Development and demonstration of a diode laser sensor for a scramjet combustor

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A thesis submitted for the degree
of Doctor of Philosophy of
the Australian National University

Alan David Griffiths

December 2004, revised September 2005

THE AUSTRALIAN NATIONAL UNIVERSITY

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge and belief, it contains no material previously published or written by another person, except where due reference is made in the text.

Alan Griffiths
December 2004

Summary of Thesis

Hypersonic vehicles, based on scramjet engines, have the potential to deliver inexpensive access to space when compared with rocket propulsion. The technology, however, is in its infancy and there is still much to be learned from fundamental studies.

Flows that represent the conditions inside a scramjet engine can be generated in ground tests using a free-piston shock tunnel and a combustor model. These facilities provide a convenient location for fundamental studies and principles learned during ground tests can be applied to the design of a full-scale vehicle.

A wide range of diagnostics have been used for studying scramjet flows, including surface measurements and optical visualisation techniques.

The aim of this work is to test the effectiveness of tunable diode laser absorption spectroscopy (TDLAS) as a scramjet diagnostic.

TDLAS utilises the spectrally narrow emission from a diode laser to probe individual absorption lines of a target species. By varying the diode laser injection current, the laser emission wavelength can be scanned to rapidly obtain a profile of the spectral line. TDLAS has been used previously for gas-dynamic sensing applications and, in the configuration used in this work, is sensitive to temperature and water vapour concentration.

The design of the sensor was guided by previous work. It incorporated aspects of designs that were considered to be well suited to the present application. Aspects of the design which were guided by the literature included the laser emission wavelength, the use of fibre optics and the detector used. The laser emission wavelength was near 1390 nm to coincide with relatively strong water vapour transitions. This wavelength allowed the use of telecommunications optical fibre and components for light delivery. Detection used a dual-beam, noise cancelling detector.

The sensor was validated before deployment in a low-pressure test cell and a hydrogen–air flame. Temperature and water concentration measurements were verified to within 5% up to 1550 K. Verification accuracy was limited by non-uniformity along the beam path during flame measurements.

Measurements were made in a scramjet combustor operating in a flow generated by the T3 shock tunnel at the Australian National University. Within the scramjet combustor, hydrogen was injected into a flame-holding cavity and the

sensor was operated downstream in the expanded, supersonic, post-combustion flow. The sensor was operated at a maximum repetition rate of 20 kHz and could resolve variation in temperature and water concentration over the 3 ms running time of the facility.

Results were repeatable and the measurement uncertainty was smaller than the turbulent fluctuations in the flow. The scramjet was operated at two fuel-lean equivalence ratios and the sensor was able to show differences between the two operating conditions. In addition, vertical traversal of the sensor revealed variation in flow conditions across the scramjet duct.

The effectiveness of the diagnostic was tested by comparing results with those from other measurement techniques, in particular pressure and OH fluorescence measurements, as well as comparison with computational simulation.

Combustion was noted at both of the tested operating conditions in data from all three measurement techniques.

Computation simulation of the scramjet flow significantly under-predicted the water vapour concentration. The discrepancy between experiments and simulation was not apparent in either the pressure measurements or the OH fluorescence, but was clear in the diode laser results.

The diode laser sensor, therefore, was able to produce quantitative results which were useful for comparison with a CFD model of the scramjet and were complimentary to information provided by other diagnostics.

Acknowledgements

Over the last few years, I have been fortunate to receive assistance from many, many people. My supervisor, Frank Houwing, provided much-needed encouragement and advice. The contribution of my advisers, John Close and Neil Mudford is also much appreciated. Paul Walsh was responsible for all things related to the scramjet model and T3, and was astounding with his technical abilities. Paul also provided support which was probably more valuable than his extensive technical skills.

Other members of the research group have also provided advice and assistance. In particular, Andrew Neely, Russell Boyce, Sean O'Byrne and Jeff McGuire provided advice with experiments and CFD, while Ingo Stotz found the time to run additional calculations for my conditions.

Phil Hobbs and Mark Allen were generous in their responses to my emails and they both supplied information that was extremely helpful for my work.

Electronics advice and fabrication was provided by Shane Grieves and Sharon López saved me from administrative chaos on many occasions.

Thanks to the other students and staff within the physics department who have helped make this experience fun. Also to all of my friends, who have, against all predictions, made living in Canberra loads o fun.

Thanks finally to my family, Jill and her family.

Thanks to you all.

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