FURTHER DEVELOPMENT OF THE SPARK TRACING TECHNIQUE FOR FLOW VISUALIZATION

V.M. Boiko, V.I. Zapryagaev, V.I. Kornilov, A.P. Petrov, A.V. Solotchin[1],
V.E. Lishchenko, and M.V. Polonevich[2]

[1] Institute of Theoretical and Applied Mechanics SB RAS,
630090 Novosibirsk Russia
[2] Novosibirsk State University, 630090 Novosibirsk, Russia

In practical aerophysical studies, there is a wide spectrum of research tools for measuring flow velocity in a vicinity of flow over a body, the most widely used ones among which still being Pitot tube and hot-wire anemometer. In spite of undoubted advantages offered by these instruments, these techniques provide only local information about a flow, and experiments aimed at the whole velocity fields require too labor-consuming measurements. That is why various kinematic methods such as PIV and PTV are finding ever-widening application. The spark tracing technique may be added to these methods.

This method, based on photographing periodic spark discharges, has clear foundations behind. A first spark discharge produces a low-resistance ionized channel that subsequently travels with the gas flow. To register the travel length of the discharge channel, a series of subsequent spark discharges initiated at fixed time intervals is used. If the period between two discharges is short enough, then a subsequent discharge passes along the already existing ionized channel whose sections for the time between the discharges, owing to low inertia of the ionized gas, travel with the flow over distances proportional to local flow velocities.

The spark tracing technique allows one to measure both steady-state and non-steady flows and reveal their characteristic features such as shock waves, flow separation regions, reverse-flow regions, etc. Setting with precise accuracy time interval between spark discharges and measuring distance between successive photographed images of spark-discharge channels enable one to built the flow velocity field in the flow region covering by sparks.

The present study was aimed at further development of the spark tracing technique for probing flows with periodic spark discharges and an automated system for processing the flow patterns obtained by this method.

To implement the method, we have designed a ten-channeled high-voltage pulse generator with adjustable pulse amplitudes and precisely controlled time intervals between pulses. The design of the generator and results of its testing were described in detail elsewhere [1]. The highest amplitude of a first pulse is $U \approx 100$ kV, and the output amplitudes of subsequent pulses are $(0.1\div0.25)$ U. The pulse duration is about $5{\cdot}10^{-7}$ s. The output pulse period can be preset in the range between 1 and 200 μs with an accuracy of $5{\cdot}10^{-8}$ s. A possibility of independent adjustment of the amplitudes of subsequent pulses provides conditions for a minimum level of induced disturbances owing to a reduced amount of energy released in the spark-discharge region.

The spark tracing visualization tests in a vicinity of a flow over a model were carried out in the core of the initial length of a turbulent subsonic air jet. The jet emanated out of an axisymmetric nozzle into a submerged space with atmospheric pressure and ambient temperature. The nozzle with the exit diameter $d_a = 4{\cdot}10^{-2}$ m was mounted in the settling chamber of a jet setup whose technical and gasdynamic characteristics were previously reported

Report Documentation Page

Report Date	**Report Type**	**Dates Covered (from... to)**
23 Aug 2002	N/A	-

Title and Subtitle Further Development of the Spark Tracing Technique for Flow Visualization	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Institute of Theoretical and Applied Mechanics Institutskaya 4/1 Novosibirsk 530090 Russia	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) EOARD PSC 802 Box 14 FPO 09499-0014	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
See also ADM001433, Conference held International Conference on Methods of Aerophysical Research (11th) Held in Novosibirsk, Russia on 1-7 Jul 2002

Abstract

Subject Terms

Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU

Number of Pages
5

in [2]. The models under study were a circular and an elliptic cylinder. The flow Mach number at the nozzle exit and, hence, in the jet core was varied in the range from 0.05 to 0.5.The Reynolds numbers determined from the jet velocity V_a and cylinder diameter were in the range $\mathrm{Re}_d = (0.95–9.5)\cdot 10^4$.

