MODELING OF A PILOTED PREMIXED JET BURNER USING LARGE-EDDY SIMULATION

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Summary A three-stream flamelet/progress variable model was applied to large-eddy simulation of the Sydney piloted premixed jet burner. This combustion model was extended to accommodate effects of heat-losses that are observed between pilot and coflow streams. Comparisons with experimental results showed that the model adequately predicts the temperature and major species in the region that is controlled by the interaction between the pilot and the fuel-stream. However, with increasing downstream distance, the model overpredicts the reactivity and shows a reduced sensitivity to changes in operating conditions.

INTRODUCTION

The implementation of partially premixed combustion technologies in modern gas turbine engines has the promise of reducing pollutant emissions and increasing overall combustor performance. However, partially premixed combustion is receptive to combustion instabilities, which results in flame flash-back, lift-off, and blow-out. The successful implementation of partially premixed combustion technologies in practical systems requires a thorough understanding of the underlying combustion-physical phenomena, which remains challenging. Of interest to the current study is the Sydney piloted premixed jet burner (PPJB) that was investigated by Dunn et al. [1]. This burner configuration was designed with the objective to resemble conditions relevant to partially premixed gas turbine combustors, but without the additional complexity of swirl and recirculation. In this burner, a central jet of a fuel-lean methane/air mixture is stabilized by a pilot-stream. The burner is embedded in an outer coflow of hot reaction products that are generated by combusting a lean hydrogen/air mixture. The objective of this work is to assess the capability of a flamelet-based LES combustion model to predict this piloted premixed jet burner. To this end, a three-stream flamelet-progress variable (FPV) formulation is employed. This model has been successfully applied to the simulation of partially-premixed and kinetics-controlled combustion configurations [2].

MATHEMATICAL FORMULATION

In this study, a three-stream flamelet-progress variable (FPV) method is used. The main idea of this method is the representation of a turbulent flame in terms of a set of laminar flamelet-structures using the steady-flamelet equations. To characterize the compositional variations that are associated with the three stream, an so-called oxidizer-split W is introduced. This scalar is independent from the mixture fraction, and only controls the progress of mixing in the oxidizer streams. In addition, a progress variable C is introduced to characterize the progress of reaction. The interaction between turbulence and chemistry is modeled through a presumed probability density function.

NUMERICAL CONFIGURATION

The simulation domain is an cylindrical domain, having a diameter of 40 D_{ref} and a length of 60 D_{ref}. The computational grid consists of 256 grid points in axial direction, 180 grid points in radial direction, and 64 grid points in azimuthal direction. The inlet velocity profiles of the central jet is that of a turbulent jet flow. The velocity profiles for the pilot and the coflow are laminar tanh profiles. In this study we focus on the cases PM1-100 and PM1-150, which only differ by the value of the jet exit velocity of 100 m/s and 150 m/s, respectively.

RESULTS

Figures 1(a) and (b) compare the instantaneous temperature (left) and average temperature fields (right) for the cases PM1-100 and PM1-150. The temperature contours have been rescaled to emphasize the upper part of the flame. For the PM1-100 case, it can be seen that the height of the pilot extends up to approximately $x/D_{ref} = 7.5$. Beyond this location, the oxygen-rich coflow is entrained into the flame. For the case PM1-150 the height of the pilot recesses, which can be attribute to larger entrainment due to the high jet-exit velocity. It is also interesting to note that the flame-brush for PM1-150 is narrower compared to its low-speed counterpart. From the instantaneous temperature field the presence of localized extinction events around $x/D_{ref} = 7.5$ can be observed. Extinction is not observed for the PM1-100 case. With increasing downstream distance, the flame recovers but the flame temperature at $x/D_{ref} = 20$ remains approximately 150 K lower than that of the PM1-100 case.

Statistical results for temperature and major and minor species along the first three measurement stations are presented in Fig. 1(c). In this figure, measurements are shown by symbols and simulations are presented by lines. The mean and rms temperature profiles are presented in the first two columns. Overall, the simulations are in reasonable agreement with the measurements for PM1-100. The first measurement location intersects the pilot stream, which is evident by the fairly

