

Dynamic response of jets and flame to an acoustic field

V V Golub and M S Krivokorotov

Joint Institute for High Temperatures of the Russian Academy of Sciences, Izhor'skaya 13 Bldg 2, Moscow 125412, Russia

E-mail: golub@ihed.ras.ru

Abstract. In experiment influence of the acoustic impact on streams reacting and nonreacting gases is investigated. Visualization of streams was carried out by a shadow method on the basis of the shadow IAB-451 device. It is revealed that in some cases at acoustic impact on a gas stream bifurcation of a stream is observed. Dependences of a corner of disclosure of a stream and distance are received from the open end of a tube to a place of division of a stream from the frequency of acoustic influence and level of sound pressure.

1. Introduction

One of the major scientific and technical tasks connected with burning process is research of effects of acceleration or braking of a flame which can be used for a fuel combustion speed control. Researches of acoustic impact on streams of reagents showed that at such type of influence instability is excited in a shift layer. Noticeable effects can be seen at excitement of fundamental fashions of instability of a stream. In work [1] the response of a laminar flame of in advance mixed methane mix with air on small acoustic indignations with the purpose to reveal acoustic fashions which can provide feedback was investigated. Besides convective instability of a flame acoustic influence can also have essential impact on processes of mixture in jet flame. Influence of acoustic impact on ignition and an initial stage of burning is studied much less. In these cases a key role in development and distribution of a flame hydrodynamic instability plays it. During researches of influence of an acoustic field at length of transition of burning a detonation in a stream of the mixing-up components the essential increase in length on which there is a transition of burning to a detonation, owing to influence of a strong sound field [2–4] was shown. In addition, essential influence of acoustics on a form and the size of the center of ignition was shown. At diffusive burning when combustible gas expires in surrounding space, reactions of burning proceed on a surface of contact of fuel with air. In this case sound waves interact with a flame both directly, and indirectly. Direct interaction between waves and a flame happens in a zone of burning [5] whereas indirect interaction happens in the field of a stream of yet not reacted gas, irrespective of features of a flame. Depending on frequency and amplitude of a sound, emergence of a site on which acoustic influence is imposed, can seriously affect structure and the movement of a flame in general. In work [6] intensification of mixture occurs due to fluctuations of a flame under the influence of a sound, and due to turbulization of a stream of yet not reacted combustible gas.



Investigating influence of acoustic fluctuations on the torn-off diffusive methane torch, authors [7] concluded that bifurcation of a torch (figure 1) is caused by division of a stream of nonreacting methane. Investigation of influence of entry conditions on structure and stability of streams is devoted work [8]. However in this work the beating of streams and development of vortex structures under the influence of a sound with a frequency up to 100 Hz that doesn't give the chance to explain the bifurcation phenomenon nature therefore the work is devoted to visualization of gas streams under the influence of a sound in the wide frequency range.

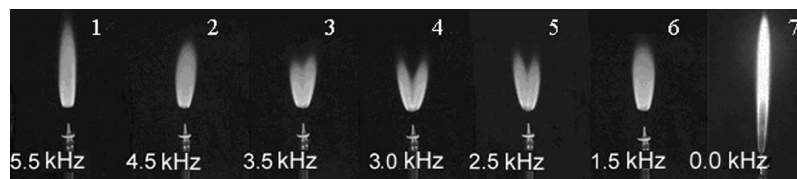


Figure 1. Photos of a flame under the influence of a sound. Level of sound pressure – 100 dB. Diameter of a nozzle of a torch of 1,25 mm.

2. Bifurcation of gas streams at acoustic influence

In experiment streams reacting (methane) and nonreacting (helium, carbon dioxide) gases were modelled. The value of number of Reynolds calculated on the speed of a current, average on section, and internal diameter of tubes changed ranging from 100 to 8000, allowing to model thereby both laminar and turbulent streams. Visualization of streams was carried out by a shadow method based on the shadow IAB-451 device. The system of creation of external acoustic influence consisted of the 2-channel generator of signals of any form Aktaky ANR-3122, the amplifier and a radiator of a sound of Ibanez Swx20yaz. In all experiments on research of influence of acoustic impact on streams of the reacting and nonreacting gases the axis of a tube was parallel to the sound radiator plane, the open end of a tube settled down opposite to the center of a source of a sound, the level of sound pressure of 80 dB. As the registering device the Cordin 222-16 chamber was used. In some cases at acoustic impact on a stream of gas it is possible to observe effect of bifurcation. In figure 1 shadow photos of a stream of helium, initial diameter of a stream of 1 mm, speed of a stream of 66.5 ± 2.8 m/s, average on section, that corresponds to value of number of Reynolds of $Re \approx 590$ are submitted.

