

# **Study on Control Factors and System for Turbulent Combustion Control**

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## **Abstract**

In order to develop a total system for turbulent combustion control, hydrogen and methane non-premixed turbulent lifted flames are studied from several aspects; (1) stability, (2) noise level, and (3) NO<sub>x</sub> level. A high speed schlieren movie, OH/NO PLIF, PIV, plasma microphone and numerical analysis are used to find out control factors such as lifted height, burner design, etc. The present study shows that there is a best point which meets a good stability, low noise level, and a low NO<sub>x</sub> level. The lifted part of the turbulent jet flame is the key for controlling the jet flame. The future plan for the total control system is also discussed briefly.

## **Introduction**

High efficiency and low emission of polluted gas and noise for combustion systems are our important goal to keep clean combustion atmosphere. To achieve this goal we started the governmental project on "Smart Control of Turbulence." New concepts, new methods, and new devices are developed for this purpose of project. Up to now, for example, dynamic behavior of steady flames are known to cause noise, vibrations, and failure in heating and power systems; furnaces, boilers, and gas turbines [1]. Flame stabilization have been discussed in the past [2] that a pilot flame is most reliable one for gas turbine to start with. Flame holder and bluff bodies are also used to stabilize flames for many purposes [3]-[5]. Flame oscillation control has been studied passively [6] and actively [1],[7],[8].

Our steps for the goal are first to confirm a stability position, noise level, and NO<sub>x</sub> level, second to find a more stable condition by changing burner configuration such as putting a shoulder, third to find a control factor, forth to develop a control device, and to construct a control system using an active feedback system. The present study will show some fundamental features of hydrogen non-premixed jet flame such as flame stability, noise levels for diffusion flames, NO<sub>x</sub> levels for different structures of flames, and some study on control factors. Experiments as well as numerical analyses are performed to obtain such features. High speed Schlieren system, PLIF and PIV laser system, microphone system, and NO<sub>x</sub> measurement system are used to clarify and visualize the phenomena for the present study.

## **Fundamental aspects of hydrogen non-premixed jet flame**

Hydrogen non-premixed jet flame is a basic unit for combustion systems such as boiler and turbine. Stability is one of the important factors to pursue by active control. For jet flame stability is in laminar flames and in turbulent lifted flames. Figure 1 shows the laminar flame height (the length between the burner nozzle exit and the transition point from the laminar to turbulent flame) in the laminar/turbulent flame region and the lifted height in the turbulent lifted flame region. When the Reynolds number increases, the laminar flame height decreases and the jet flame is suddenly lifted at the jet velocity of about 500 m/s for hydrogen non-premixed jet flame with a 1mm nozzle exit. Then for the further increase of jet velocity the lifted flame is again suddenly lifted up to about the velocity of 670 m/s to 10mm of lifted height and is lifted further with increasing the jet velocity. The lower lifted position should be a stable flame one. Red crosses in the figure implies the numerically calculated lifted heights which correspond to the experimental result of the same point. Figure 2 shows that the comparison between the numerical results and the experimental Schlieren photos for lifted flames. One of the important understandings obtained in this figure is that the lifted height is also interpreted as the distance of mixing length where the ignition could occurs.

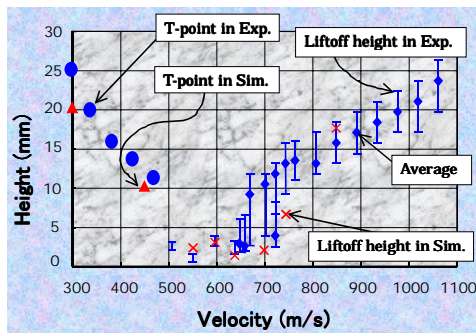


Fig.1 Transition points and lifted heights for hydrogen non-premixed jet flames

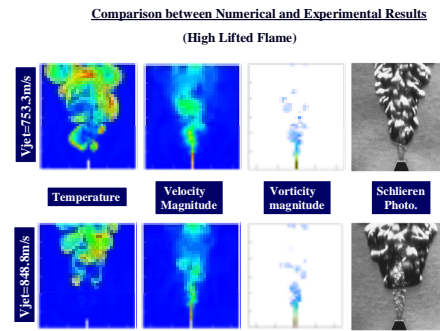


Fig.2 Comparison between numerical results and experiments for hydrogen non-premixed jet flames

### Noise level

A plasma microphone is used to measure noise profiles of hydrogen-air non-premixed jet flames. Figure 3 shows the noise level configurations of jet flames depending on the jet velocities. The noise level increases to the increase of jet velocity from the laminar flame to turbulent one until the lower lifted jet flame appears. At the lower lifted jet flame the noise level decreases drastically once and again increases when the jet flame velocity increases.

### NOx level

NOx is measured in the duct after the burnt gas is collected through the hood above the jet flame. NOx level continuously decreases as the hydrogen-air non-premixed jet flame velocity increases although there is a small jump, which is hardly recognized in Fig.4, when the jet flame transfers from the lower stable lifted position to the higher unstable lifted position. The result is obtained using the 1mm exit diameter nozzle. When the different size and configuration of nozzle are used, this little jump becomes more visible.

