

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

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A thesis submitted for the degree  
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Alan David Griffiths

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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



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## 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 complementary to information provided by other diagnostics.

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## Contents

<b>Summary</b>	<b>v</b>
<b>Acknowledgements</b>	<b>vii</b>
<b>1 Introduction</b>	<b>1</b>
<b>2 Supersonic combustion research</b>	<b>5</b>
2.1 Principles of Scramjet operation . . . . .	5
Fuel-air mixing . . . . .	6
Supersonic combustion . . . . .	7
Airframe–engine integration . . . . .	8
2.2 Scramjet testing . . . . .	8
Flight testing . . . . .	8
Blow-down facilities . . . . .	10
Pulsed flow facilities . . . . .	10
2.3 Diagnostics for scramjet-like flows . . . . .	11
Surface measurements . . . . .	11
Optical diagnostics . . . . .	12
<b>3 T3 flow facility and scramjet model</b>	<b>15</b>
3.1 The T3 shock tunnel . . . . .	15
Configuration . . . . .	15
Operation . . . . .	16
Determination of free-stream conditions . . . . .	19
Additional discussion of free-stream conditions . . . . .	20
3.2 Scramjet combustor model . . . . .	22
Instrumentation . . . . .	26
Calculation of equivalence ratio . . . . .	27

<b>4</b>	<b>Absorption spectroscopy theory</b>	<b>31</b>
4.1	Molecular ro-vibrational energy levels and absorption lines . . . .	31
4.2	The relationship between line and gas properties . . . . .	33
	Strength of absorption lines . . . . .	35
	Shape of absorption lines . . . . .	36
	Natural broadening . . . . .	37
	Pressure broadening . . . . .	37
	Doppler broadening . . . . .	37
	Combined pressure and Doppler broadening . . . . .	38
	More advanced line shapes . . . . .	38
4.3	Spectral model of water vapour . . . . .	39
<b>5</b>	<b>Sensor design</b>	<b>43</b>
5.1	Other diode laser based sensors . . . . .	43
5.2	Selection of spectral lines . . . . .	45
5.3	Physical sensor design . . . . .	51
	Diode lasers . . . . .	52
	Optical components . . . . .	56
	Signal detection . . . . .	58
5.4	Data reduction . . . . .	63
	Time-to-frequency conversion . . . . .	65
	Absorbance measurement . . . . .	66
	Log-ratio detector . . . . .	66
	Effect of luminosity . . . . .	69
	Linear detector . . . . .	70
	Integrated absorbance from spectral absorbance . . . . .	71
	Error estimation . . . . .	72
	Determination of temperature and number density . . . . .	74
<b>6</b>	<b>Sensor verification</b>	<b>77</b>
6.1	Measurements at room temperature . . . . .	77
	Experiment configuration . . . . .	78
	Applicability of Voigt profile . . . . .	79
	Comparison with literature . . . . .	81
	Sensitivity to pressure . . . . .	82

<i>Contents</i>	xi
Temperature measurement in room air . . . . .	83
6.2 Flame measurements . . . . .	85
Experimental configuration . . . . .	86
Independent measurement of flame properties . . . . .	88
Determining temperature with a bare thermocouple . . . . .	88
Determining water vapour number density . . . . .	91
Spectroscopic measurements of flame properties . . . . .	91
Radial temperature and concentration profiles . . . . .	92
Calibration results . . . . .	93
Time-resolved measurements . . . . .	95
<b>7 Scramjet-based measurements</b>	<b>99</b>
7.1 Test outline and sensor configuration . . . . .	99
7.2 Absorbance before processing . . . . .	104
7.3 Luminosity check . . . . .	107
7.4 Integrated absorbance . . . . .	108
7.5 Temperature and water vapour time series . . . . .	112
7.6 Traverse across duct . . . . .	113
7.7 Measurements in ethylene-fueled combustor . . . . .	115
<b>8 Interpretation of results</b>	<b>119</b>
8.1 Confirmation of combustion . . . . .	119
8.2 The source of measurement uncertainty . . . . .	122
8.3 Water vapour mixture fraction . . . . .	123
8.4 Comparison with CFD . . . . .	126
<b>9 Conclusions</b>	<b>135</b>
<b>References</b>	<b>137</b>
<b>Glossary of symbols</b>	<b>147</b>