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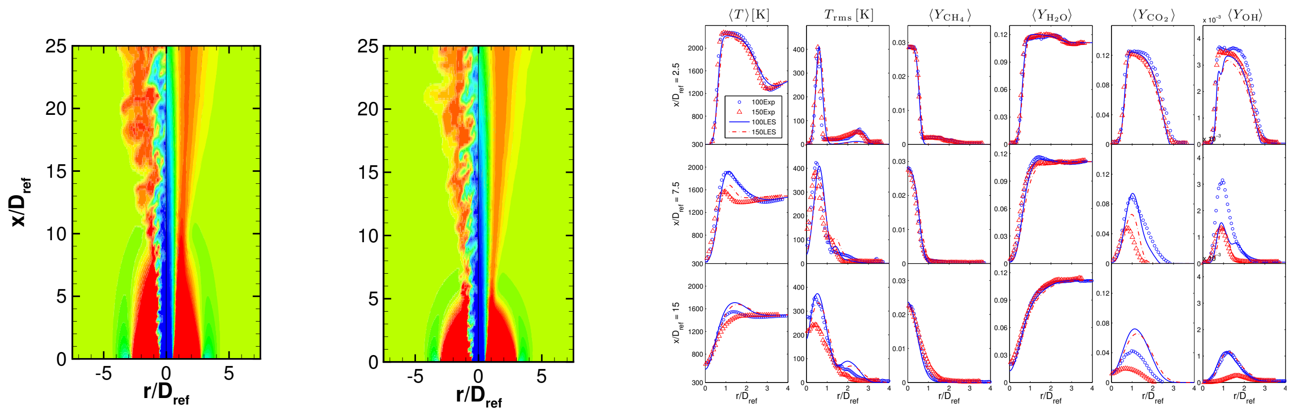

(a) PM1-100. (b) PM1-150. (c) PM1-150.

Figure 1. LES results for (a) PM1-100 and (b) PM1-150 PPJB-cases, showing instantaneous temperature field (left) and mean temperature field (right); (c) comparison of statistical results.

homogeneous temperature profile between $1 \leq r/D_{ref} \leq 2$. A comparison of the results at $x/D_{ref} = 15$ shows that the simulation overpredicts the mean temperature by approximately 150 K. Predictions for the temperature fluctuations, shown in the second column, are in good agreement with the measurements. At the first measurement station, small temperature fluctuations at $r/D_{ref} = 3$ can be seen. This region corresponds to the location at which the pilot mixes with the coflow. This suggests that local unsteadiness due to the interaction between the hot pilot-stream with the colder coflow is present. Results of major species mass fractions of CH_4, H_2O, and CO_2 are shown in columns 3–5. It can be seen that the predicted CH_4-mass fraction is in good agreement with the experiments, and exhibits modest sensitivity to the different operating conditions. Small amount of CH_4 is found in the inner part of the pilot for the measurements, suggesting incomplete combustion in the pilot stream. The pilot is a burned stoichiometric mixture and therefore no excess reactant is expected to be present in this stream. This unburned CH_4 in the pilot is rapidly consumed before $x/D_{ref} = 7.5$. The predicted water mass fraction, shown in the fourth column, is in good agreement with experiments. At $x/D_{ref} = 2.5$ we see a slightly higher H_2O mass fraction. The predicted CO_2 mass fraction at the first measurement station is in good agreement for both cases. The measurements show a significantly lower CO_2 formation for PM1-150 above $x/D_{ref} = 2.5$. While this effect is captured at $x/D_{ref} = 7.5$, the model overpredicts the reactivity at further downstream locations. This is an indicator that the predicted reaction progress is faster than observed in the experiment. Similar findings have been made in Ref. [3]. Comparisons for the mean OH-mass fraction are presented in the last column. The OH-mass fraction for the PM1-100 case is under-predicted, however, a good agreement is obtained for the case PM1-150. The model exhibits little sensitivity at the last reported measurement location.

CONCLUSIONS

A three-stream flamelet/progress variable model was applied to large-eddy simulation of a piloted premixed jet burner (PPJB) that was experimentally investigated by Dunn et al. [1]. This combustion model was extended to accommodate effects of heat-losses that are observed between pilot and coflow streams. Comparisons with experimental results showed that the model adequately predicts the temperature and major species in the region that is controlled by the interaction between the pilot and the fuel-stream. However, with increasing downstream distance, the model overpredicts the reactivity and shows a reduced sensitivity to the operating conditions. In a separate sensitivity analysis it was found that the temperature profiles in the pilot and coflow have a significant effect on the flame in the lower part of the burner, and this effect disappears for the region above $x/D_{ref} = 7.5$. Furthermore, a comparison of the species distribution at the first measurement station shows the presence of residual fuel and excess of radicals in the pilot-stream. By accounting for these effects, improved predictions for species-profiles were obtained.

References

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