Experimental research of the supersonic core length in the supersonic jet flowing from the rectangular micro-nozzles with different aspect ratios

I V Timofeev and V M Aniskin
Khristianovich Institute of Theoretical and Applied Mechanics SB RAS, 4/1, Institutskaya str., Novosibirsk, 630090, Russia
ivan.timofeev.koi@gmail.com

Abstract. The supersonic core length of the air microjets flowing from rectangular micro-nozzles with different aspect ratios has been experimentally studied. The height and width of the nozzles varied from 119 to 135 \( \mu \text{m} \) and from 927 to 2185 \( \mu \text{m} \), respectively.

1. Introduction
Subsonic and supersonic micro-jets can be used for the macro-flow control [1-5], to reduce the noise of macro-jets, as well as in jet cooling systems. There is evidence of attempts to use synthetic mini-jets (with zero integral flow rate) to suppress pulsations in laminar and turbulent flows. Supersonic micro-jets are promising to be used in the aerospace field to protect the surfaces streamlined by high-temperature flow and suppress plasma formations around a high-speed aircraft and lander spacecraft [6, 7]. Small-size supersonic jets have also been used in reactive satellite orientation systems with a mass below 10 kg, the so-called nanosatellites [8, 9]. One of the technological applications of jets is gas mixing and protection of surfaces from chemically aggressive or high-temperature media. The jet penetrating power and the intensity of the mixing processes are the main jet characteristics in this case.

At the expiration of the supersonic jet, a complex shock-wave structure forms (figure 1). The supersonic core length is the distance from the nozzle exit to the point on the jet axis where the flow rate becomes equal to the local sonic speed. In other words, it is the supersonic part of the jet.

![Figure 1](image-url)

**Figure 1.** Scheme of the supersonic underexpanded jet. \( L_s \) is the shock sell size, \( L_c \) is the supersonic core length.
Previously, the gas-dynamic parameters of supersonic air micro-jets escaping from the circular and rectangular micro-nozzles with a large aspect ratio (AR> 40) were investigated. The dimensions of the first shock wave structure, the average shock cell size and the supersonic core length of such jets were determined. It has been shown that, if the supersonic microjet escapes from the nozzle below 50 μm, a high supersonic core length forms. The supersonic core length of the microjets is 6-8 times longer than the one for macrojets [11, 12]. The long supersonic core length from the microjets results from the laminar flow in the mixing layer.

The object of this study is the supersonic microjets escaping from the rectangular micron-sized nozzles with different aspect ratios. The nozzle parameters are shown in Table 1; the nozzle exits are shown in Figure 2.

### Table 1. The nozzle parameters

| h, μm | w, μm | AR | h, μm | w, μm | AR |
|-------|-------|----|-------|-------|----|
| 121   | 927   | 7.7| 119   | 1470  | 12.3|
| 135   | 2185  | 16.2|

Figure 2. SEM images of the nozzles.

2. **Experimental technique**

The supersonic underexpanded microjets are studied by the Pitot tube. The total pressure distribution is measured along the jet axis line. Figure 3 presents the scheme of the experiment. The room-temperature air is used as the process fluid, and the supersonic air jet is escaping into atmosphere. The glass Pitot tube with the outer diameter of 40 μm and inner diameter of 20 μm is installed in the holder that can be moved in three mutually perpendicular directions with a Narishige NT 88E micromanipulator, and be positioned in space within an accuracy of ±1 μm. The Pitot tube position is monitored by the Nikon SMZ1500 stereoscopic microscope.

Figure 3. The scheme of the experiment.
The Pitot tube is located at a certain distance from the nozzle exit. The pressure in the nozzle pre-chamber rises gradually, and the pressure in the Pitot tube is measured. Figure 4 shows as an example the graph of the Pitot tube pressure versus the jet pressure ratio when the Pitot tube is located at a distance of 8 calibers from the nozzle exit. The red line corresponds to the pressure of 1.89 atm. According to isentropic formulas, this pressure corresponds to $M=1$. As a result, the jet pressure ratio is determined, which corresponds to the supersonic core length specified by the position of the Pitot tube.

**Figure 4.** Graph of the Pitot tube pressure growth at the fixed distance with changing jet pressure ratio.

**Figure 5.** The supersonic core length of microjets escaping from circular and rectangular micro-nozzles with different aspect ratios.
Figure 5 shows the results of measurements of the supersonic core length.

It is evident from the graph that the supersonic core length of microjets escaping from rectangular micronozzles with AR \leq 16.2 does not differ significantly from the one of the jets escaping from flat nozzles with a large aspect ratio at low JPR values. However, later the difference is growing. The lower the aspect ratio, the earlier growth begins.

3. Results

The supersonic core length of microjets escaping from the rectangular nozzles generally coincides with the range of jets escaping from flat nozzles. At some jet pressure ratio, the supersonic core length of jets escaping from rectangular nozzles exceeds the range of the flat jets.

Acknowledgments

This work was supported by the Russian Science Foundation (Grant No. 17-19-01157).

References

[1] Tabeling P 2005 *Introduction to microfluids* (Oxford: Oxford University Press)
[2] Alvi F S, Shih C, Elavarasan R, Garg G and Krothapalli A 2003 *AIAA J.* 41 1347-55
[3] Lou H, Alvi F S and Shih C. 2006 *AIAA J.* 44 58-66.
[4] Choi J J, Annaswamy A M, Lou H and Alvi F S 2006 *Exp. Fluids* 41 841-55
[5] Tanney J W 1970 *Prog. Aeron. Sci.* 10 401-510
[6] Parmentier E M, Wray K L and Weiss R F 1970 *Proceedings the reentry plasma sheath and its effect on space vehicle electromagnetic systems* vol 1 (NASA Langley Research Center) pp 579-616
[7] Akey N D 1970 *Proceedings the reentry plasma sheath and its effect on space vehicle electromagnetic systems* vol 1 (NASA Langley Research Center) pp 25-6
[8] Bayt R and Breuer K 2001 *AIAA Paper* 2001-0721
[9] Zilić A, Hitt D L and Alexeenko A A 2007 *AIAA Paper* 2007-3984
[10] Kandlcar S G and Grande W J 2003 *Heat Transfer Engineering* 24 3-17
[11] Aniskin V M, Mironov S G and Maslov A A 2013 *Microfluidics and Nanofluidics* 14 605-14
[12] Aniskin V M., Mironov S G and Maslov A A. 2013 *Tech. Phys. Let.* 39 734–6
[13] Shirie J W and Seubold J G 1967 *AIAA J.* 5 2062-4.
[14] Pogorelov V I 1977 *Sov Tech. Phys. Let.* 47 444-5