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Tailored Operating Conditions in the T6 Reflected Shock Tunnel

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Abstract

Reflected shock tubes are used extensively to study a range of high enthalpy aerothermodynamic phenomena, typically associated with hypersonic flight. A reflected shock is utilised to produce a region of stagnated high-pressure gas which flows through a converging-diverging nozzle. The test time is defined by the duration of steady conditions in the stagnated supply region, typically on the order of 1-10ms [1]. This necessitates a method for increasing the duration of steady supply conditions through a process known as contact interface tailoring. A tailoring method based on a state-to-state equilibrium thermochemistry solver is described which maintains the reflected shock strength across the driver and test gas. The method is applied to an Earth re-entry condition, and validated through a shot conducted within the T6 Stalker Tunnel in RST mode.

Keywords: *Hypersonic, Tailored contact surface, Reflected shock*

1. Introduction

Due to high flight cost, the vast majority of hypersonic flow phenomena have been experimentally studied using ground testing facilities. The high enthalpy variants, impulse facilities, utilise shock waves to produce a short duration hypersonic flow which is inexpensive and repeatable. A basic shock tunnel consists of a driver section and a driven section separated by a diaphragm. The driver gas is compressed by detonation or piston motion until the primary diaphragm burst pressure is achieved. Upon diaphragm rupture the large pressure differential causes the driver gas to rapidly expand into the driven section, simultaneously producing an incident shock. The incident shock processes the test gas, and the driver continues to expand forcing the test gas along the driven section. A reflected shock tunnel is a derivative facility of the basic shock tube, which reflects the incident shock at the entrance to a converging-diverging nozzle. As the area ratio is small the shock is almost completely reflected, reprocessing the test gas [2]. The advantage over other facility types is that the test flow is initiated from almost constant stagnated supply conditions. The shock reflection enables higher total temperatures to be achieved and issues relating to shock attenuation and boundary layer build-up are avoided.

The test time is limited to the interval between the arrival of the incident shock at the nozzle and the return of a secondary wave generated at the contact surface [3]. The test time can be dramatically increased if the reflected shock passes across the contact surface without the production of any secondary waves. This matches the acoustic impedance of the driver and test gases - known as the tailored operating condition.

The behaviour of a shock tube is non-ideal and drastically differs between facility. With different gemetries, pressure capaciites and driver compression mechanisms, a tailored solution is unique to each facility. Commissioning of the T6 in RST mode was initially conducted for low enthalpies with a mild undertailing observed [4]. This study builds upon this to investigate higher enthalpy test cases with a tailored contact surface.

2. Tailored Operating Conditions

The numerical program is a state-to-state solver which incorporates the NASA CEA program [5] to compute state variables, assuming thermochemical equilibrium. Stagnation properties are selected and the

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program produces tables of tailored operating conditions for a range of driver gas compositions. Across the contact surface the program enforces the criteria that the particle velocities and pressures are equal, thus eliminating any secondary expansion or compression waves passing through the test gas. These values represent theoretical conditions but do not consider the volumes of the gas slugs, or the tuning of the piston. These variables are a function of individual facility geometry. To incorporate the facility geometry the preliminary conditions are simulated within L1D, a quasi-one-dimensional lagrangian gas dynamics code for transient gas flow facilities. The loss of driver pressure after rupture can be compensated for by additional compression produced by the piston. Typically, it is seen as advantageous to push the pressure to 10% higher than the rupture pressure - known as overdriving [6]. At the point of diaphragm rupture, the piston will be approaching the end of the compression tube whilst still travelling at a high velocity. To protect the facility a volume of driver gas is required to slow the piston to an acceptable velocity before it reaches the end of the tube. The piston velocity and position are a function of driver composition and pressure. With L1D the most suitable combination is selected from the state-to-state solver producing a driver fill pressure and composition that maximises the test time, and protects the facility.

3. Experimental Setup

The experimental portion of the study will be conducted within the multimodal high enthalpy shock tunnel at the University of Oxford - the T6 stalker tunnel. The computed tailored operating conditions will be produced within the T6 before December 2023 to validate the tailoring methodology.

4. Results and Discussion

This section will outline the data produced from the experiments conducted within the T6 in RST mode. Pressure traces from shock timing stations will indicate the shock speed variance. The total enthalpy is inferred from the ESTCj code [7], which uses the measured shock speed to calculate an ideal reflected shock process. These properties are then isentropically relaxed to the measured stagnated pressure. This will be measured by the upstream pressure transducer located just ahead of the entrance to the laval nozzle. A plateu in the pressure trace is expected, indicating the level of trailoring with the absense of expansion and compression waves.

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