Combustion and Flame 170 (2016) 63–78

Contents lists available at ScienceDirect

Combustion and Flame

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

Large-eddy simulations of gas- and liquid-fueled combustion instabilities in back-step flows

Tomoaki Kitano, Keisuke Kaneko, Ryoichi Kurose*, Satoru Komori

Department of Mechanical Engineering and Science, and Advanced Research Institute of Fluid Science and Engineering, Kyoto University, Kyoto daigaku-Katsura, Nishikyo-ku, Kyoto 615-8540, Japan

ARTICLE INFO

Article history:
Received 24 November 2015
Revised 5 May 2016
Accepted 5 May 2016
Available online 30 May 2016

Keywords:
Combustion instability
Spray combustion
Droplet evaporation
LES

ABSTRACT

LES of gas and spray combustion in back-step flows are performed to investigate the mechanism underlying combustion instability and the effect of initial droplet diameter on combustion instability. Methane and kerosene are used as fuel for gas and spray combustion, respectively, and two-step global reaction models are used for the reactions. A dynamic thickened flame model is employed as the turbulent combustion model. The motions of evaporating droplets are tracked using the Lagrangian manner. The results show that in gas combustion, the pressure, heat release rate and streamwise velocity oscillate with the same frequency but different phases, and that the inlet velocity oscillation periodically generates a large vortex near the dump plane that drives combustion instability. In spray combustion, an oscillation of droplet evaporation rate is also observed. Whereas the difference in the initial droplet diameter slightly affects the mode of the pressure oscillation, it strongly affects the intensity of the pressure oscillation and causes a maximum value for a specific initial droplet diameter. This arises from the difference in the initial droplet diameter causing a difference in the droplet evaporation rate, which alters the relationship between the oscillations of the heat release rate and pressure near the dump plane.

1. Introduction

To solve global problems such as environmental protection and energy security, it is necessary to reduce CO_2 and NOx emitted from industrial devices such as gas turbine engines and diesel engines for energy-conversion and propulsion devices. To optimally design and operate such industrial devices, a precise prediction of the combustion behavior is essential. However, as combustion is a complex phenomenon, the predictions of combustion flow behavior have been based on an engineer's expertise and a reliable predictive analysis has yet to be developed. In particular, spray combustion is a complex phenomenon in which liquid fuel is used and the dispersion of the liquid spray fuel, its evaporation, and the combustion reaction of the evaporated fuel with the oxidizer take place interactively at the same time. Hence, the underlying physics governing these processes has not been well understood [e.g., 1–12].

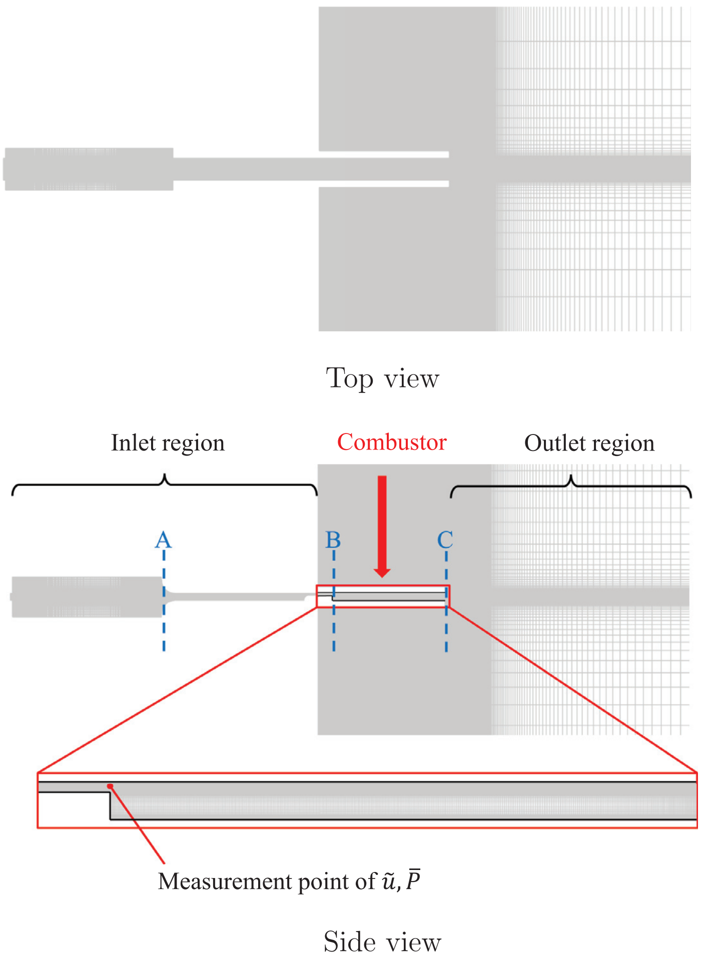
One of the most important issues of combustion research is the prediction and suppression of combustion instability, which induces flashback [e.g., 13–15], generates combustion noise [e.g., 16,17] and damages combustor [e.g., 18]. A number of studies have been performed, however, the mechanism underlying combustion instability has yet to be adequately clarified [e.g., 19–23].