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## List of Figures

1.1	Comparison of rocket and aircraft take-off mass fractions. . . . .	2
2.1	Scramjet-powered vehicle concept. . . . .	6
2.2	The rocket-boost stage of two scramjet flight tests. . . . .	9
2.3	A piezoelectric pressure transducer. . . . .	12
3.1	Side elevation of T3 . . . . .	16
3.2	Operation of the T3 shock tunnel. . . . .	17
3.3	Stagnation pressure trace. . . . .	18
3.4	Scramjet duct geometry. . . . .	23
3.5	Scramjet inlet. . . . .	24
3.6	Scramjet inlet luminosity. . . . .	24
3.7	Important components of the fuel injection system. . . . .	26
3.8	Details of the pressure transducer mounts. . . . .	26
3.9	Hydrogen mass flow. . . . .	30
3.10	Equivalence ratio during tunnel runs. . . . .	30
4.1	Vibrational quantum number assignments for H <sub>2</sub> O. . . . .	32
4.2	Ro-vibrational energy levels in H <sub>2</sub> O. . . . .	33
4.3	An idealised spectroscopy experiment. . . . .	33
4.4	Pressure and Doppler broadening effects on line shape. . . . .	36
4.5	Voigt profile fitted to a Galatry profile. . . . .	39
4.6	Water vapour spectrum between 1 and 2 $\mu\text{m}$ . . . . .	41
4.7	Water vapour absorption at 500, 1000, 1500 K. . . . .	41
5.1	Line strength and ratio variation with temperature. . . . .	48
5.2	Line ratio sensitivity as a function of temperature. . . . .	49

5.3	Uncertainty in water concentration as a function of temperature.	50
5.4	Layout of the TDLAS system. . . . .	51
5.5	The LabVIEW-based acquisition and control system. . . . .	52
5.6	Schematic of a diode laser. . . . .	53
5.7	Types of single-mode diode lasers. . . . .	53
5.8	Laser diode control subsystem. . . . .	55
5.9	Multiplexing circuit schematic . . . . .	55
5.10	Waveforms from the multiplexing box. . . . .	56
5.11	Optical components of the sensor. . . . .	57
5.12	The shape of detector signals. . . . .	60
5.13	Circuit diagram of the log–ratio detector. . . . .	61
5.14	Circuit diagram of temperature stabilisation electronics. . . . .	63
5.15	Data processing steps during data reduction. . . . .	64
5.16	Raw TDLAS signals from a flame. . . . .	64
5.17	Conversion from time to frequency over the laser scan. . . . .	66
5.18	Equipment configuration for log–ratio detector calibration. . . . .	67
5.19	Detector stability. . . . .	68
5.20	Effect of luminosity on detector signal. . . . .	70
5.21	The analysis technique for direct-absorption measurements. . . . .	71
5.22	The analysis technique for direct-absorption measurements. . . . .	74
6.1	Test cell measurement configuration. . . . .	78
6.2	Voigt and Galatry fits to test cell absorption data. . . . .	80
6.3	Comparison of observed and predicted spectra in test cell. . . . .	82
6.4	Comparison of measured, HITRAN and Toth line strengths. . . . .	84
6.5	Sensitivity of integrated absorbance determination to pressure. . . . .	84
6.6	Histogram of temperature measured in room air. . . . .	85
6.7	McKenna Products flat-flame burner. . . . .	86
6.8	Experimental arrangement for flame measurements. . . . .	87
6.9	Model of the thermocouple used for radiation correction. . . . .	89
6.10	Flame temperature profile and fitted trapezoid profile. . . . .	92
6.11	Temperature from thermocouple and TDLAS in a burner. . . . .	94
6.12	Ratio of measured to predicted water vapour concentration. . . . .	95
6.13	Temperature measured in an unsteady flame. . . . .	96
6.14	Histogram of measurement uncertainty in a flame. . . . .	97

7.1	Fibre-optic launch module. . . . .	102
7.2	Detector module. . . . .	103
7.3	Launcher module installed in duct. . . . .	104
7.4	Scramjet with covers in place. . . . .	105
7.5	Unprocessed absorbance signal. . . . .	105
7.6	Raw signal from standard detector. . . . .	107
7.7	Flow luminosity. . . . .	108
7.8	Curve fits to high equivalence ratio data. . . . .	110
7.9	Curve fits to low equivalence ratio data. . . . .	110
7.10	Absorbance as a function of run time, high $\phi$ . . . . .	111
7.11	Absorbance as a function of run time, low $\phi$ . . . . .	111
7.12	Temperature time-series. . . . .	112
7.13	Temperature time-series from multiple shots. . . . .	113
7.14	Number density time-series from multiple shots. . . . .	114
7.15	Temperature across the duct. . . . .	115
7.16	Water vapour concentration across the duct. . . . .	116
7.17	Temperature for ethylene test. . . . .	117
7.18	Water vapour concentration for ethylene test. . . . .	117
8.1	Pressure along scramjet floor. . . . .	120
8.2	Pressure rise due to combustion. . . . .	121
8.3	OH-PLIF for high $\phi$ . . . . .	122
8.4	OH-PLIF for low $\phi$ . . . . .	123
8.5	Pressure at duct floor . . . . .	124
8.6	Water partial pressure normalised by wall pressure. . . . .	125
8.7	Measured and CFD-predicted pressure. . . . .	127
8.8	Temperature predicted by CFD. . . . .	128
8.9	Water mole fraction predicted by CFD. . . . .	129
8.10	Temperature and water vapour in the measurement plane. . . . .	130
8.11	CFD-predicted, simulated TDLAS and measured temperature. . . . .	130
8.12	CFD-predicted and simulated TDLAS H <sub>2</sub> O concentration. . . . .	131

