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NUMERICAL SIMULATION OF UNSTEADY NON-EQUILIBRIUM FLOWS OF HYBRID ROCKET IGNITION USING SIZE-OPTIMIZED REACTION MECHANISM

Abstract

The ignition process of hybrid rocket contains various phenomena; such as heat transfer, fuel degradation, diffusive and turbulent mixing of fuel and oxygen, and coupling of flow and unsteady non-equilibrium chemical reaction.

The purpose of this study is to clarify the ignition characteristics of hybrid rocket by numerical simulations.

In general, it is extremely time-consuming to calculate unsteady non-equilibrium reactive flows with a detailed chemical reaction mechanism. It is, therefore, necessary to use a size-optimized chemical reaction mechanism. For this purpose, we have devised a systematic method for the optimal reduction of chemical reaction mechanism of hydrocarbon and oxygen system. In order to conduct such an optimal reduction, we employ the deviation of the chemical-composition time history between the reduced and the detailed reaction mechanism in two reduction processes. The first process is for reducing the number of chemical species, and the second for the elementary reactions. In the second process, we use a preliminary procedure in which sensitivity analyses on the deviation with respect to the reaction rate of each elementary reaction are employed. As the result, for example, for the system of propylene and oxygen, we have succeeded in reducing the number of species to 50 percent and reactions to 25 percent, respectively, from those of the detailed mechanism, without losing accuracy of not greater than 5 percent, for the wide range of conditions such as initial pressure, temperature and mixture ratio.

A two dimensional rectangular region with its lower boundary as fuel surface and the left boundary as the oxygen inflow is considered. The governing equations are the mass conservation equations for 47 species with mass addition/loss source terms, the Navier-Stokes equations, and the energy conservation equation for fluid flows; and the thermal conduction equation for the solid fuel. The fuel gasification rate is evaluated from the energy flux balance at the fuel surface. Initially, all substances are at normal temperature. The fuel is then heated to gasify, for a few seconds, by the injected hot oxygen. From the simulation we obtain the characteristics of the diffusive flame growth and stability during the heating and after the oxidizer cools down. The influences of various parameters, such as the pressure, the heating rate, and the unsteadiness of chemical reactions, are discussed. For example, the chemical reaction unsteadiness is very influential when the fuel is propylene, because propylene decomposes immediately to become unrealistically high temperature with infinite reaction rates.