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Visualization of conventional and combusting subsonic jet instabilities

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Abstract
Based on new information obtained for free microjets, this study is aimed to explain some phenomena of flame evolution at round and plane propane microjet combustion in the presence of transverse acoustic field. It gives an overview of recent experimental results on instability and dynamics of jets at low Reynolds numbers and provides the recent advances in jet flow stability and combustion. Some clarification of the differences between top-hat and parabolic round and plane jet instability [1] is also given.

1. Influence of initial conditions at the nozzle exit and acoustics on the characteristicsof the round and plane macrojet evolution

Round macrojet with top - hat mean velocity profile at the nozzle exit is subjected by Kelvin–Helmholtz instability (see, figure 1) and round macrojet with parabolic mean velocity profile at the nozzle exit results in an extended laminar flow region and suppression of the ring vortices (see, figure 1).

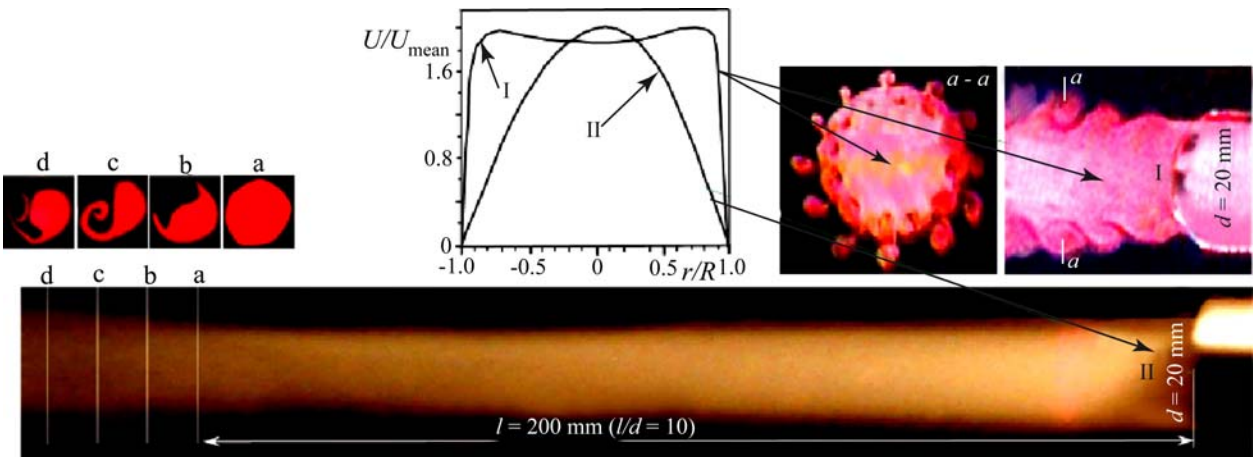

Figure 1: Influence of initial conditions at the nozzle exit on structure and characteristics of a round jet evolution: I,II – top - hat and parabolic mean velocity profiles, accordingly; a, b, c, d - macrojet cross sections, U_0= *5 m/sec (Re* = $U_0 \times d / \nu$ = 6667).

Plane macrojet with top – hat and parabolic mean velocity profile at the nozzle exit are subjected to sinusoidal instability (see, figure 2, ***I***) and round macrojet with parabolic mean velocity profile at the nozzle exit results in an extended laminar flow region and suppression of the ring vortices. Plane macrojet with top – hat mean velocity profile at the nozzle exit involve three independent of each other instability areas. First area consists of the two independent of each other narrow regions of strong velocity gradient near nozzle in case of top – hat mean velocity profile at the nozzle exit. Second area is region with parabolic mean velocity profile far downstream from a nozzle (see, figure 2, ***II***). Plane macrojet is subjected to sinusoidal instability in this region.

