# Visualization of Conventional and Combusting Subsonic Jet Instabilities

**V.V. Kozlov**[1,2,*]
[1]Khristianovich Institute of Theoretical and Applied Mechanics, Novosibirsk, Russia
[2]Novosibirsk State University, Novosibirsk, Russia

**Abstract** Results of experimental studies of round and plane propane micro - jet combustion in a transverse acoustic field at small Reynolds numbers are presented in this paper. Features of flame evolution under the given conditions are shown. Based on the new information obtained on free micro - jet evolution, new phenomena in flame evolution in a transverse acoustic field with round and plane propane micro - jet combustion are discovered and explained.
**Keywords:** round and plane jets; acoustic; flow visualization; combustion

## 1. Introduction

The experiments [1] gave an impetus to experimental investigations of the flame development during gas fuel combustion in microjets at low Reynolds numbers. The goal of [1] was to understand the mechanism of the flame bifurcation in a round jet generated by gas fuel combustion in a transverse acoustic field. However, this mechanism still remains unclear. The experimental studies presented in the monograph [2] and other papers [3-8], where the influence of the initial conditions at the nozzle exit and acoustics on the development of round and plane macro- and microjets in the absence of combustion at low Reynolds numbers was investigated in detail, made it possible to understand and explain some phenomena in the flame behaviour observed during propane combustion in these jets. Results of these studies are presented below.

## 2. Physical aspects of the flame evolution in a transverse acoustic field during round and plane propane microjet combustion

Results of the experimental studies presented in [2-8] allowed us to understand and explain, in particular, the evolution of the flame in a transverse acoustic field during diffusion and premixed combustion of propane microjets.

### 2.1 Experimental setup and procedure

The experiments were carried out on the experimental setup shown in Figure 2.1.

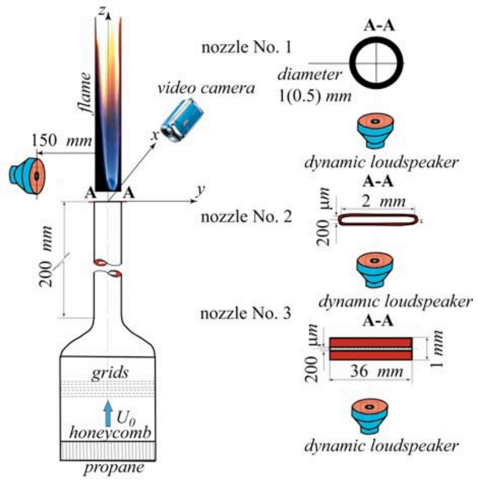


**Figure 2.1. Experimental set – up.**

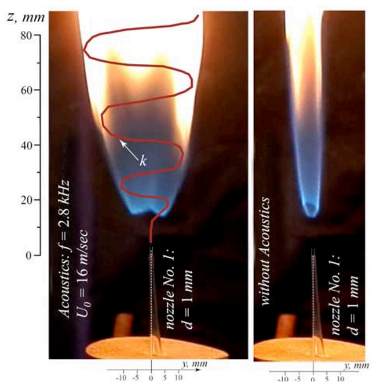


**Figure 2.2. Round minijet flame flattening under the action of a transverse acoustic field**

A gas fuel (propane) or its mixture with air was fed to the nozzle through a honeycomb and a set of grids in the settling chamber. Three types of nozzles were used (Figure 2.1). The process of propane jet combustion subjected to the influence of a transverse acoustic field was registered by a digital video camera. The transverse acoustic field was created with the help of a dynamic loudspeaker excited by sinusoidal electric signals of different frequencies. The jet velocity was measured by a precision flowmeter.

