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Experimental study of an air-breathing pulse detonation engine ejector

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ABSTRACT

Experimental studies were performed in order to improve the understanding of the performance of ejector driven by an air-breathing pulse detonation engine (PDE) with a convergent nozzle. This research utilized a gasoline-air PDE at four different operating frequencies of 8 Hz, 10 Hz, 12 Hz and 15 Hz. The performance of PDE-ejector was quantified by thrust measurements. The effects of single ejector length and axial location on thrust augmentation were investigated. It was found that the single ejector with L/D of 2 showed the best performance and the maximum thrust augmentation occurred at a downstream placement of +1 tube diameter. The performances of two-stage and three-stage ejectors were also investigated. The results indicated that both the overlap ratio and the flow area between two stages should not be too large. The performance of the two-stage ejector was not as sensitive as single-stage ejector to axial position in current conditions. The three-stage ejector behaved better than the two-stage ejector but worse than the single-stage ejector in this work. A maximum thrust augmentation of 1.8 was obtained with an L/D of 2 at a downstream placement of +1 position and 15 Hz operating frequency.

1. Introduction

Pulse detonation engine (PDE) is a new propulsion technology that obtains thrust from the intermittent detonation wave. PDE has the potential to operate with a higher efficiency, reduced complexity, and lower operational costs compared to conventional propulsion devices such as gas turbines [1]. A great deal of attention has been devoted to the study of PDE over the recent years [2–5]. As a propulsion device, the thrust of PDE is a very important parameter [6–10]. One of the challenges is how to make use of the tremendous energy completely from the detonation wave. Ejector has been recognized as an effective way of extracting the energy from detonation wave and enhancing the system thrust. In general, ejector is placed around the exhaust of an engine and performs as a fluidic pump. The surrounding ambient air is entrained by the primary exhaust flow and directed into the ejector. This entrainment causes an increase in momentum of the engine exhaust flow and a larger system thrust. The theory and application of steady-flow ejectors are well established. The use of ejectors, however, to unsteady-flow is less common. The mechanism of these two kinds of ejectors is different. Lockwood [11] showed that the steady ejectors relied primarily on viscous shear mixing while the unsteady ejectors mostly depended on energy transfer process between the primary flow and the secondary flow through inviscous process which is more efficient than the process of viscous shear mixing. In fact, some analytical studies have indicated that the best performance for unsteady ejectors can be attained for relatively short ejector lengths with a fluid pulse that is of high momentum, low mass and short duration [11]. Since these characteristics are basically coincident with the unsteady nature of PDE, ejectors could be highly effective in increasing the performance of PDE.

Many experimental studies have been performed on the effects of PDE operating parameters as well as on ejector geometric parameters [12–20]. PDE parameters include fill-fraction, operating frequency while ejector geometric parameters comprise ejector length, inlet geometric, inner diameter, axial position of ejector and so on. Allgood et al. [13] made a good summary of those relevant literatures in his paper. The opinions of researchers are not unanimous, however. For example, there is no disagreement that the ejector should be properly rounded or contoured because it is an aerodynamic surface which guides the entrainment of the surrounding mass flow. As for the axial placement of the ejector, however, the conclusions are even contrary. Some people showed an optimum ejector performance with an upstream placement [18] while someone pointed out that a downstream placement could enhance ejector performance [13,14]. These different conclusions showed that the ejector is sensitive to its especial working environment and its own configuration. It should be mentioned that all of these PDEs worked as rockets in these PDE-ejector systems. That is to say, one end of the PDE is closed and it is so-called pulse detonation rocket engine. (PDRE) There are no published reports of ejector driven by air-breathing pulse detonation engine (air-breathing PDE) recently. Since the working of PDRE and PDE

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