LARGE-EDDY SIMULATION OF COMBUSTION INSTABILITY IN A BACK-STEP FLOW

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Abstract A large-eddy simulation of combustion instability in a back-step flow is performed, and the effect of equivalent ratio on the combustion instability is investigated. Methane is used as the fuel and a two-step global reaction model is used for the reaction. As the turbulent combustion model, a dynamic thickened flame model is used. The results show that flame is stably formed behind the step by the recirculation flow. Large pressure oscillation and periodical change of flame shape are observed in the case of equivalent ratio of 1.0, and the power spectra of the pressure oscillation has peaks whose frequencies and intensities well agree with those of the previous experimental study. The intensity of the pressure oscillation becomes much smaller in the cases of equivalent ratio of 0.8 and 1.3, and the change of flame shape also becomes smaller.

BACKGROUND AND NUMERICAL SIMULATION

To solve global problems such as environmental protection and energy security, it is necessary to reduce CO_2 and NOx emitted from industrial devises such as gas turbine engine and diesel engine for energy conversion and propulsion devises. In order to optimally design and operate such industrial devises, precise prediction of the combustion behavior is essential. However, since combustion is a complex phenomenon, the prediction of the combusting flow behavior has been based on the engineers' experiences. One of the most important challenges in combustion researches is the prediction and suppression of combustion instability [5]. In spite of a large number of studies, however, the mechanism of the combustion instability has not been well clarified yet [2, 9, 10]. In this study, a large-eddy simulation (LES) of combustion instability in a back-step flow is performed, and the effect of equivalent ratio on the combustion instability is investigated.

The governing equations for LES with Arrhenius formulation are the conservation equations of mass, momentum, energy and chemical species mass. The SGS terms are calculated by the dynamic Smagorinsky model [6, 8]. Methane (CH_4) is used as the fuel. As the reaction model, a two-step global reaction model which incorporates a dynamic thickened flame model as the turbulent combustion model [1, 4] is used. The computational domain and conditions are the same as the previous experiment [9]. The computational domain is a combustor in which flame is held by a step, and premixed gas of fuel (CH_4) and air is injected form the inlet. Initial gas temperature and pressure are 300 K and 0.1 MPa, respectively, and the equivalent ratio, ϕ, is changed from 0.8 to 1.3. As the computational grid, a non-uniform structural staggered grid is used, and the total grid number is about 10 millin. The pressure perturbation is captured by employing a pressure-based semi-implicit algorithm for compressible flows [3, 7].

RESULTS AND DISCUSSION

Fig. 1 shows the distributions of instantaneous streamwise velocity and iso-surface of temperature at 1600 K in the case of ϕ=1.0. It is found that recirculation region is formed behind the step, and flame is stably formed. In the combustion filed, periodic oscillations of pressure, streamwise velocity and reaction rate which have the amplitude of 8, 30 and 50%, respectively, were observed. The amplitude of the pressure oscillation at each streamwise position of the combustor indicated that the dominant mode of the oscillation was 1/4 mode of the combustor length.

Fig. 2 shows the spectra of the pressure oscillation in the case of ϕ=1.0. In this figure, the red line indicates the spectra obtained in the previous experiment [9]. It is found that the spectra has peaks at around 500 Hz, and the values of frequencies and intensities well agree with those of the previous experiment [9]. From this agreement, it is conformed that the present LES captured the combustion instability accurately.

Fig. 3 shows the effect of equivalent ratio on the intensity of the pressure oscillation. It is observed that the intensity in the case of ϕ=1.0 is much higher than those in the cases of ϕ=0.8 and 1.3. This reason is considered that the heat release rates in the cases of ϕ=0.8 and 1.3 are smaller than that in the case of ϕ=1.0, and driving force of combustion instability becomes smaller.