**2.2 Diffusion combustion of propane round mini- and microjets**

The flame of round mini and microjets is transformed through flattening and transformation into a plane microjet in a transverse acoustic field (Figure 2.2). In this situation, the jet as a whole performs sinusoidal oscillations. The sinusoidal oscillations of the jet result in its bifurcation into two jets far downstream (Figures 2.3 ). It should be noted that the frequency of the transverse acoustic field is approximately doubled as the nozzle exit diameter is reduced from 1 to 0.5 mm. The flame behaviour is correlated with the process of round free jet flattening and bifurcation in a transverse acoustic field [2]. Acoustic forcing of a slit burner flame was experimentally investigated in [1], and it was confirmed that the bifurcation of the jet due to acoustic forcing is basically a two-dimensional phenomenon. Thus, the bifurcation mechanism of the round mini- or microjet flame in a transverse acoustic field is related to free jet flattening or, in other words, round jet transformation to a plane (2D) jet. The sinusoidal oscillations of the free plane jet result in its splitting into two jets. The flame propagates over the external surface of the jet.

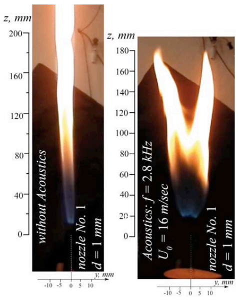


Figure 2.3. Round minijet (nozzle d = 1 mm)

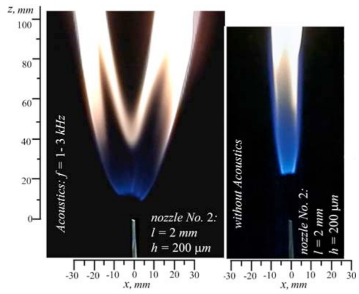


Figure 2.4. Plane microjet flame

**2.3 Diffusion combustion of a plane propane microjet**

**<u>Short nozzle No.</u> 2: (l = 2 mm, h = 0.2 mm, l/h = 10), acoustics (f = 1-3 kHz, A = 90 dB)**

As the jet velocity increases, the flame sharply lifts-off from the nozzle at a certain threshold value of the jet velocity, and the so-called lifted flame is formed (Figure 2.4). In this situation, a flame bifurcation under the acoustic influence is clearly observed in the frequency range from 1 to 3 kHz (Figure 2.4). Apparently, acoustics stabilizes the combustion process and promotes intensification of heat/mass transfer between propane and air, which results in combustion region spreading and, finally, in the flame bifurcation.

**<u>Long nozzle No. 3</u>: (l = 36 mm, h = 0.2 mm, l/h = 180), acoustics (f = 2 kHz, A = 90 dB)**

The flame evolution of a plane microjet in a transverse acoustic field in the yz-plane is shown in Figure. 2.5. In this case, in contrast to the short nozzle situation, it is possible to observe not only the process of the flame bifurcation in a transverse acoustic field, but also flame folding due to the edge effect. This folding occurs in directions opposite to each other on each period of the acoustic effect (Figure 2.5 *b, c*). In the course of diffusion combustion of this propane jet, it is also possible to observe flame propagation on the surfaces of these two bifurcated and rolled-up jets (Figure 2.5*a*).

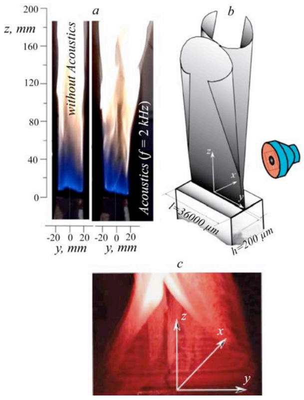


Figure 2.5. Plane microjet flame bifurcation in a transverse acoustic field: *a* - pattern of flame folding, *b* - scheme of the free jet bifurcation and folding, *c* - smoke visualization pattern of free jet folding (taken from [2]).

## 3. Summary

On the basis of information obtained on the evolution of macro- and microjet flows, some new phenomena in the behaviour of the flame during microjet combustion in a transverse acoustic field have been discovered and explained for the first time. It has been shown for the first time that the flame during round propane microjet combustion displays flattening and bifurcation; the behaviour of the jet in the absence of combustion has been also studied. A similar result has been found for the first time in the flame behaviour during diffusion and premixed combustion of propane microjets in a transverse acoustic field, i.e., flame bifurcation and folding, as in the case of the jet development in the absence of combustion.

**Acknowledgement**

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