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# 공동이 있는 수직 분사 초음속 연소기 내의 불안정 연소유동 해석

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# Numerical Analysis of Unstable Combustion Flows in Normal Injection Supersonic Combustor with a Cavity

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## Abstract

A comprehensive numerical study is carried out to investigate for the understanding of the flow evolution and flame development in a supersonic combustor with normal injection of normally injecting hydrogen in airsupersonic flows. The formulation treats the complete conservation equations of mass, momentum, energy, and species concentration for a multi-component chemically reacting system.For the numerical simulation of supersonic combustion, multi-species Navier-Stokes equations and detailed chemistry of H2-Air is considered. It also accommodates a finite-rate chemical kinetics mechanism of hydrogen-air combustion GRI-Mech. 2.11[1], which consists of nine species and twenty-five reaction steps. Turbulence closure is achieved by means of a k-two-equation model [2]. The governing equations are spatially discretized using a finite-volume approach, and temporally integrated by means of a second-order accurate implicit scheme [3~5].


The supersonic combustor consists of a flat channel of 10 cm height and a fuel-injection slit of 0.1 cm width located at 10 cm downstream of the inlet. A cavity of 5 cm height and 20 cm width is installed at 15 cm downstream of the injection slit. A total of 936160 grids are used for the main-combustor flow passage, and 159161 grids for the cavity. The grids are clustered in the flow direction near the fuel injector and cavity, as well as in the vertical direction near the bottom wall. The no-slip and adiabatic conditions are assumed throughout the entire wall boundary. As a specific example, the inflow Mach number is assumed to be 3, and the temperature and pressure are 600 K and 0.1 MPa, respectively. Gaseous hydrogen at a temperature of 151.5 K is injected normal to the wall from a choked injector.

A series of calculations were carried out by varying the fuel injection pressure from 0.5 to 1.5 MPa. This amounts to changing the fuel mass flow rate or the overall equivalence ratio for different operating regimes. Figure 1 shows the instantaneous temperature fields in the supersonic combustor at four different conditions. The dark blue region represents the hot burned gases. At the fuel injection pressure of 0.5 MPa, the flame

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is stably anchored, but the flowfield exhibits a high-amplitude oscillation. At the fuel injection pressure of 1.0 MPa, the Mach reflection occurs ahead of the injector. The interaction between the incoming air and the injection flow becomes much more complex,and the fuel/air mixing is strongly enhanced. The Mach reflection oscillates and results in a strong fluctuation in the combustor wall pressure. At the fuel injection pressure of 1.5 MPa, the flow inside the combustor becomes nearly choked and the Mach reflection is displaced forward. The leading shock wave moves slowly toward the inlet, and eventually causes the combustor-upstart due to the thermal choking. The cavity appears to play a secondary role in driving the flow unsteadiness, in spite of its influence on the fuel/air mixing and flame evolution. Further investigation is necessary on this issue.

The present study features detailed resolution of the flow and flame dynamics in the combustor, which was not typically available in most of the previous works. In particular, the oscillatory flow characteristics are captured at a scale sufficient to identify the underlying physical mechanisms. Much of the flow unsteadiness is not related to the cavity, but rather to the intrinsic unsteadiness in the flowfield,as also shown experimentally by Ben-Yakar et al. [6]. The interactions between the unsteady flow and flame evolution may cause a large excursion of flow oscillation. The work appears to be the first of its kind in the numerical

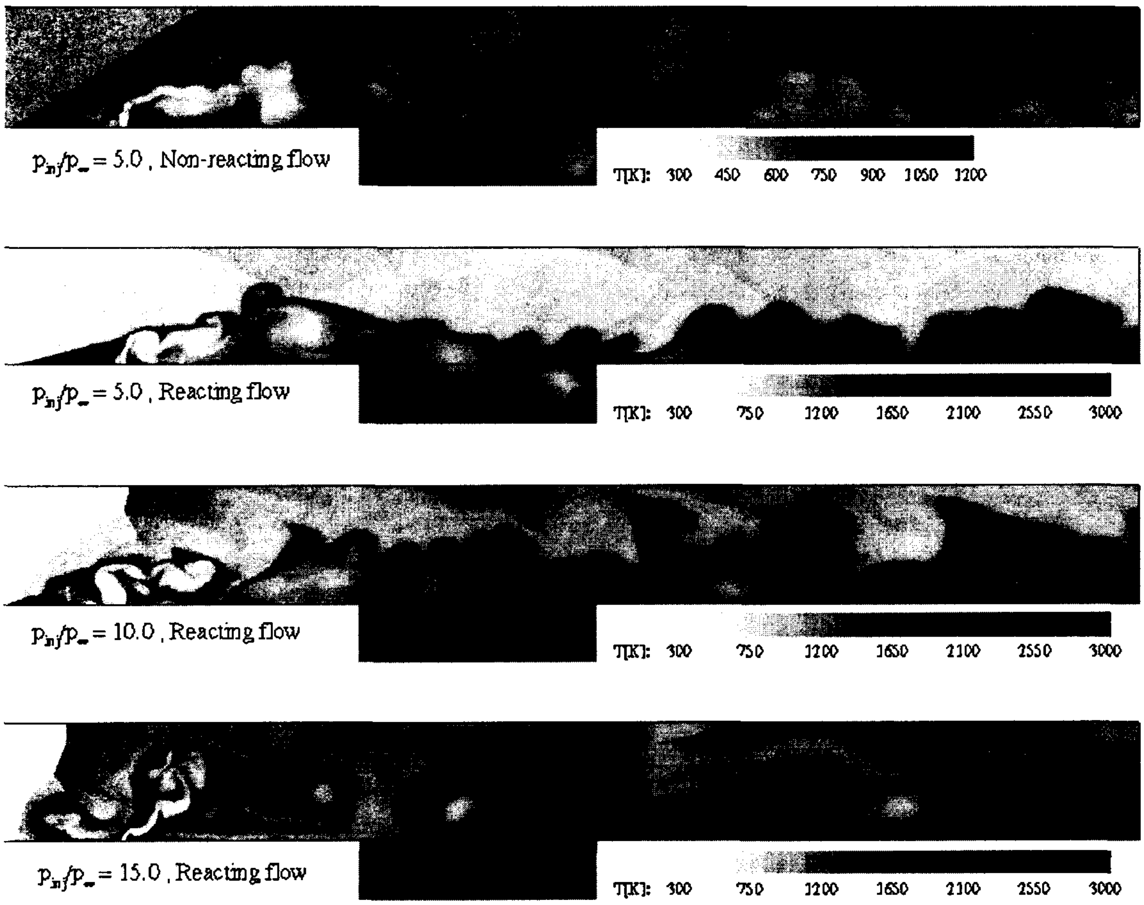


Fig. 1 Snapshots of temperature fields in a supersonic combustor with normal injection of hydrogen in air.

study of combustion oscillations in a supersonic combustor, although a similar phenomenon was previously reported experimentally. A more comprehensive discussion will be given in the final paper presented at the colloquium.

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