Figure 1, *a* shows the schematic of the nozzle (the flow is directed upwards) with the installed circular-cylinder model; also shown is the layout of knife electrodes with respect to the issuing jet. The photographs of Fig. 1, *b, c,* and *d* show a representative succession of spark tracks for a spark series obtained at different Mach numbers of the flow M and different time intervals Δt between the discharges. In the case shown in Fig. 1, *b*, the conducting body of the model was used as one of the electrodes. Different spark patterns were obtained in the tests in which the model was an insulating (Fig. 1, *c*) or a conducting body (Fig. 1, *d*).

Similar photographs, from which exact positions can be easily found, allows one to reveal a number of flow features and properties. The following flow features are clearly seen in the photographs: a flow separation region that becomes more pronounced with increasing M, a distinct reverse-recirculation region in the wake behind the cylinder, breakdown of regular structures of the Karman-street type, and effects caused by the three-dimensional structure of the flow. The brightness and contrast of spark-channel images depends on the flow density. The lower the density, the wider and less bright are the spark tracks. It may be therefore concluded that the spark tracing method is especially promising for studying dense gas flows.

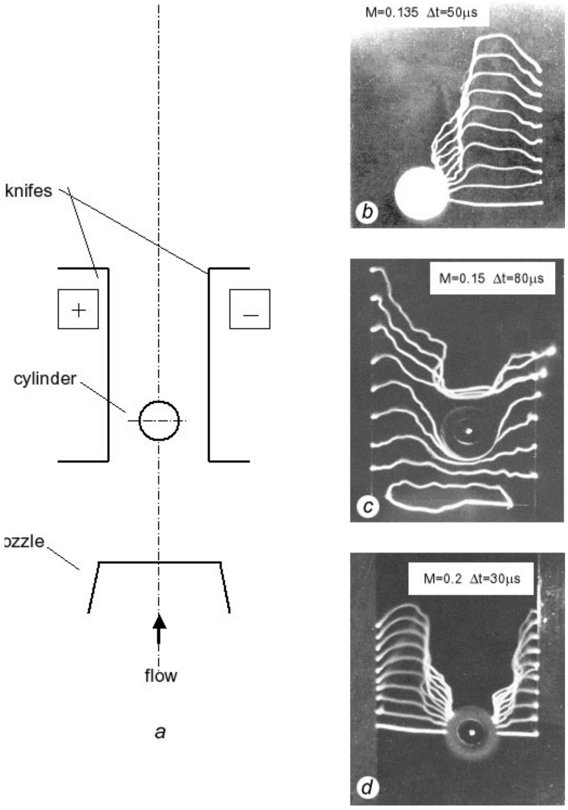
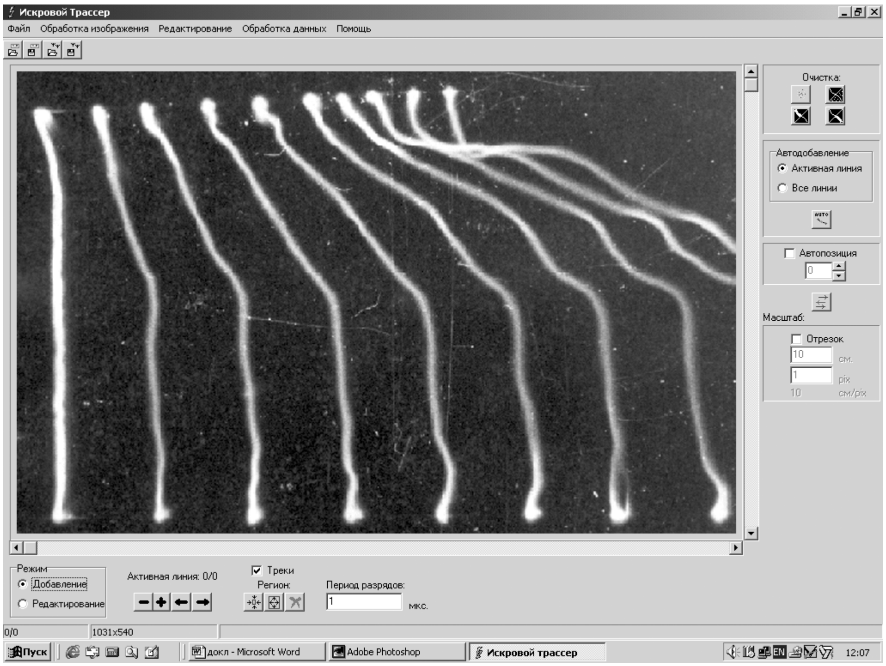


