Experimental Thermal and Fluid Science 35 (2011) 265–271

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

journal homepage: www.elsevier.com/locate/etfs

Propulsive performance of a liquid kerosene/oxygen pulse detonation rocket engine

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ARTICLE INFO

Article history:
Received 11 June 2010
Received in revised form 25 September 2010
Accepted 29 September 2010

Keywords:
Pulse detonation
Specific impulse
Fill fraction
Frequency
Kerosene

ABSTRACT

Thrust and specific impulse are two critical parameters to estimate the performance of rocket engine. Utilizing liquid kerosene as the fuel, oxygen as oxidizer and nitrogen as purge gas, a series of multi-cycle detonation experiments were conducted to systemically investigate the relationships among the operating frequency, fill fraction and performance parameters of the pulse detonation rocket engine (PDRE). The operating frequency of PDRE was up to 49 Hz. The mass flow of liquid kerosene was measured by orifice meter and the mass flow of oxygen was measured based on the method of gas collection. The detonation chamber pressure traces were recorded by dynamic piezoelectric pressure transducers. A dynamic piezoelectric thrust transducer was used to record the instantaneous thrust produced by PDRE. Average thrust and detonative mixture-based specific impulse of PDRE with different operation frequency were obtained by experiments. The experimental results indicate that in the practical operation, the operating frequency caused the change of fill fraction, which resulted in a thrust enhancement. Due to the effect of fill fraction, average thrust did not linearly increase as the frequency rises. Fill fraction has a significant influence on the specific impulse of PDRE. The detonative mixture-based specific impulse presented a second order exponential decay with fill fraction, and was correspondingly increased with the raise of the operating frequency. With the strategy of partial filling in detonation tube, the specific impulse can be remarkably enhanced.

1. Introduction

The pulse detonation engine (PDE) [1,2] is a new-concept propulsion system utilizing repetitive detonations to produce thrust or power. It differs from conventional systems in two major ways: unsteady operation and detonation combustion. Currently, PDE is considered for both air-breathing and pulse detonation rocket engine (PDRE) applications. Compared with the conventional rocket engine based on constant pressure combustion, PDRE has its potential advantage in thermodynamic cycle efficiency. Furthermore, since the propellants are injected into a PDRE detonation chamber at relatively low pressures, the need for massive turbo-machinery is eliminated. Hence, PDRE is potentially a simple and efficient alternative to today's conventional rocket engine. Currently, many studies dealing with PDRE have been carried out in several countries including China, Japan and France, in addition to USA [3].

The basic PDRE cycle consists of the following processes: (a) filling a fuel–oxidizer mixture, (b) initiating the detonation, (c) propagating the detonation, (d) exhausting the burned gas through a blow-down process, and (e) the purging process that ejects the burned gas and cools of the hot chamber by charging some amount of cold buffer gas to prevent pre-ignition of fresh fuel–oxidizer mixture in the next cycle. When the purging process ends, the injection valve of purge gas is closed immediately; the injection valve of fuel–oxidizer mixture is opened again, and the next cycle begins. Thrust and specific impulse are two important parameters to estimate the performance of rocket engine. Theoretically, the average thrust lineally increases as the frequency rises, for a given PDRE [4]. Hence, great efforts [5] have been paid to improve the operating frequency of PDRE.

The previous studies have shown that fill fraction (*ff*) also has a great influence on the performance of PDRE. Here, fill fraction refers to the ratio of the detonation tube volume initially filled with a detonable mixture to the total tube volume. At fill fraction less than 1.0, only part of the tube is filled with fresh reactants while the remainder occupied by either a purge gas or hot expanded products from the previous cycle. At the fill fraction of 1.0, the detonation travels through the entire tube and exits through the open end with its full strength. As the detonation exits the tube, a sizable portion of the converted chemical energy in the high-pressure region traveling along with the detonation is lost. Thrust enhancement by partial filling has been extensively numerically discussed in the literature [6–9]. The experimental studies [10,11] also show that partial fuel-filling can improve the efficient use of energy released from the detonation process and enhance thrust and specific impulse of PDE. However, the fuels used by both Zitoun and Desborders [10] and Cooper and Shepherd [11] were

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doi:10.1016/j.expthermflusci.2010.09.014