For combustion instability in gas combustion, many numerical simulations have been performed. For example, Sato et al. [24] performed LES of combustion instability caused by acoustically forced inlet flow. They compared their results with experimentally measured data and showed that the LES was able to predict the flame response to the forcing. Wolf et al. [25] numerically analyzed combustion instability in an annular combustion chamber using LES and an acoustic solver. They showed that the LES was able to predict an azimuthal mode of combustion instability. Moreover, it was suggested that a reduction of the time delay of the flame transfer function stabilized the mode. Franzelli et al. [23] developed a two-step global reaction model of methane that precisely predicts the flame temperature and laminar burning velocity for various conditions. With the reaction model, they performed LES of combustion instability in a laboratory-scale combustor, and investigated the effects of mixing of air and fuel on combustion instability. They showed that the insufficient mixing was probably the source of the unstable mode observed in the simulation.

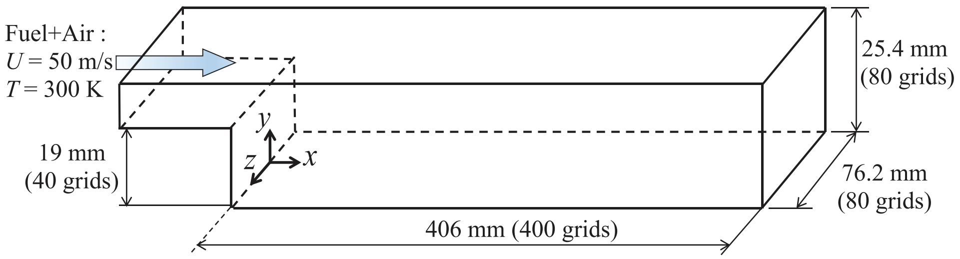
---

* Corresponding author.
E-mail address: kurose@mech.kyoto-u.ac.jp (R. Kurose).

http://dx.doi.org/10.1016/j.combustflame.2016.05.005
0010-2180/© 2016 The Combustion Institute. Published by Elsevier Inc. All rights reserved.



(a) Grid



(b) Conditions

Fig. 1. Computational grid and conditions (Gas combustion).

For combustion instability in spray combustion, in contrast, the number of previous studies is very small. Most recently, Tachibana et al. [26] were the first to perform LES of combustion instability in spray combustion and showed that the LES could accurately reproduce combustion instability observed in the experiment. Also, they elucidated the phase relationship between the fluctuations in pressure, velocity, droplet evaporation rate and heat release rate, and then the physical route to generating heat release oscillations from the pressure oscillations. However, the LES was performed under the single condition, and the effects of differences in the combustion conditions on combustion instability were not discussed.

In this study, LES of gas and spray combustion in back-step flows are performed. Methane and kerosene are used as the fuel for gas and spray combustion, respectively, and two-step global reaction models [23,27] are used for the reactions. A dynamic thickened flame model is employed as the turbulent combustion model [28,29]. The motions of evaporating droplets are tracked using the Lagrangian manner. In regard to the LES of gas combustion, the present LES code is validated by comparing the results with the previous experiment [19] and then the behavior of combustion instability is investigated in detail. Regarding the LES of spray combustion, the effect of initial fuel droplet diameter on combustion instability is examined in the virtual back-step combustor