Fig. 1.

To work out the experimental procedure, at the first stage the velocity fields were determined using a simplified algorithm devised for the simplest case of a one-dimensional shear flow. An equidistant grid oriented along the approach-flow direction was superimposed onto the image obtained, and the intersection points of the grid with the tracks were determined. The local flow velocities were found as quotients of the coordinate difference between the neighboring spark tracks along the grid lines and the period between the sparks multiplied by a scale factor. It was assumed that the values thus obtained corresponded to the midpoint between the two tracks.

The total error in the determination of the flow velocity is owing to the measurement errors of the time interval and spacing between the spark, and also owing to the error caused by possible lack of correspondence between the travel velocities of the spark tracks and flow *a*



Автодобавление: ● Активная линия ○ Все линии

☐ Автопозиция: 0

☐ Отрезок: 10 см.; 1 pix; 10 см/pix

Режим: ● Добавление ○ Редактирование

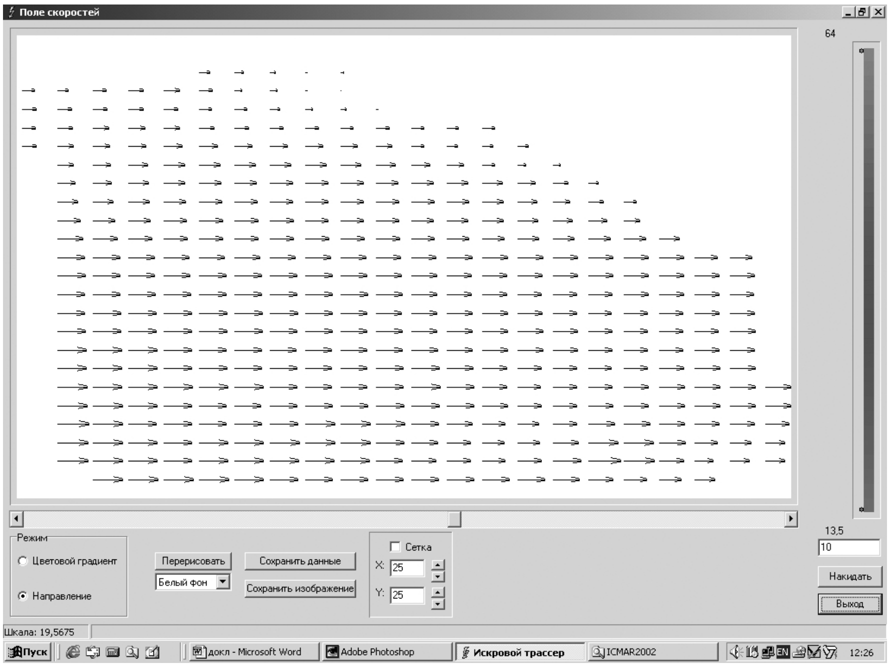
Активная линия: 0/0

☑ Треки

Период разрядов: 1 мкс.

