Experimental Study on Autoignition in a Scramjet Combustor

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Abstract

AUTOIGNITION characteristics of hydrogen fuel in a scramjet combustor were examined using a direct-connect test apparatus with particular reference to the effect of fuel injection patterns.

Autoignition behavior fell into four distinct categories, separated by the three bounding curves. One of the boundaries was independent of fuel injection patterns, while the others significantly depended on them. In the case of fuel injection from a single wall or from a single orifice, local flame quenching caused by expansion wave emanating from the step on the opposite wall was observed.

Compared with injection from a single orifice, injection from multiple orifices appreciably enhanced autoignition. The reason for this is that fuel jets from adjacent orifices and from the opposite wall tended to attenuate the local flame quenching caused by the expansion waves from the opposite wall. Ignition limit curves derived from the present experiment were compared with an autoignition criteria proposed by Huber et al. They agree well in the case of fuel injection from a single orifice. For the case of injection from multiple orifices, however, the agreement is poor.

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Figure 1 illustrates the combustor section. A Mach 2.5 vitiated air flows into the combustor with a stagnation pressure of 1.0 MPa and a stagnation temperature from 1000 to 2500 K. The combustor is stainless steel without cooling. The duct is rectangular in cross section and consists of two side walls, a top wall, and a bottom wall. The width and height of the entrance section are 32 mm and 147.3 mm, respectively. There are 3.2-mm-high rearward-facing steps on both side walls at the same streamwise location. Downstream of the step, the duct remains constant in cross section for a distance of 96 mm, beyond which the side walls are flared outward at an angle of 1.7 deg toward the combustor exit.

The fuel injection orifices are located 12.8 mm downstream of the step at lateral intervals of 32 mm in a staggered pattern. After steady air flow was established, gaseous hydrogen at room temperature was injected from all the orifices on both side walls (a double-wall injection), from all the orifices on one of the side walls (a single-wall injection), or from only one orifice (a single-orifice injection).

In order to detect ignition, streamwise wall temperature distribution was measured by thermocouples. For single-wall injection, the ignition behavior represented by wall temperature distributions in Fig. 2 was classified into four categories: wall temperature rise observed in all parts (○); in parts close to the step and the combustor exit (□); only in a part close to the step (◇); and in no part (△).

With the categories □ and ◇, it appears that the expansion waves from the step on the opposite side wall have created localized zones of low temperature and pressure, which caused local flame quenching. In the □ category, however, the second rise of temperature and pressure due to a reattachment shock following the expansion waves induced reignition in the vicinity of the combustor exit. Such phenomena were not observed for the double-wall injection, in which case the expansion waves are suppressed by the jet from the opposite wall.

In Fig. 3, autoignition limit curves for the three injection patterns derived from the present experiment are drawn on a graph of air stagnation temperature T_{ta} vs total fuel equivalence ratio ϕ. In the figure, fuel equivalence ratio corresponding to injection from one orifice ϕ_{eq} is also shown in parallel with ϕ. The consistent negative slope of the autoignition limit curves in all cases indicates enhancement of autoignition by temperature and pressure rise with increasing ϕ, which is induced by strengthened interaction between the air stream and the fuel jets.

The lines Ⓛ separating the regions of the categories ◇ and △ almost coincide for all injection patterns on the ϕ_{eq} basis. This is mainly due to the fact that, in a supersonic stream, phenomena in the region upstream of each injection orifice are not affected by the fuel jets from adjacent or opposite

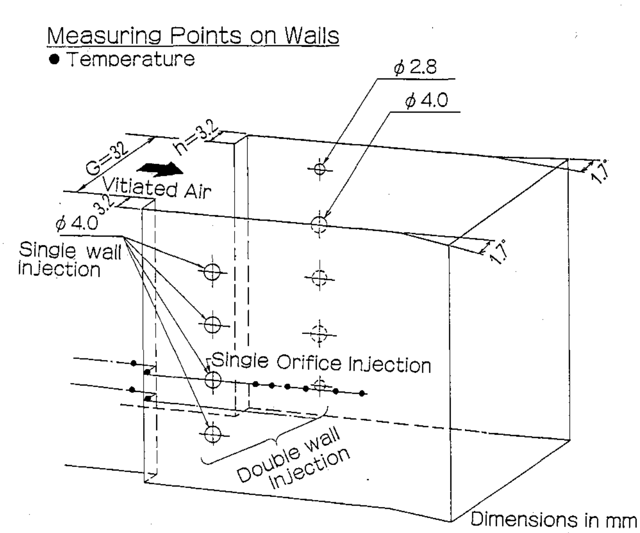

Fig. 1 Combustor detail.

