9. Conclusions

The aim of this work was to test the effectiveness of TDLAS as a diagnostic for a scramjet combustor operating in a free-piston shock tunnel. At the onset of the project, no such diode laser sensor was available so a considerable fraction of the project was spent designing, building and testing the sensor. Measurements in a hydrogen–air flame were able to verify the accuracy of the sensor with a maximum systematic error of 5% at 1550 K. Validation uncertainty was limited by flame fluctuations as well as the variation in flame properties along the beam line-of-sight.

The validated sensor was used to make measurements in a scramjet combustor, and the effectiveness of the sensor was discussed in the previous chapter. Measurements were possible at all four conditions tested, which included high and low equivalence ratio cases of hydrogen and ethylene fuel. The success of the sensor in ethylene was limited by the reduced amount of water vapour present in the flow when compared with hydrogen tests. However, the measurement was selective enough not to be affected by the additional species present in the ethylene-fuel case.

Measurements were limited to the lower part of the scramjet duct, where the most water vapour was present. Measurement of other species, such as oxygen, would compliment the present sensor and allow measurements to be made through the entire duct. With the present sensor, trends were resolved over the test time, and different results were obtained at different locations within the duct and at different equivalence ratios.

Comparison of TDLAS results with pressure measurements, OH fluorescence measurements and CFD were used as the basis for judging the usefulness of the TDLAS sensor. The conclusions that arise from this discussion are given below.

Evidence of combustion was observed by TDLAS at both of the scramjet operating conditions through the detection of the water vapour combustion product. The presence of combustion was supported by pressure and OH–PLIF measurements, validating the result inferred from the diode laser sensor.

As expected from theory, the uncertainty in the temperature measurement increased with increasing temperature. While dependent also on water concentration, typical values ranged from ±2% at 500 K to ±10% at 1500 K. This is higher than the uncertainty in flame verification experiments, which was a maximum of ±5% at 1550 K. Calibration experiments, therefore, were able to
characterise the sensor with sufficiently high precision for the intended application of the sensor.

Improved precision in scramjet experiments might be possible if the effect of the interference filter were eliminated. In the present configuration, this filter was essential for blocking broadband luminosity from the flow. Nevertheless, improvement of this feature of the system could provide the largest improvement in future measurements.

Turbulent fluctuations also influenced the measurement. Comparison with PLIF images showed that the sampling rate of the sensor was a factor of $10^2$ below what would be required to resolve turbulent fluctuations in the duct. A decrease in the time between the two absorption measurements would improve the sensor. This could be achieved by increasing the scanning rate or selecting new spectral lines that are close enough to be scanned with a single diode laser.

The previous chapter also presented a simulation of the scramjet flow. The simulated flow-field was used to simulate the absorption along lines-of-sight. The simulated absorption was then used to find apparent temperature and water vapour concentrations, based on a hypothetical TDLAS measurement along that line of sight.

This showed that the error associated with assuming constant properties along the line-of-sight results in a small error, for this simulated flow. Temperature was low by 5% and concentration by 3%. Despite the 3–D nature of scramjet flow fields, therefore, TDLAS can be used to effectively determine mean temperature and water concentration provided that the beam path is chosen carefully. This conclusion, however, is limited to the CFD-predicted flow and is only valid in the experimental case if the simulation correctly predicted the variability in temperature and water concentration along the line of sight.

The value of the TDLAS measurement is best demonstrated by comparison with CFD results. Diode laser measurements showed that CFD temperature predictions were low. More strikingly, water concentration was under-predicted by a factor of $10^2$.

The diode laser sensor, therefore, is effective at producing data which can be used to verify CFD predictions. Without the availability of the diode laser sensor, the under-prediction of water vapour would have been difficult to discover from the PLIF or pressure measurements. It produces quantitative data which compliments other experimental techniques. With the possibility of future enhancements to the sensor, diode laser sensors seem to be a valuable tool for scramjet research.