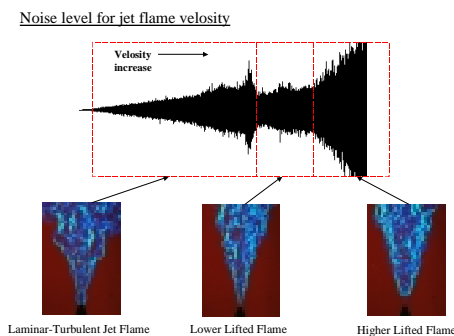


Fig.3 Noise level for hydrogen non-premixed jet flame

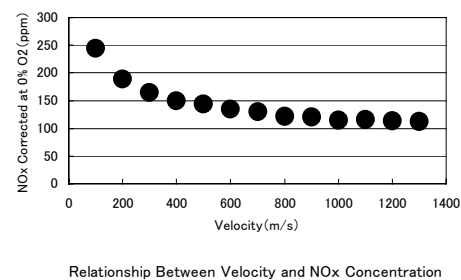
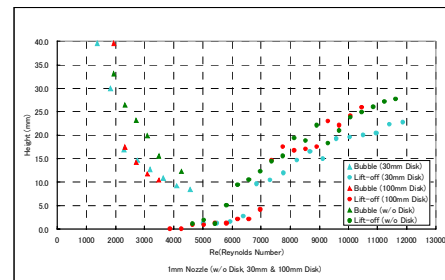
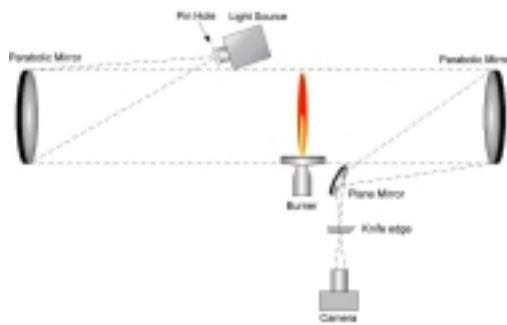


Fig.4 NOx concentration profiles vs. jet jet flame velocity for hydrogen non-Premixed jet flame

From the results of the features in the turbulent hydrogen non-premixed lifted jet flame on “stability”, “noise level”, and “NOx level”, it is understood that in non-premixed hydrogen jet flames the lower lifted flame is the flame we were looking for and the lifted part of lifted flame is the key region to control the flame. Hence the following study is performed further experimentally and numerically.

## Control factors

A simple exercise is performed to find out control factors. First of all the hydrogen jet burner nozzle is redesigned to have a shoulder which size is 30mm and 100mm in diameter (Fig.5). We found that the shoulder shown in the figure provides the wider region of the lower lifted flame for different sizes of burner nozzle. Figure 6 shows the hydrogen jet flame configuration using burners without a shoulder, with a 30mm diameter shoulder, and with a 100mm diameter shoulder. The stable region using a burner without shoulder is from  $Re=4600$  through 5700, but that using a burner with a 30mm diameter shoulder is from  $Re=4600$  through about 6700 and that using a burner with a 100mm diameter shoulder is from  $Re=3800$  through about 7100. Apparently a shoulder helps widening the stable, noiseless, and low  $NO_x$  region.



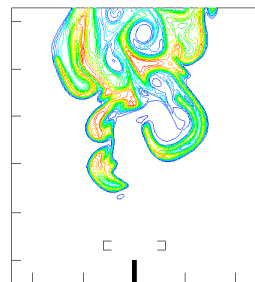
$\Phi$  1mm : shoulder - w/o, 30mm & 100mm Disk

Fig.5 Schematics of Schlieren system for hydrogen non-premixed jet flame using a burner with a shoulder

Fig.6 Transition points and lifted heights for hydrogen non-premixed jet flame using a burner with a shoulder

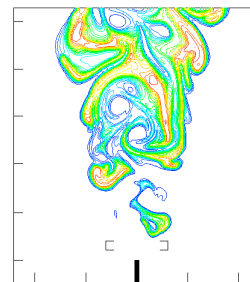
## Side jet control

Since the lifted part of jet flame is the region where fuel and air are mixed and its length is the mixing length, if air is jetted in this region, the lifted length will be shortened. The side jet experiment reveals such effects which are not shown here but the numerical analysis shows the apparent effects in Fig. 7-(a) and -(b). Fig.7-(a) is the case of without air jet and Fig.7-(b) is the one with an air jet of



- 10 10  $r/D$

(a) Air speed=0m/s



- 10 10  $r/D$

(b) Air speed=20m/s

Fig. 7 Side jet effects on the lifted region of hydrogen lifted jet flame

Sensors are used to find out whether the flame is at the lower lifted position or not and actuators can be used to get the lower lifted flame. When the flame is a laminar/turbulent flame, the flame speed is increased and when it is a higher lifted flame, the shoulder can be installed or the air is jetted from the side to the lifted part of the flame to get a lower lifted flame. A feedback system can be used to control flames and the next step will be the jet flame burner control using such devices.

A speaker is another control device for stabilize flames, but it can be used for up to a certain size. For the further combustion system new ideas should be applied. An air jet system can be such method.

### **Summery**

Hydrogen non-premixed jet flame is studied for the aspect of its control. The followings are found presently:

- (1) Hydrogen non-premixed jet flame has a stable lower lifted position and unstable higher lifted position.
- (2) A low noise is detected in the lower lifted region of hydrogen non-premixed jet flame.
- (3) NO<sub>x</sub> level becomes low as Reynolds number or jet velocity increases.
- (4) A shoulder to the burner exit helps widening a stable lower lifted flame region.
- (5) A side jet to the lifted part of hydrogen non-premixed jet flame lowers its lifted height.

A lifted jet flame will be studied further with a feedback control system and then will be a real combustion system. In this point a total combustion system is again studied with respects to stability, noise, and NO<sub>x</sub>/CO<sub>x</sub> emission. Parallely hydrogen premixed jet flame, methane non-premixed and premixed jet flame are also studied for the above points of view. Especially methane jet flame is popular fuel and has different features from hydrogen jet flame, then its control factors and control systems are also different.

### **References**

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