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Proceedings of the Combustion Institute 32 (2009) 2429–2436

Proceedings of the Combustion Institute

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Planar laser-induced fluorescence imaging of OH in a supersonic combustor fueled with ethylene and methane

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Abstract

A supersonic combustor was experimentally investigated using both conventional instrumentation and laser-based diagnostics. Planar laser-induced fluorescence (PLIF) imaging of OH was used in the main section of the combustor to examine flameholding and flame propagation during a series of evaluations at conditions simulating Mach-5.5 flight. Parameters of interest in this study included the angle of the primary fuel injectors, the distribution of fuel throughout the combustor, and the fuel composition. Changes in fuel-injection angle were expected to influence the mixing and combustion processes, and therefore combustor operation. Fuel-distribution variations were expected to modify the flame propagation between flameholding regions. Finally, ethylene and methane were used to examine the suitability of the flameholder designs over a wide range of fuel reactivity. Results suggest that the combustor provides relatively robust flameholding regardless of the fuel used and good flame propagation as long as the fuel distribution provides favorable conditions in the flameholding regions. In addition, the results show that the primary injectors can be useful in controlling certain aspects of combustor operability.

Keywords: Scramjet; Supersonic combustion; OH PLIF; Combustor performance; Flameholding

1. Introduction

Scramjet engines provide the possibility of airbreathing hypersonic flight. To maximize thrust, these engines must be designed to provide adequate mixing and combustion over a short flow path to overcome drag and to minimize structure weight. This is a significant challenge because the residence time inside the combustor is on the order of 1 ms. A common design mechanism involves anchoring flames in lower velocity regions, behind flow obstructions or steps, and in wall cavities to enable the flame to stabilize and burn without blowing off [1]. As the main flow interacts with these recirculation regions across shear layers, the majority of the fuel–air mixture is ignited and burns as it propagates through the combustor.

This work continues the experimental program on scramjet combustors in research cell 22 at the

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1540-7489/$ - see front matter © 2009 Published by Elsevier Inc. on behalf of The Combustion Institute.
doi:10.1016/j.proci.2008.06.209

Air Force Research Laboratory (AFRL). Goals for this experiment were several, including a better understanding of the role of body and cowl walls on the combustion zone, observation of the influences of fuel reactivity (via changes in fuel composition) on scramjet operation and performance, and an understanding of the effects of primary-fuel-injection angle on combustor performance and operability. This study extends previous work to include the role of body-to-cowl coupling (i.e., body and cowl-side fuel injection and flameholding) at higher Mach numbers and with different fuels.

There are many possibilities for fueling [2–4] and flameholding [5–8] schemes inside these combustors. For this experiment, the combustor was operated with both ethylene and methane as fuels. Ethylene and methane were selected because they essentially bound the entire range of hydrocarbon-fuel reactivity (based on ignition delay time or extinction strain rate) [9,10]. Injection and flameholding/combustor geometry were chosen for performance reasons. The injection scheme for this study is direct-wall injection through an array of ports along the combustor (Fig. 1). This provides more mixing with the main flow than injection inside a cavity, with a lower pressure loss than that of injection behind a strut. To provide improved mixing with the air supply, multiple small injection ports span the width of the combustor. Three flameholding regions are designed into the combustor, with fuel injection ports selectable both upstream and downstream of the main flameholding cavity on the *body-side* wall, and just upstream of the step on the *cowl-side* wall. By varying fuel flow rate, injection angle, injection placement, and fuel choice, observations can be made on the effects of these parameters on the viability and performance of this combustor design.

Ground-based tests of scramjet combustors normally rely on global measurements, such as thrust (via thrust stand) and total heat release (via calorimetry), and wall-based sensors, such as thermocouples and pressure transducers, to determine performance and operability [11,12]. Concurrent hydroxyl (OH) planar laser-induced fluorescence (PLIF) imaging provides the additional ability to examine instantaneous and averaged flame structure at specific positions along the combustor. This adds insight into the specific flow-field and reaction zone that result from changing fuel schemes and combustor geometries.

PLIF of the OH radical is a well-established technique for study of the reaction zone in a turbulent, non-premixed flame [13]. Its tendency to persist downstream of the flame front at super-equilibrium concentrations, especially in premixed flames, limits one in discerning between the reaction zone and hot combustion products. However, the OH signal can be used as a reaction progress variable for a specific performance metric and also in general to gain insight into the combustion dynamics of supersonic combustors [14–17].

2. Experimental apparatus

2.1. Facility

The direct-connect supersonic combustion facility at AFRL [18–20] is continuously supplied with clean air up to 13.6 kg/s at 5.2 MPa and 920 K total pressure and temperature. A hydrocarbon-fueled vitiator can further heat the supply air to 2500 K. The entire combustor is mounted on a thrust stand to measure thrust. In addition the facility is instrumented with multiple pressure taps and thermocouples for evaluating combustor performance. Combustor run times are typically 30 s to limit heat load to certain combustor components. For this study a 2D Mach-2.84 facility nozzle and a distortion generator [21] were installed to simulate an engine at Mach-5.5 flight speed. The air was supplied at 4.2 kg/s and had stagnation conditions of 1388 K and 1.7 MPa.

Within the combustor a flameholding cavity on the *body* (top) *side* is recessed from the surface with a 90° upstream facing step and a 22.5° trailing edge ramp (see Fig. 1). The cavity has a depth of 2.2 cm. and a length of 7.1 cm. Fuel-injection ports are placed upstream and downstream of the cavity as well as on the *cowl* (bottom) *side* of the combustor at the cavity. B1 and B2 denote

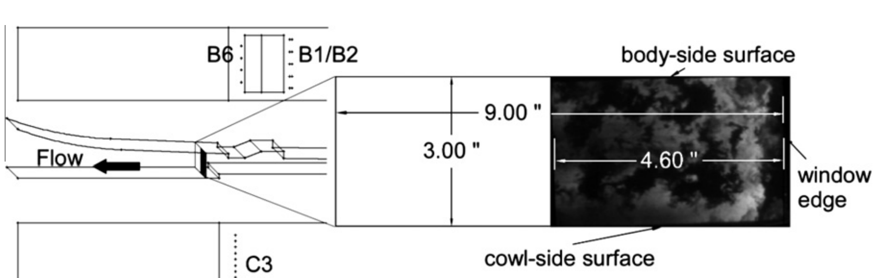

Fig. 1. Combustor geometry showing image plane. Image is taken from run A.