Apparently from figure 1, the behavior of a gas stream considerably depends on external acoustic influence. With a low frequency of influence a laminar stream (figure 2. (a)) becomes turbulent (figure 2b)), at increase in frequency it is possible to observe bifurcation (division of a stream, figure 2(c) and figure 2(d)), at further increase in frequency of influence the stream again becomes laminar (figure 2(e)). Thus value of number of Strukhal changes within $St = 0 - 0.07$.

In figure 3 and figure 4, shadow photos of a stream of helium with an initial diameter of 1 mm and the speed of 42.8 ± 2.0 m/s and 76.1 ± 3.2 m/s, average on section, respectively are submitted.

Apparently from the photos of helium streams given above, the sound frequency with which the effect is observed depends on stream speed. Research of this dependence, and also influence of other parameters, such as diameter and gas of a stream is given in further sections.

3. Influence of frequency of a sound and level of sound pressure

In figure 5, shadow photos of a stream of the helium expiring in air from a tube with $d = 1.00$ mm and $D = 60$ mm are submitted. Average speed of a stream in a tube of 65 m/s that corresponds to value of number of Reynolds 590.

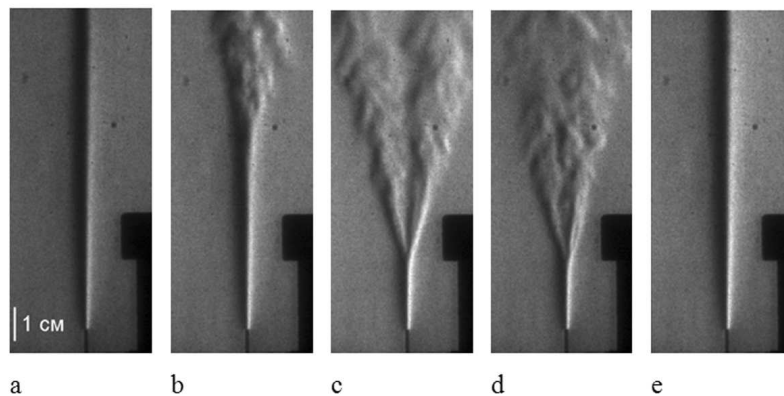


Figure 2. Bifurcation of a stream (initial diameter of a stream is 1 mm, the speed of a stream, average on section, is 66.5 ± 2.8 m/s) helium at external acoustic influence: a) 0 Hz; b) 200 Hz; c) 2300 Hz; d) 3200 Hz; e) 4800 Hz.

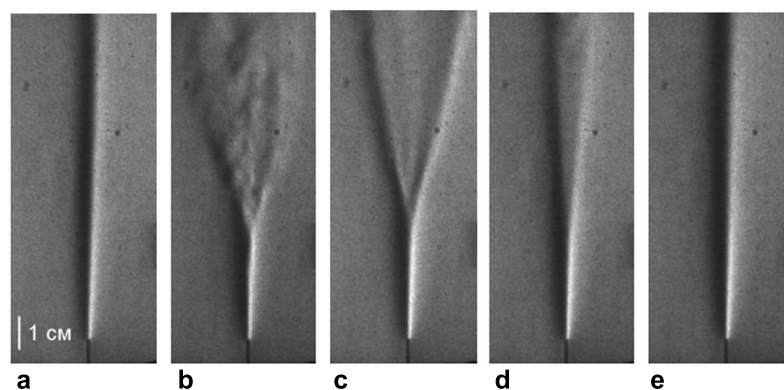


Figure 3. Bifurcation of a stream (initial diameter of a stream is 1 mm, the speed of a stream, average on section, is 42.8 ± 2.0 m/s) helium at external acoustic influence: a) 0 Hz; b) 140 Hz; c) 300 Hz; d) 560 Hz; e) 800 Hz.