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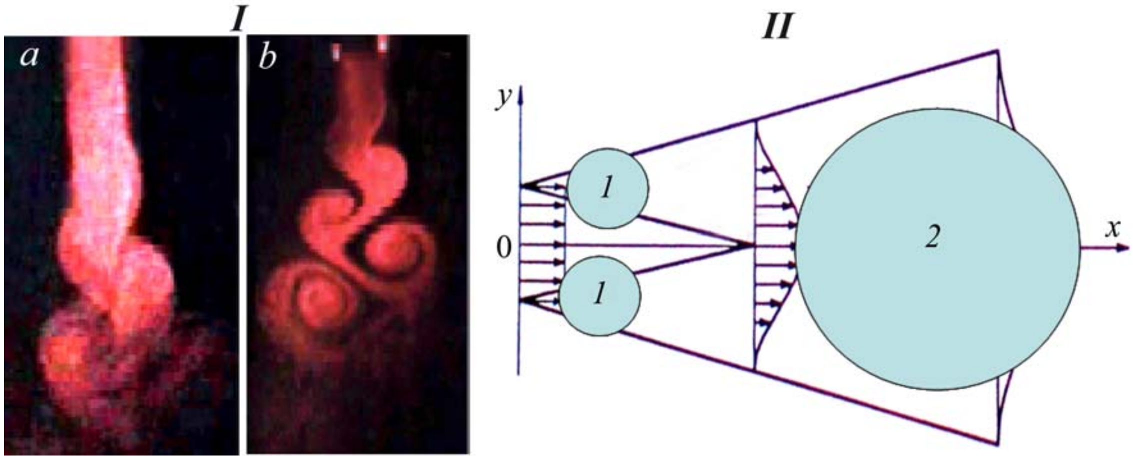

Figure 2: Sinusoidal instability of the plane macrojet with top-hat and parabolic mean velocity profile at the nozzle exit – ***I*** (*a* – under natural conditions, *b* - under external acoustic forcing at frequency f = 40 Hz). Plane macrojet with top – hat mean velocity profile at the nozzle exit involve three independent of each other instability regions: 1 - two independent of each other narrow regions of strong velocity gradient near nozzle, 2 - region with parabolic mean velocity profile far downstream from a nozzle – ***II***.

2. Influence of initial conditions at the nozzle exit and acoustics on the characteristics of the round and plane microjet evolution

Round microjet is subjected to flattening and bifurcation in a transverse acoustic field (see, figure 3,***I***). In the absence of acoustic excitation the entire plane microjet is subjected to sinusoidal oscillations. At low-frequency (30 to 150 Hz) transverse acoustic forcing of a plane microjet, alongside with occurrence of a sinusoidal vortex street it was possible to observe folding of the jet at its edges in the direction of variable velocity vector of the flow created by acoustic waves. It is well seen in figure 3***II***, that at sound pressure level of 90 dB the vortex sheet is rolled up in directions opposite to each other on each half-cycle of acoustic oscillations. The flow patterns of figure 3***II*** demonstrate the sinusoidal vortex street in the center of the jet (section 1, y = 0 mm). Also it is possible to observe a bifurcation of the plane jet (sections 2 and 3, y = 15, 18 mm).

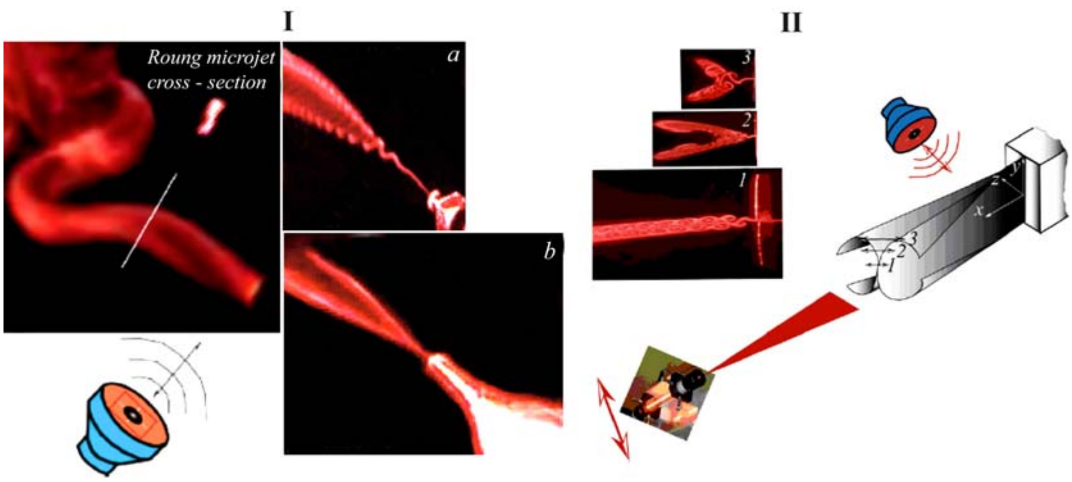

Figure 3: Round microjet flattening (f = 40 Hz) and bifurcation (a - f = 200 Hz, b – 1500 Hz) in a transverse acoustic field (nozzle diameter d = 200 mm) – ***I***. Bifurcation scheme of the plane macrojet in a transverse acoustic field (nozzle: l = 36 mm, h = 200 mm): flow patterns in x-z planes at variation of the y coordinate (1, 2, and 3 correspond to y = 0, 15, and 18 mm, respectively), f = 150 Hz, 90 dB – ***II***.

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3. Diffusion combustion of the round and plane propane microjet in a transverse acoustic field

All features of the round (flattening and bifurcation) and plane (bifurcation) microjet evolution in a transverse acoustic field without combustion remain also in a situation of the flame evolution at their diffusion combustion, for example, propane combustion (see, figure 4). Round microjet flame is subjected to flattening and bifurcation in a transverse acoustic field (see, figure 4**I**). Plane microjet flame is subjected to bifurcation in a transverse acoustic field (see, figure 4**II**).

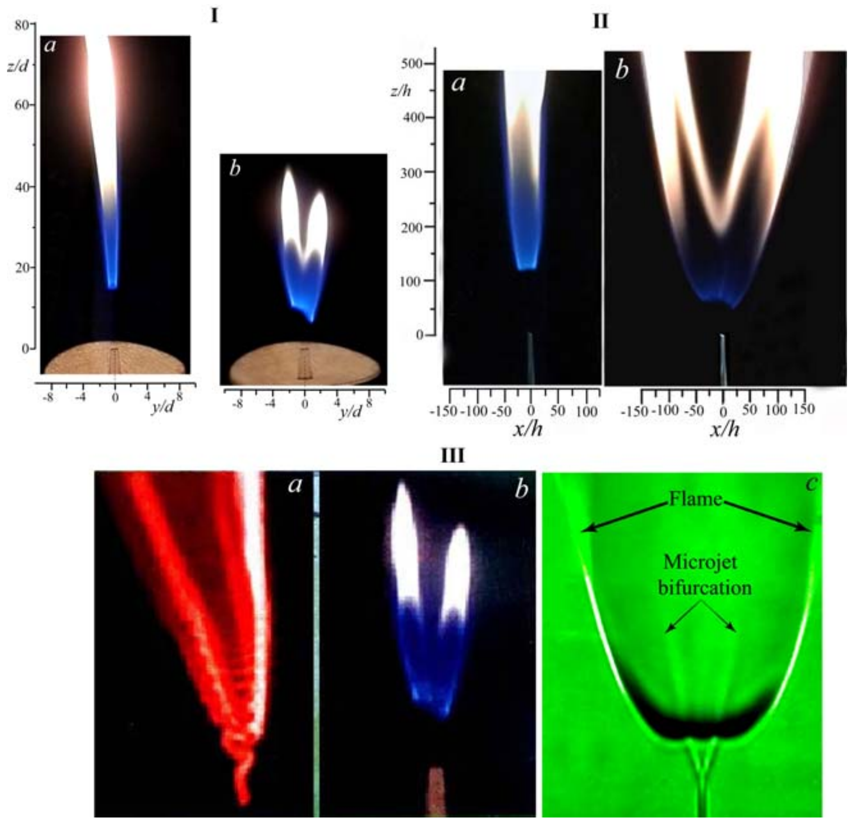

Figure 4: Round (**I**) and plane (**II**) microjet flame bifurcation in a transverse acoustic field: nozzle No. 1, d = 0.5 mm, acoustics, f = 5 - 7.5 kHz, U_0 = 12.5 m/sec (I); nozzle No. 2, l = 2 mm, h = 200 µm, acoustics, f = 1 – 3 kHz, U_0 = 21 m/sec (II); without acoustics (*a*), with acoustics (*b*), A = 90 dB. **III** - Round microjet bifurcation (*a*), round propane microjet flame bifurcation (*b*), and shadowgraph image of a round propane microjet combustion (*c*).

4. Conclusions

Visualizations of conventional and combusting subsonic jet instabilities are presented**.** Features of structure and characteristics of subsonic round and plane macro- and microjets evolution depending on initial conditions at the nozzle exit and acoustic effect are shown. It is found, that round and plane propane microjets combustion in a transverse acoustic field result in flame bifurcation.

Acknowledgement

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[1] Kozlov V, Grek GR, Litvinenko Yu.A. 2016. Visualization of Conventional and Combusting Subsonic Jet Instabilities**.** *Book Springer Briefs in Applied Sciences and Technology*, 1 - 126, ISBN: 978-3-319-26957-3 (Print), 978-3-319-26958-0 (Online).