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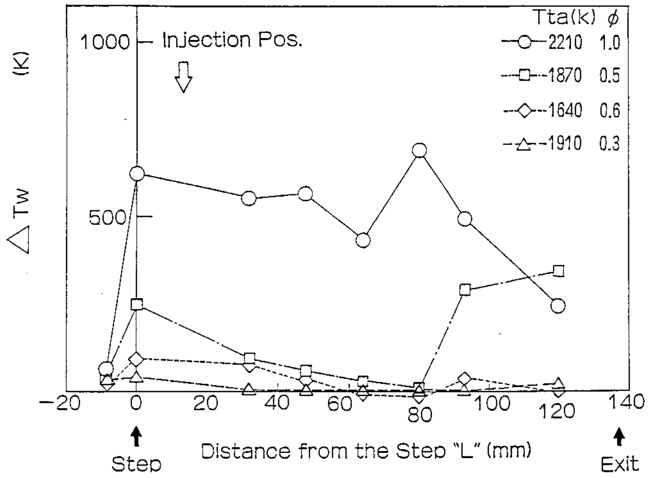

Fig. 2 Streamwise distribution of wall temperature (single-wall injection).

wall orifices. The lines Ⓜ and Ⓗ, on the other hand, widely vary with the injection patterns. This suggests that autoignition is governed by phenomena downstream of an injection orifice strongly influenced by the fuel jets from adjacent or opposite wall orifices. The fuel jets from adjacent orifices generate bow shock waves to raise the temperature and pressure to shift the lines Ⓜ and Ⓗ toward a lower T_{ta} compared to the single-orifice injection. With injection from opposite wall, the effect would be further enhanced by attenuation of the expansion wave from the step on the opposite wall, which otherwise lowers the wall temperature and pressure. It should be noted that the regions encompassing the categories □ and ◇ are almost nonexistent for the double-wall injection.

The autoignition limit curve calculated with a model proposed by Huber, Schexnayder, and McClinton[1] (the HSM model) is shown in Fig. 3. This model presumes autoignition to occur in the recirculation region zone upstream of the fuel orifice. In applying this model, wall temperature and fuel injection pressure are evaluated from the experimental data. Air flow conditions are calculated under the assumption of one-dimensional flow in chemical equilibrium. The values of empirical constants in the model are the same as those used by McClinton.[2]

It is seen that the calculated curves do not coincide with the Ⓛ lines in any instance. In the ◇ category, the flame does not persist downstream. In applying the HSM model, McClinton[2] has classed such cases as nonignition where localized visible emission was observed only in the vicinity of the injection orifices. Therefore, the ignition limit line for the HSM model should correspond to the Ⓜ line.

Comparing the Ⓜ lines with the results of the HSM model which was fitted to the McClinton's data,[2] good agreement is seen for the single-orifice injection, but not for the single- or double-wall injection. The disagreement might be due to the difference in the value of the ratio of orifice interval to diameter. The value of the ratio in McClinton's experiment[2] was 11 to 20, whereas that in the present experiment was only 8. Greater interference from adjacent orifices could be expected for smaller value of the ratio. This effect is enhanced by the additional weakening impact of the expansion waves from the opposite wall.

The present data are used as a reference in a study[3] of forced ignition for low-speed flight conditions.

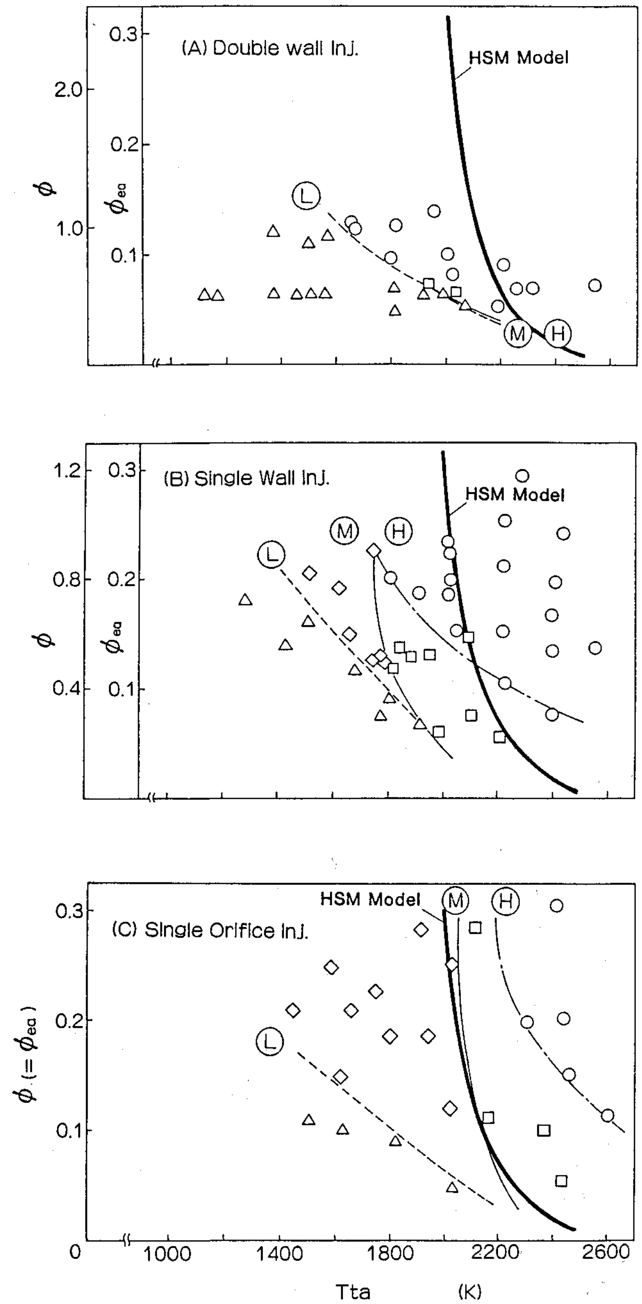

Fig. 3 Autoignition categories and limit curves.

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