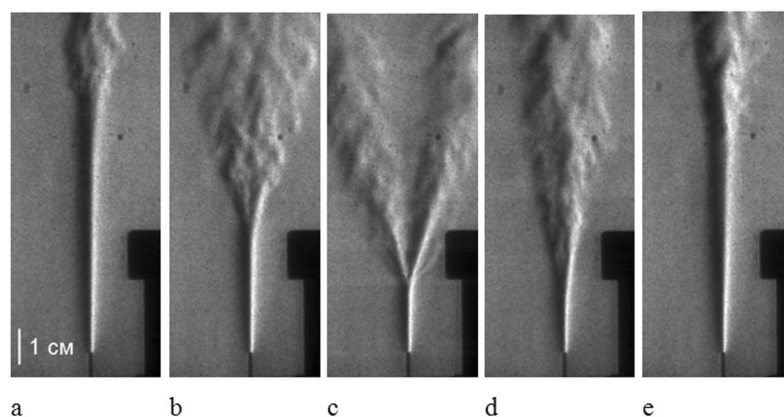


Figure 4. Bifurcation of a stream (initial diameter of a stream is 1 mm, the speed of a stream, average on section, is 76.1 ± 3.2 m/s) helium at external acoustic influence: a) 0 Hz; b) 1100 Hz; c) 3100 Hz; d) 6000 Hz; e) 8000 Hz.

The bifurcation corner, φ and distance from the open end of a tube to a place of division of a stream, h was measured in work. In figure 5 results of such measurements are presented. Not to load drawing, the error of measurements is shown separately. Lines in drawing are built by method of the sliding average with a width of window of 5.

Apparently from figure 6 the behavior of a gas stream considerably depends on the frequency of external acoustic influence. At emergence of external influence of low frequency ~ 100 Hz laminar (the initial speed of 35 - 65 m/s) streams become turbulent, bifurcation is observed, at increase in frequency of influence the corner of bifurcation decreases, and height grows. In turbulent streams at external influence of low frequency length of laminar - turbulent transition is reduced.

With increase in frequency of influence length of laminar- turbulent transition decreases,

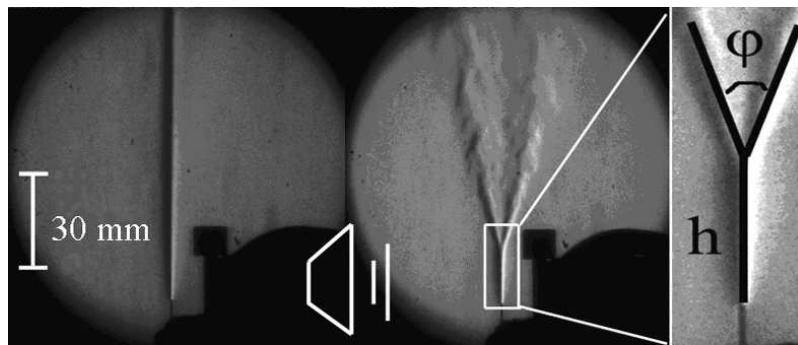


Figure 5. Shadow photos of a stream of helium: at the left – in lack of a sound, on the right – under the influence of a sound of 1700 Hz, 80 dB.

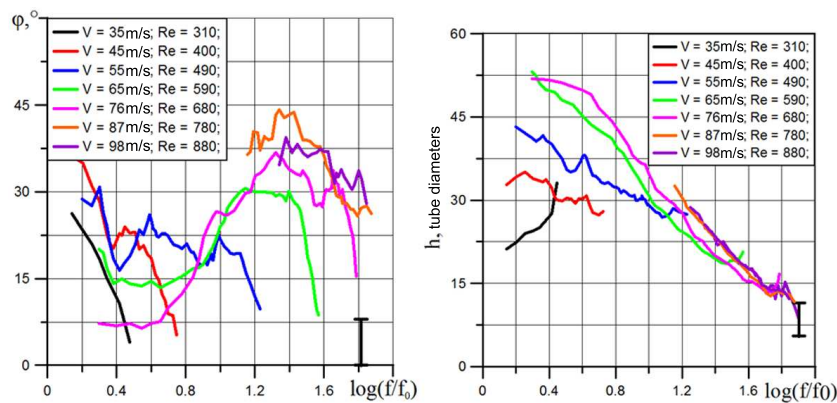


Figure 6. Dependence of a corner (and) and heights bifurcations from the frequency of external influence, $f_0 = 100$ Hz.

bifurcation starts being observed distinctly, the bifurcation corner also grows up to some value (~ 20 - 40°). At further increase in frequency of influence the corner of bifurcation remains almost invariable, height of bifurcation decreases. If further to continue to increase influence frequency, the corner of bifurcation will decrease, height grow, and at some value of frequency the effect vanishes.

In figure 7 results of measurement of a corner and height of bifurcation for a helium stream with an initial diameter of 1 mm and the speed of 65 m/s at acoustic influence with various level of sound pressure are presented. Not to load drawing, the error of measurements is shown separately. Lines in drawing are built by method of the sliding average with a width of window of 5.

