1. Introduction

In order to reach low earth orbit, a vehicle must travel at a speed in excess of Mach 25. The present method of obtaining such a speed is to use a rocket engine for propulsion. This has the disadvantage, however, that most of the vehicle's take-off mass is comprised of oxygen, or some other oxidiser, leaving little allowance for payload and vehicle structure. This is despite the fact that the majority of the rocket's energy is expended during flight through the earth's oxygen-rich atmosphere.

In contrast to rockets, aeroplanes powered by jet engines need not carry oxidiser, so that a vehicle with the same take-off mass as a rocket can transport a larger payload. Furthermore, take-off mass can be distributed to the vehicle structure, which can allow the vehicle to be re-usable and safer to operate. This is compared graphically in figure 1.1.

The problem with using aeroplanes to enter orbit is speed: the fastest piloted air-breathing vehicle, the SR-71 Blackbird, has a maximum flight Mach number of 3.2 and its engine technology, the ramjet, has a theoretical maximum Mach number of around 6 [50]. This implies that another engine concept is required for an airbreathing vehicle to enter orbit.

An airbreathing engine with the ability to operate in this flight regime is the *supersonic-combustion ramjet* or *scramjet*. As suggested by the name, a scramjet is a ramjet engine where the airflow, and hence combustion, remains supersonic through the engine rather than being slowed to below Mach 1, which is the case in a conventional ramjet. This concept is far from new and, at first glance, represents an evolutionary step up from an existing engine technology.

In practice, this step has shown itself to be non-trivial with the first successful flight testing of a scramjet-powered vehicle occurring in 2004. Part of the reason for this lag between the idea and demonstration is due to incomplete understanding of the physical processes that occur in the complex supersonic, turbulent and combusting flow found in a scramjet combustor.

Development of such an understanding requires experiments to be carried out at conditions which simulate the conditions inside a scramjet engine in flight, a formidable task in itself, and then use some diagnostic to work out what is actually happening in the test combustor. These results can then be used directly, or used as part of a computer model, to assist with the development of a new scramjet design.

Tunable diode laser absorption spectroscopy (TDLAS) is one such diagnostic technique and has been applied to environmental measurements, combustion

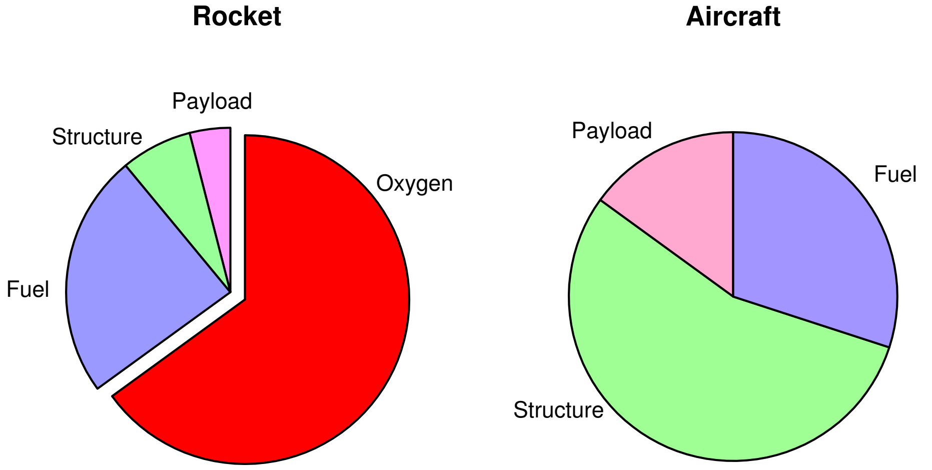

Figure 1.1: Comparison of rocket and aircraft take-off mass fractions (data from [50]).

measurements, shock tube measurements and measurements in hypersonic flows. Examples of its use in scramjets, however, are few. This thesis documents the development of a sensor based on tunable diode laser absorption spectroscopy, and its application to a model scramjet combustor.

Specifically, the aim of this research project was to test the effectiveness of tunable diode laser absorption spectroscopy as a diagnostic, when applied to the measurement of water vapour concentration and temperature in a scramjet combustor.

The scope of this research was limited as follows:

- Testing was limited to a generic scramjet combustor which had been designed for use in a free-piston shock tunnel—the T3 shock tunnel located at the Australian National University; and
- Although tuned for the particular measurement environment, the TDLAS sensor would be based on proven techniques and existing designs.

These limits were chosen so as to maximise useful results produced by the research while accepting the limited time and resources available to the project.

In order to fulfil this aim, it is useful to have an understanding of the field of supersonic combustion research to help judge what is required of a new diagnostic. Chapter 2 provides a brief background of this research effort including the principles of scramjet operation, ways of testing scramjets and an overview of some diagnostics that are used with scramjet flows. Following this, chapter 3 describes the particular facility and scramjet model used for this work.

The theory underlying TDLAS follows in chapter 4. This is included to explain the processes that make the measurement possible and give some insight into the strengths and limitations of the technique. Chapter 5 builds on this theory with more practical discussion of how a sensor can be designed, and describes the sensor built for this work. This chapter also includes some discussion of previous applications of TDLAS. The operation of the sensor is verified in chapter 6 and measurements in the combustor are reported in chapter 7.

In chapter 8, results obtained with other techniques are collated and compared with those from the sensor developed in this work. This provides a means to judge the effectiveness of the TDLAS sensor. Conclusions based on this comparison are presented in chapter 9.