facilities has led to a lot of recent interest in aerothermodynamics and reentry flows, and in particular flows which contains large amounts of radiation. Work completed in 2010 on the collaborative ESA AMOD grant to simulate radiating reentry flows, the NASA

grant for Earth re-entry studies and the USAF Asian overseas funding body (AOARD), and two new collaborative ARC Discovery applications are under review.

- The HyShot flight testing activities have increased in scope, and are now being run through a newly established 'DSTO Brisbane' branch based at Pinjarra Hills. This led to the establishment in 2006 of the $US 54 million 'HIFiRE' collaborative flight test program between USA and AustraliaIn June 2007 the HyCause scramjet was flown from Woomera, managed by DSTO Brisbane and using the launcher refurbished under SSRFF funding.
- The HIFiRE flight program (a series of nine launches) is a direct result of hypersonics research at UQ, and continues to make full use of the research facilities at the QHTF.
- 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.
4 PhD degrees were awarded

Refereed Journal Articles

Full Conference Papers (refereed on full or partial manuscript)

Buttsworth D, D'Souza M, Potter D, Eichmann T, Mudford N, McGilvray M, McIntyre TJ, Jacobs P, Morgan R (2010) Expansion Tunnel Radiation Experiments to Support Hayabusa Re-entry Observations, Proceedings of the 48th AIAA Aerospace Sciences Meeting, Orlando, Florida.

KPI 6:
Professional Development
Invited lectures were given by staff members at the von Karmen Institute (Brussels) Lecture in April 2010 and an invited lecture tour of China was made in 2009.

Conference attendance has been strong, with many staff and students given the chance for professional development through presenting their work to international audiences, such as the following recent presentations:

4. Accounts

All funds have been spent, except for the remaining component for the rocket static testing facility. All contributions in kind and in cash from the participants have been made.

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 inhouse programs to be made available to commercial users. No commercialisation of services occurred in 2010.

5. Collaboration

The HyShot flight testing activities continue to increase in scope, and the 'DSTO Brisbane' branch based at Pinjarra Hills, which has led to the creation of several new professional appointments in aerospace. This led to the establishment of the $US 54 million 'HiFire' collaborative flight test program between USA and Australia. The ASRP proposal for scramjet testing was prepared in 2009 in collaboration with many International groups. Strong links were formed with Italian researchers. Involvement with the new Centre for Defence Materials has led to extension of contacts to include people from the materials testing and development fields, which are fundamental to the successful application of our hypersonic studies. In the field of radiation and ablation, collaborative proposals have been prepared for 2012 with partners from the University of Stuttgart, Ecole Central Paris, and the Air Force Institute of Technology.

6. USQ Activities

(1 January to 31 December 2010)

Awarding of the Australian Space Research Program funding for "Scramjet-based access-to-space" project which is being lead by a The University of Queensland has significantly boosted USQ activities. The USQ facility is providing scramjet inlet starting experimental support for the ASRP project. A post-doctoral research fellow, Sudantha Balage has been appointed to work with the TUSQ facility on the execution of the ASRP project.

Experiments performed during 2010 have included: (1) stagnation temperature measurements and facility characterisation; (2) scramjet inlet testing for tuneable laser diode absorption measurements of temperature and velocity; (3) scramjet inlet testing for start-ability; and (4) hypersonic free-flying experiments.

1. Stagnation temperature measurements were performed by Mr Agung Widodo, PhD candidate being supervised by Prof David Buttsworth. A publication on these measurements was presented at the Fluid Mechanics conference in Auckland in December 2010 [1]. Additional measurements of stagnation temperature are currently in progress to reduce uncertainties in the initial results.

2. Further experiments were performed by Dr Sean O'Byrne (of UNSW@ADFA) and his PhD student, Sven Wittig in November 2010 to investigate a temperature measurement technique for scramjet inlet. This work is a continuation of trials which were first performed in November/December 2009. Results from these experiments and those of the earlier program in 2009 have been presented in various forums, but are yet to be released in an archival form.

3. Axisymmetric scramjet inlet starting experiments were performed by DSTO during November 2010. This scramjet model is part of the 'HIFiRE' program and the model featured two diametrically opposed inlet doors which are designed to close after flow through the engine has been properly established. TUSQ is the only facility in Australia which can be used for this work because it provides sufficient hypersonic flow duration to investigate this flow interaction process. The program of experiments was very successful and has enabled the DSTO team to progress the axisymmetric scramjet design towards a flight system.

4. A pilot program being led by Dr Neil Mudford of UNSW @ ADFA to demonstrate free-flying capabilities in the TUSQ facility was also initiated in November/December 2010. The idea is to release a model into the Mach 6 nozzle flow and deduce aerodynamic coefficients from the model acceleration which is being deduced from photography and on-board accelerometers on the model. The primary advantage of this technique is that sting effects can be completely eliminated. Although the technique is yet to be fully proved, initial results from this program indicate that this technique can provide high quality aerodynamic coefficient data. Additional experiments for optimisation of the techniques are being planned for 2011.

[1] A. S. Widodo, D. R. Buttsworth, Stagnation Temperature Measurements in the USQ Hypersonic Wind Tunnel, 17 Australasian Fluid Mechanics Conference, Auckland, NZ, 5-9 December 2010.