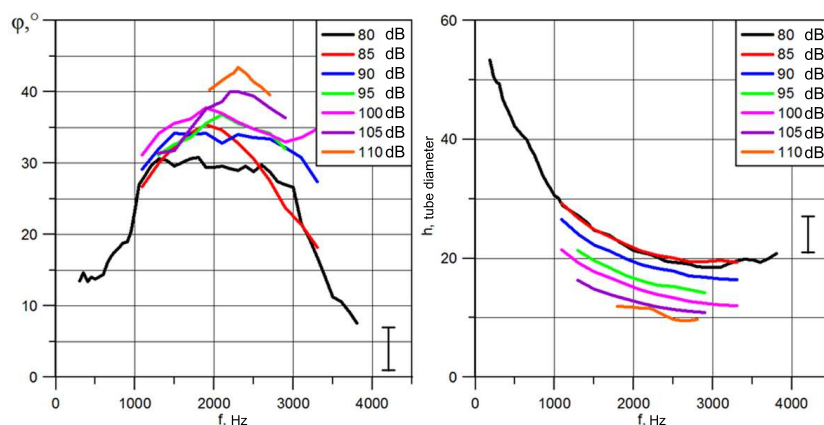


Figure 7. Dependence of a corner (and) and heights bifurcations from the frequency of acoustic influence at various levels of sound pressure.

Apparently from figure 7, the corner and height of bifurcation depend on the level of sound

pressure. At increase in level of sound pressure the corner of bifurcation grows, and height decreases. These changes become noticeable at increase in level of sound pressure upon 30 dB.

4. Influence of gas of a stream and its diameter

In some cases at acoustic impact on a stream of gas it is possible to observe effect of bifurcation (figure 8). The effect is observed at acoustic influence of a certain frequency and depends on the level of sound pressure. Concerning frequency the effect possesses threshold properties – with frequencies above some threshold the effect isn't observed. Value of this threshold frequency depends on the speed of a stream, its diameter and gas.

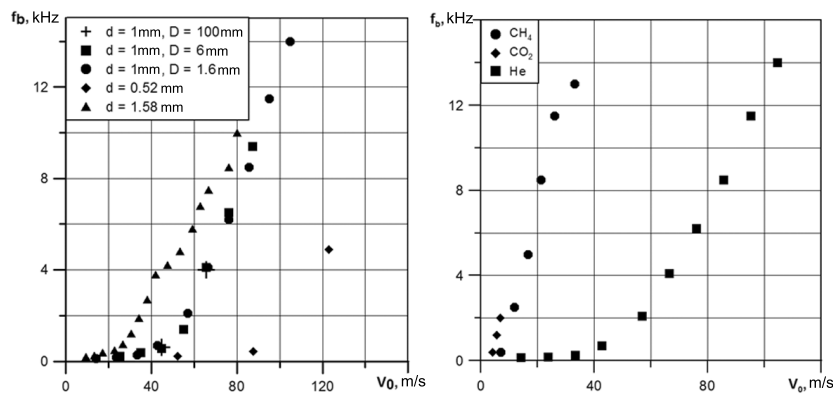


Figure 8. Dependence of threshold frequency of bifurcation on stream speed: a) helium streams of various geometry; b) streams of different gases, $d = 1$ mm.

In figure 8 (a) dependence of threshold frequency of f_b on V_0 stream speed for various helium streams, in figure 8 (b) is presented. Dependence of threshold frequency of f_b on V_0 stream speed for streams of different gases is presented.

Apparently from figure 8 (a) the external diameter of a tube in which the stream (D) was formed, doesn't influence effect of bifurcation, namely, values of threshold frequency at an identical speed of a stream are identical to tubes with various external diameter. On the contrary, the internal diameter of a tube (initial diameter of a stream) considerably influences dependence of threshold frequency of bifurcation on stream speed. At the same speed of a stream value of threshold frequency is more for a stream of bigger initial diameter. Dependences of threshold frequency of bifurcation on stream speed for streams of different gases with an initial diameter of 1.00 mm are given in figure 8 (b). At the same speed of a stream value of threshold frequency is more for a stream of more dense gas.

5. Conclusions

In some cases at acoustic impact on a gas stream bifurcation is observed (at some distance from the beginning the stream becomes turbulent and gets –Y a form). Dependences of a corner of disclosure of a stream and distance are received from the open end of a tube to a place of division of a stream from the frequency of acoustic influence and level of sound pressure for streams of various speeds. It is shown that bifurcation of a gas stream at acoustic influence is observed up to some threshold frequency; at influence with a bigger frequency, the effect is not observed. It is shown that threshold frequency depends on the speed of a stream, its diameter, and also gas.

Acknowledgments

This work was supported by the Russian Science Foundation, grant No. 14-50-00124.

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