LAMINAR-TURBULENT TRANSITION IN SUPersonic AXISYMMETRIC MICROJET

A.A. Maslov, V.M. Aniskin, S.G. Mironov,
Khristianovich Institute of Theoretical and Applied Mechanics SB RAS
Institutskaya str., 4/1, Novosibirsk, 630090, Russian Federation
maslov@itam.nsc.ru, aniskin@itam.nsc.ru, mironov@itam.nsc.ru

In recent years there has been growing interest in the study of high-subsonic and supersonic gas microjets virtue of their potential use in microjet engines [1], in pneumatic microdevices, for cooling microelectronic components [2] and for the active control of gasdynamic flows.

In this paper, we investigate the structure of axisymmetric supersonic underexpanded microjets, issuing into the ambient space, as well as questions of the laminar-turbulent transition in the mixing layer of microjets.

On technology developed by us [3] were made axisymmetric sound micronozzles with diameter from 341 to 10.4 μm.

The axial jet pressure distribution are obtained, hot-wire measurements of integral fluctuations in the jet are performed, as well as numerical simulation are carried out with the Fluent package.

The experiments were performed using a specially designed Pitot microtube [3]. The Pitot microtube had an outer diameter of 12 μm and the wall thickness of 0.1 μm.

All experiments were carried out using a nitrogen and air as the working gas. The gas at room temperature was fed into a nozzle prechamber while passing three filters 10, 1.4 and 0.45 microns. In the experiments the pressure in the prechamber was varied from 2 to 8 atm.

Determination of the microjet supersonic core length \( L_c \) and average-sized shock cells was carried out on the axial pressure distribution. The microjet supersonic core length is the distance from the nozzle exit to the point on the jet axis, where the velocity reaches the local sound speed.

The data on the microjet supersonic core length can be divided into three groups. The first group (Fig. 1,a) includes jets issuing from nozzles with diameters of 65 micrometers and greater. Solid and dashed lines in Fig. 1 shows the distributions of the supersonic core length of turbulent jets of macroscopic size [4], [5]. It is seen a good agreement with data for microjets and generalized dependences for turbulent macrojets.

The second group includes jets issuing from nozzles with diameters 61.4-21.4 microns, for which data are shown in Fig. 1,b. In this case, there is a significant, several times, increase in supersonic core length compared to macrojets supersonic core length. Then, by increasing \( n \), mode change occurs: large supersonic core length mode changes to the macrojet supersonic core length mode, and, in some cases, there is again an increase in supersonic core length.

Fig. 1. Supersonic core length depending on the off-design of jet

The third group (Fig. 1,c) can be attributed microjet issuing from the nozzles with diameter of 16.1 and 10.4 microns. In this case, the supersonic core length is also higher than the values for macrojets but there are no mode change all over the range of \( n \).

Of particular interest are the large supersonic core length data of the second and third groups. Significant increase of supersonic core length of microjets is revealed for the first time. Also for the
first time observed the effect of the second increase of supersonic core length after its decrease (with increasing degree of off-design of jet, for example for microjet issuing from the nozzle of 24.3 μm).

Numerical simulation of supersonic microjets was performed using a commercial package ANSYS Fluent. The problem is solved in two-dimensional axisymmetric formulation. Stationary two-dimensional Navier - Stokes equations are solved for laminar case, or with the addition of k-ω SST-turbulence model.

Numerical simulation results predict the possibility of large supersonic core length for microjet. In this case, the supersonic microjet must be laminar (Fig. 2).

![Fig. 2. Contours of the Mach number M> 1 for the microjet issuing from the nozzle with diameter of 44.3 μm, n = 1.6: a - laminar model, b - k-ω SST-turbulence model](image)

The integrated pulsations in microjet and their spectral composition were determined by hot-wire anemometer.

For microjets issuing from the nozzle diameter less than 60 microns were obtained data that gave more clearly understanding the processes occurring in the microjets, and find out that the sharp drop of the microjets supersonic core length are due to the laminar-turbulent transition in a jet mixing layer.

Fig. 3 shows the supersonic core length of the jet issuing from the nozzle with diameter of 21.4 μm. Red lines in the graph denote the off-design values of jet, in which the axial integral pulsations distributions were obtained (Fig. 3,b-d). The off-design values of jet chosen from the following considerations. When \( n = 1.49 \) the large supersonic core length of microjet is observed. When \( n = 1.89 \) jet flow mode changes: the large supersonic core length ends. When \( n = 3.35 \) the supersonic core length of microjet is corresponded to supersonic core length of macrojets.

![Fig. 3. The supersonic core length of the microjet issuing from the nozzle with diameter of 21.4 μm](image)

When the microjet has the large supersonic core length (Fig. 3,b, \( n = 1.49 \)), the level of the axial integral pulsations throughout the entire range of distances \( Lc/D \) is low. When \( n = 1.89 \) (Fig. 3,c) the level of the axial integral pulsations rapidly increases. The observed phenomena can explain the sharp drop of the supersonic core length of microjet.
3. (c) in the range of distances $X/D = 0\div20$ integral pulsations level remains low, but then with increasing $X/D$, there is a growth of integral pulsations. When $n = 3.35$ (Fig. 3,d), as well as in the previous case, there is a sharp increase in integral pulsations.

A sharp increase in the level of integrated pulsation and filling fluctuation spectrum is treated as laminar-turbulent transition in the jet mixing layer. It follows that increasing the supersonic core length of microjets associated with laminar flow in them.

References: