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論文題目： “Direct Numerical Simulation of Near-wall Behavior of Turbulent Premixed Flames”
（乱流予混合火炎の壁面近傍挙動の直接数値計算）

This thesis entitled “Direct Numerical Simulation of Near-wall Behavior of Turbulent Premixed Flames” is composed of five chapters as follows.

In the first chapter, the significance of the combustion technique to the current world energy structure and the current issues related to fossil fuel combustion are discussed. The near-wall flame behaviors and the flame-wall interaction (FWI) phenomenon are introduced with the relevant studies. The significance of the near-wall flame behavior and FWI on the performance of combustion machines are discussed. The challenges and knowledge gaps regarding the relevant studies are elaborated.

In the second chapter, a series of two-dimensional (2-D) direct numerical simulation (DNS) studies of turbulent premixed methane-air combustion in a constant volume vessel (CVV) are conducted with different turbulent intensities and equivalence ratios. A newly developed diagnosis method is introduced to identify the local flame-wall interaction events and near-wall flame quenching positions. And, based on that, the local quenching distance and quenching-induced wall heat flux during the combustion process are defined and calculated. The statistical analysis is carried out to investigate the effect of turbulent intensity and equivalence ratio on the quenching characteristics. In addition, the quenching characteristics under different FWI quenching modes are also investigated. The results suggest that due to the flame-turbulence interaction, the wrinkled flame surface causes the FWI events locally occur at multiple positions near the wall with a wide range of local quenching distances. The local maximum of wall heat flux can be found on the wall where the local flame gets quenched nearby. As indicated by the identified local FWI quenching mode, the flame-wall geometry of the local FWI event shows diversity, and it is connected to the turbulent intensity and equivalence ratio of the combustion. Both local quenching distance and quenching-induced wall heat flux show dependence on the FWI quenching mode.

In the third chapter, a three-dimensional (3-D) DNS of turbulent premixed methane-air combustion in a CVV is conducted with an equivalence ratio of 0.6. The geometric characteristic of the flame surface in the near-wall area is investigated with the principal curvatures. The temporal development of the quenching characteristics and the effect of the quenching mode on the quenching characteristics are studied statistically. The analysis of flame curvatures shows that the flame elements with the curved surface are mostly convex to the unburned gas at the early stage of combustion and change to be convex to the burned gas at the end. The near-wall flame elements mostly show a cylindric shape. Local quenching distance and quenching wall heat flux also show the quenching-mode dependence which is consistent with the 2-D DNS result in the second chapter. For the near-wall turbulent flame in CVV, the statistics of flame-wall distance and wall heat flux conditioned on the fuel consumption speed are close to the results of one-dimensional (1-D) HOQ flame under corresponding thermal conditions.

In the fourth chapter, a 3-D DNS of the turbulent premixed V-shape hydrogen-air flame in the turbulent channel flow is conducted with an equivalence ratio of 1.0. The geometric characteristic of the flame surface in the near-wall area is investigated with the principal curvatures. Then, the local near-wall flame quenching positions and quenching characteristics are identified. The effects of the quenching mode on the quenching characteristics are studied statistically. The strip-like vortexes exist in the turbulent boundary layer along the stream-wise direction, and the vortexes would continuously interact with the near-wall flame and modify the local flame-wall geometric relationship. As a result, the development of local FWI events follows a pattern: the FWI quenching mode is local HOQ when the local flame first reaches the wall and changes to local SWQ, then local BOQ, and switches to HOQ again. This further affects the statistics of the FWI quenching mode of local FWI events. The statistics of flame-wall distance and wall heat flux conditioned on the fuel consumption speed also show different results compared with that of the turbulent flame in CVV.

In the fifth chapter, the main conclusions of each chapter are summarized. The results obtained from the research included in this thesis provide unique physical insights into the near-wall flame behavior and FWI process in the turbulent field. The significant roles of near-wall flame-wall geometry and the turbulence feature of combustions on the FWI characteristics are revealed.