Fig. 4 shows the instantaneous temperature distributions at each time step in the cases of (a) ϕ=1.0 and (b) ϕ=0.8. The figures of upper and lower side show the bottom ($\theta = \frac{3}{2}\pi$) and top ($\theta = \frac{5}{2}\pi$) of the pressure oscillation, respectively. It is found that the flame shape is different between the bottom and top of the pressure oscillation in the case of ϕ=1.0. This is due to the fact that the inlet velocity changes with the pressure oscillation, and large vortices whose frequency corresponds to that of the pressure oscillation are generated.On the other hand, the notable difference is not seen in the case of ϕ=0.8. This is due to the fact that the intensities of pressure oscillation in the case of ϕ=0.8 is much smaller than that in the case of ϕ=1.0 as shown in Fig. 3, and streamwise velocity oscillation also becomes smaller .

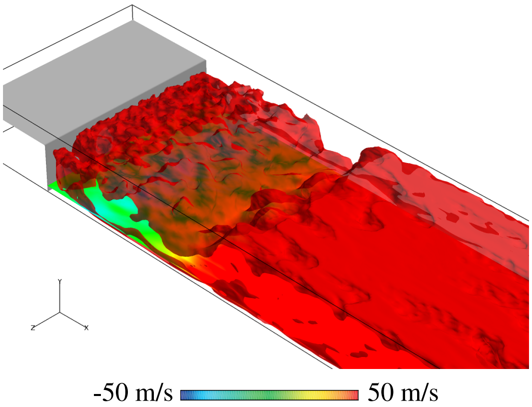


Figure 1. Instantaneous streamwise velocity and iso-surface of gas temperature at 1600 K in case of ϕ=1.0.

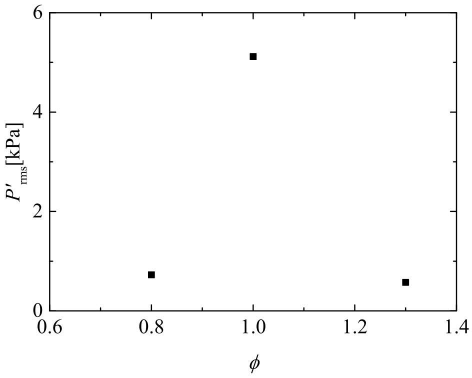


Figure 3. Effect of equivalent ratio on intensity of pressure oscillation.

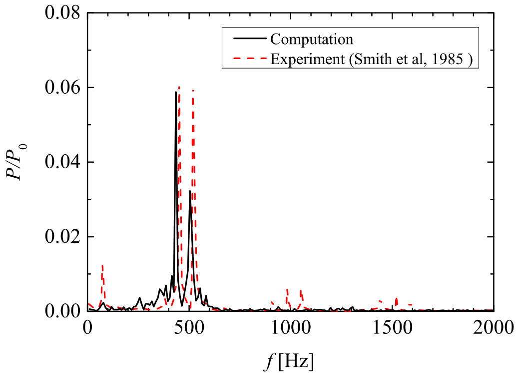
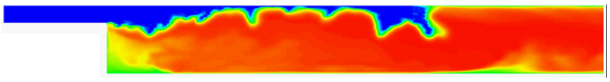
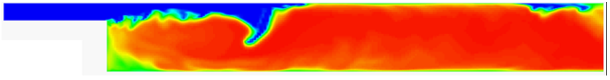


Figure 2. Spectra of pressure perturbation in case of ϕ=1.0. (Red line indicates the peak frequencies obtained in the previous experiment [9].)

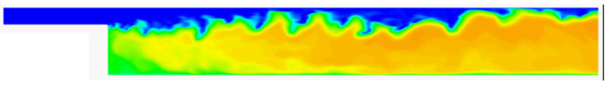


Bottom of pressure oscillation ($\theta = \frac{3}{2}\pi$)

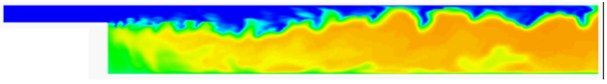


Top of pressure oscillation ($\theta = \frac{5}{2}\pi$)

(a) ϕ=1.0



Bottom of pressure oscillation ($\theta = \frac{3}{2}\pi$)



Top of pressure oscillation ($\theta = \frac{5}{2}\pi$)

(b) ϕ=0.8

Figure 4. Instantaneous temperature distributions at top and bottom of pressure oscillation in cases of ϕ=1.0 and 0.8.

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