Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 29 (2018) 279–288

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th CEAS AIR & SPACE CONFERENCE AEROSPACE EUROPE 2017, CEAS 2017, 16-20 October 2017, Bucharest, Romania

A preliminary heat transfer analysis of pulse detonation engines

Berke Olcucuoglu[a], Bayindir H. Saracoglu[b,*]

[a]*Graduate student, von Karman Institute for Fluid Dynamics, Chaussee de Waterloo, 72, Rhode-Saint-Genese B-1640, Belgium*
[b]*Senior research engineer, von Karman Institute for Fluid Dynamics, Chaussee de Waterloo, 72, Rhode-Saint-Genese B-1640, Belgium*

Abstract

Detonation engines offer higher theoretical thermal efficiencies as compared to their deflagration-based counterparts. Simultaneous pressure gain during heat addition through the detonation wave provides the superiority to the Zeldovich-von Neumann-Dring (ZND) cycle which is used to define the thermodynamic process of detonation engines. Combustion temperatures can rise as high as 3000 K across the detonation wave. The continuous exposure to such elevated temperature may risk the integrity of the structural components of the engines. Consequently, heat management of the detonation engines highlights an important parameter on the construction of a demonstrator. In order to be able to design an appropriate cooling system, both for pulse detonation and rotating detonation engines (PDE & RDE), an accurate estimation of the heat load stands as an essential prerequisite. Hence, a preliminary numerical study of the heat transfer on a pulse detonation engine model was conducted to quantify the heat load. Conservation equations for deflagration-to-detonation transition (DDT) in detonation engines were solved through open source fluid dynamics solver OpenFOAM equipped with ddtFoam module. Reactive flow field of premixed mixtures (Hydrogen-air) was modeled with a URANS second-order approximate Riemann solver equipped with Weller combustion model, and Arrhenius equations of O'Connaire reaction scheme for Hydrogen-air detonation. Multiple boundary conditions were tested to achieve the most appropriate model. Natural convection over the lateral combustor peripheries found to be the most realistic boundary condition for the problem. In order to observe cooling process better, PDE tubes in different length were also simulated. Finally, the transient heat transfer phenomenon across the pulse detonation tube is documented for various conditions investigated.

Keywords: Detonation engine; heat transfer; pulse detonation; OpenFOAM; combustion

---

1. Introduction

Detonation engines are one of the most attractive propulsion systems in the 21th century due to their higher theoretical thermal efficiency and specific impulse compared to deflagration engines. Based on their frequencies, these systems are classified into two main categories; pulse (PDE) and rotating detonation engines (RDE). Differing from

---

* Corresponding author. Tel.: +32-2-359-96-53 ; fax: +32-2-359-96-00.
E-mail address: saracog@vki.ac.be

2352-1465 © 2018 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the 6th CEAS Air & Space Conference Aerospace Europe 2017.
10.1016/j.trpro.2018.02.025

periodically ignited PDEs, RDEs work with much higher frequencies thanks to continuously rotating detonation shock or shocks.

Nomenclature

c	reaction progress variable
D	diffusion coefficient
$\mathrm{f_b}$	body forces
G	flame quenching factor
$\mathrm{h_t}$	total enthalpy
k	thermal conductivity
p	pressure
q	heat flux
R	specific gas constant
$\mathrm{s_L}$	laminar flame speed
$\mathrm{s_T}$	turbulent flame speed
$\mathrm{T_w}$	wall temperature
$\mathrm{T_\infty}$	ambient temperature
t	time
$\mathrm{t_{ign}}$	auto-ignition delay time
V	velocity
ξ	flame wrinkling factor
λ	heat transfer coefficient
ρ	density
ρ_u	unburnt density
σ	deviatoric component of total stress tensor
τ	dimensionless auto-ignition time
ω_c	source term for reaction progress variable
$\omega_{c,ign}$	ignition source term for reaction progress variable
$\omega_{c,T}$	turbulent source term for reaction progress variable
ω_τ	source term for dimensionless auto-ignition time

The main principle behind the detonation engines is Zeldovich-von Neumann-Dring (ZND) process, which assumes that the detonation shock is frozen and fluid flows through the shock with an immediate escalation of pressure and temperature (Vutthivihayarak et al. (2012)). The relevant model is illustrated on Fig. 1 (Braun (2015)). Throughout detonation, flame speed is constant and named as Chapman-Jouget (CJ) speed. This is known as Chapman-Jouget principle, basis of detonation theory.

Since the middle of the last century, analyses on detonation engines have been being performed either experimentally or numerically and gained speed throughout 21st century. Earlier measurements of thrust, hydrogen (fuel) flow, air flow and temperature for intermittent detonation shocks was made by Nicholls, Wilkinson and Morrison (Nicholls et al. (1957)). Experiments on ZND cycle proved that detonation engines are 6-7% more efficient than traditional combustors (Frolov et al. (2014)). Paxson et al. performed experiments and numerical simulations for determination of heat transfer from PDE and compared the results (Paxson et al. (2011)). Apart from hydrogen-air mixture, numerical simulations for PDE filled with octane-air mixture and comparisons with experimental results were performed to compute heat fluxes from PDE (Fan et al. (2003)). Also, experiments on heat losses from RDEs performed under unsteady heating shows maximum heat losses occurs from the mixing region and number of detonation shocks affects heat transfer (Bykovskii et al. (2009)). Frolov et al. developed a numerical tool which simulates operation process of RDEs to determine design parameters for combustion chamber and isolators (Frolov et al. (2013)). Numerical analyses on heat loss from detonation engines performed by open-source and packaged softwares (Randall et al. (2015) and Roy et al. (2016)).