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ORIGINAL ARTICLE

Comparative performance analysis of combined-cycle pulse detonation turbofan engines (PDTEs)

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Abstract Combined-cycle pulse detonation engines are promising contenders for hypersonic propulsion systems. In the present study, design and propulsive performance analysis of combined-cycle pulse detonation turbofan engines (PDTEs) is presented. Analysis is done with respect to Mach number at two consecutive modes of operation: (1) Combined-cycle PDTE using a pulse detonation afterburner mode (PDA-mode) and (2) combined-cycle PDTE in pulse detonation ramjet engine mode (PDRE-mode). The performance of combined-cycle PDTEs is compared with baseline afterburning turbofan and ramjet engines. The comparison of afterburning modes is done for Mach numbers from 0 to 3 at 15.24 km altitude conditions, while that of pulse detonation ramjet engine (PDRE) is done for Mach 1.5 to Mach 6 at 18.3 km altitude conditions. The analysis shows that the propulsive performance of a turbine engine can be greatly improved by replacing the conventional afterburner with a pulse detonation afterburner (PDA). The PDRE also outperforms its ramjet counterpart at all flight conditions considered herein. The gains obtained are outstanding for both the combined-cycle PDTE modes compared to baseline turbofan and ramjet engines.
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1. Introduction

Pulse detonation engine (PDE) is an air-breathing intermittent combustion engine in which detonations at high frequencies are driven through a tube, simultaneously burning and accelerating the fuel-air mixture to create thrust. PDEs are currently attracting considerable attention because they promise performance improvements over

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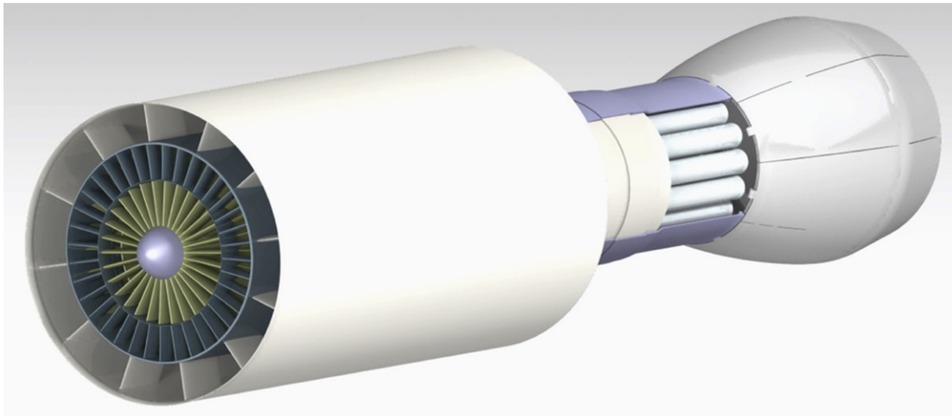

Figure 1 Conceptual model of the combined-cycle PDTE analyzed in this study.

existing air-breathing propulsion devices, especially at low fight Mach numbers [1,2]. During the past 60 years or so, there have been numerous research efforts at harnessing the potential of detonations for propulsion applications [3].

Recently, more advanced concepts have been studied, such as integrated PDEs that use pulsed detonation combustor (PDC) incorporated into a gas-turbine engine as the primary combustion system, with the intention of increasing efficiency by utilizing the strengths of both engines [4]. The studies about integrated PDEs have also been related to the performance analysis of gas-turbine engine with a pulse detonation afterburner (PDA), in which PDA is integrated into a baseline gas-turbine, hence, replacing the conventional deflagration afterburners [5,6]. It was shown that the pulse detonation turbofan engine (PDTE) concept would have superior performance for an operating frequency of 100 Hz and higher compared to the conventional afterburning turbofan engine. Another concept suggested the embodiment of PDC into the bypass duct of turbofan engines for thrust augmentation in place of afterburners [7]. In these studies, integrated PDEs have shown possibilities of obtaining a more efficient engine by the replacements of conventional core combustor and afterburner with PDC [8].

The embodiment of PDE into combined-cycle turbojet engines that can operate in variable operation modes enabling aircrafts to fly at wider ranges of speeds, altitudes and environmental conditions was the subject of a series of recent studies by Johnson et al. [9–11]. At conceptual level, the combined-cycle PDTE is a combination of two or more modes of operation, where a PDE is embodied into a baseline turbofan/turbojet engine. So far, studies related to the combined-cycle PDTEs have mostly been limited to conceptual levels only. In spite of the progress made to date, there still remains a major concern about the propulsive performance of combined-cycle PDTEs, especially in comparison with such well-established propulsion systems as ramjet and gas-turbine engines.

The objective of the present study is to research combined-cycle PDTE configurations, explain their operating principle and analyze the performance of an ideal combined-cycle PDTE at each mode of operation. The combined-cycle engine in this study uses a PDC embodied downstream of the mixer as an afterburner in the turbofan engine, and an auxiliary ram duct for direct ram air intake (Figure 1). The following performance comparisons are made for each combined-cycle engine operation modes to the baseline configurations:

(1) Performance comparison of baseline turbofan engine (with conventional afterburner) to the combined-cycle PDTE in PDA-mode where the PDC is used as afterburner for thrust augmentation.
(2) Performance comparison of baseline ramjet engine to the combined-cycle PDTE in pulse detonation ramjet engine mode (PDRE-mode) where the PDC operates directly on ram air.

The choice of gas-turbine engine in this study is a high bypass turbofan engine.

For flight operations from takeoff to approximately Mach 3, the main engine and an engine fan system provide airflow at a pressure and quantity used by the PDA for thrust augmentation. To maintain flight operations from supersonic speeds to hypersonic speeds of nearly 6, the core engine system is shut-down and ram air is introduced directly into the PDC by utilizing an auxiliary ram duct.

Pursuing the combined-cycle PDTE concept only makes sense if the comparison demonstrates comparative propulsive performance benefits. The present study provides a method for comparison of the performance of combined-cycle PDTE concept with conventional ramjet-based combined-cycle concept, i.e., the combined-cycle turbo-ramjet engine. The goal of this comparison is to show the prospects of combined-cycle PDTE for future applications in hypersonic, as well as in the initial phases of single-stage-to-orbit (SSTO) flights.

2. Combined-cycle PDTE design concepts

The combined-cycle PDTE concepts explore the alternative use of PDC as afterburner for thrust augmentation in

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