11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20–25, 2014, Barcelona, Spain

LARGE-EDDY SIMULATION OF TRANSIENT BEHAVIOR IN A COMBUSTION FIELD FOR GUS-TURBINE ENGINE

Yusuke Takahashi[1], Nobuyuki Oshima[2] and Yasunori Iwai[3]

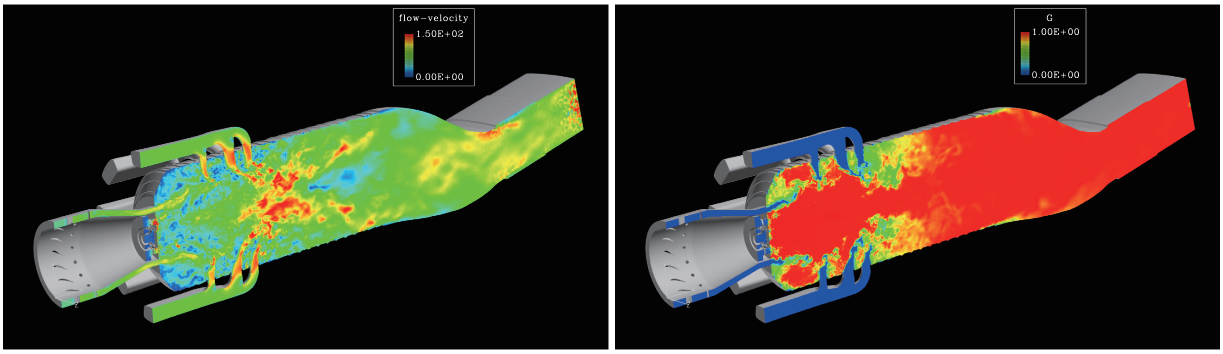
[1] Hokkaido University, Kita 13 Nishi 8, Kita-ku, Sapporo, Hokkaido 060-8628, Japan, ytakahashi@eng.hokudai.ac.jp.
[2] Hokkaido University, Kita 13 Nishi 8, Kita-ku, Sapporo, Hokkaido 060-8628, Japan, oshima@eng.hokudai.ac.jp.
[3] Toshiba Corporation, 2-4, Suehiro-cho, Tsurumi-ku, Yokohama, 230-0045, Japan, yasunori.iwai@toshiba.co.jp

Key words: *Industrial combustor, Large eddy simulation, Flamelet approach.*

In development of combustors such a gas turbine engine, reduction in NO_x emission for environmental problem is strongly demanded by emission regulations with high thermal efficiency. To solve the issues, it is important to clarify detail flow field in the combustor. In recent times, remarkable progress has been made in the development of high-performance computers and algorithms for numerical simulation. Computational fluid dynamics (CFD) technique, in particular, large-eddy simulation (LES), has become a powerful tool for investigating such details of flow field and chemical reactions in addition to transient behavior, e.g., flame extinction and flame holding. Moreover, to resolve flame in combustion field, a flamelet approach is suitable to LES. Because computational cost of the approach becomes low compared with a detailed chemical reaction model and LES can finely capture fluctuation of flow field by turbulence. In the present study, combustion field in an industrial combustor (DLE combustor for 158 MW class gas-turbine produced by Toshiba Corporation) is numerically simulated by the LES and flamelet approaches.

Flow field considered herein is described by LES derived under a low Mach number approximation. Sub-grid scale (SGS) turbulent stress is represented by the standard Smagorinsky model. In the present simulations, the Smagorinsky constant is assumed to 0.1. The molecular viscosity is evaluated by the Sutherland's law. In the flamelet approach, equations of combustion field are composed of an improved G-equation which is proposed by Liu and Oshima [1] and a conservation of scalar (ξ-equation) of the mass and thermal mixture. A partially-premixed flame is expressed by a combination of both scalar functions. Note that the scalar ξ is defined by a normalized enthalpy or the mass fraction of chemical species. Turbulent flame speed is obtained by Daniele's formulation [2]. The present simulations are performed with a software"Frontflow/Red ver. 3.1" for the multi-physics simulation solver developed and distributed by Hokkaido University. The numerical scheme is discretized based on the finite volume method for unstructured grid systems. For advection and viscous terms, the second-order central difference scheme are applied. However, momentum equations of flow field are blended by first-order upwind scheme of 5% to suppress numerical oscillation. For the time integrations, the Crank-Nicolson implicit scheme is adopted. Flamelet data which determines temperature, density, laminar flame speed in combustion field with ξ is evaluated by the chemical reaction analysis using CHEMKIN with the elemental chemical reaction GRI-MECH 3.0 and NASA physical variables.

For the DLE combustor, we fully use tetrahedral unstructured grid. The combustor geometry including the multi brunching main premixed burner, the swirling pilot premixed burners, diffusion sub-burners and cooling slits and holes on the side wall is solved by fine resolutions mesh of 45 million tetrahedral elements and 7.7 million nodes. Figures 1(a) and 1(b) show instantaneous distributions of flow velocity and function G, respectively. It is indicated that a large recirculation zone with flame holding is formed by the swirling pilot and main burners, and turbulent fluctuations of the burners are simulated well. The flame propagation in the recirculating region of swirling burner and the downstream of the main burner reasonably captured. The SGS flame speed is kept low enough level to suppress the flash back of flame in the ducts which becomes often problem in the flamelet approach. This is because of the effect of improved G-equation model with the local flame speed concept. Thus, complicated behavior in the combustor field are clarified with the present combustion model.



(a) Flow velocity. (b) Function G.

Figure 1: Distributions of instantaneous flow properties.

REFERENCES

[1] Y. Liu and N. Oshima. "A new level set approach for a premixed flame based on a new concept of flame speed". *Journal of thermal science and Technology*, 6(1):140–153, 2011.

[2] S. Daniele and P. Jansohn. "Correlations for turbulent flame speed of different syngas mixtures at high pressure and temperature". In *Proceedings of ASME Turbo Expo 2012*, GT2012-69611, Copenhagen, Denmark, June 11-15 2012.