0/0 1031x540

b



Режим: ○ Цветовой градиент ● Направление

Белый фон

☐ Сетка

X: 25

Y: 25

10

Шкала: 19,5675

Fig. 2.

itself. The ion fluctuation in the gas flow may give rise to spark gap breakdowns in quite unexpected places, which circumstance should necessarily be taken into account. The discharge channel widening may also largely affect the measurement accuracy since subsequent discharge trajectories may pass through different particles inside the relaxing plasma pinch. The track expanding, a subsequent discharge will follow a shortest path, i.e., the path along the concaved side of the track.

A human processing of a track pattern is too labor-consuming one. The use of a video-camera substantially facilitates inputting the taken image into a computer and its subsequent mathematical processing. A special computer code was developed to process multi-spark discharge images in an automated mode. This software code allows a preliminary processing of the image, i.e., it allows one to eliminate a small-scale noise from the image, widen or narrow the channel image (see the «Cleanup» option in Fig. 2, *a*), etc.

Then the operator denotes individual tracks with several points, the tracks subsequently being enumerated. The program adds a sufficient number of additional points to each track with simultaneous positioning all available points along the line of maximum intensity of the track image. A provision is made for editing the location of the points by hand. The latter option may prove useful if the image is too noisy or if the distance between neighboring tracks is too short so that a "jump" onto adjacent tracks may occur.

The time and linear scales shall be input into a «Period between discharges» window and into a «Scale; segment» window, respectively.

On pressing the key ⇄, the program calculates and plots the velocity field. The results may be represented either in color or as a vector field (see Fig. 2, *b*).

Both the numeric-data array and the flow velocity pattern may be saved as a bmp-file.

The developed instrumentation was tested by comparing the results it yielded with the data obtained by other methods. As an example, Fig. 3 shows the Mach number profile (plotted in the form M= *f*(r/r$_a$)) over the initial length of a subsonic jet. Here, the solid line shows the average data obtained with the help of a Pitot tube, and symbols show the data obtained by the spark tracing method. In the former case, the value of M was determined from the distribution of the total excessive pressure measured by a cylindrical Pitot with the diameter $d_{в} = 3\cdot10^{-4}$ m.

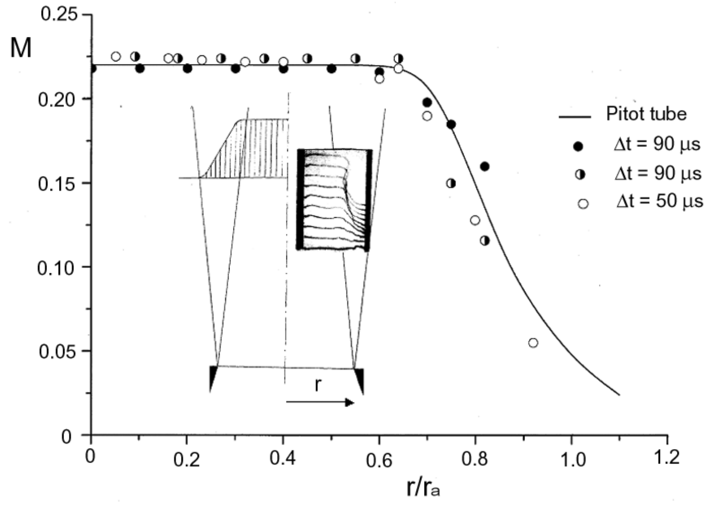


Fig. 3

The profiles of the total excessive pressure in various cross sections of turbulent jets were recorded by an H307/1 plotter. The electric signal from a pressure probe connected to the Pitot tube was fed to a plotter through auxiliary electronic devices. The total error ensured by the measuring system was less than ±3%.

The turbulent jet displayed the following regularity: the static pressure in the whole flow region was spatially uniform; for this reason, the flow velocity in the core formed by the internal boundaries of the mixing layer remained unchanged. Indeed, as follows from the Mach-number profiles across the jet, the distributions measured provide an indication that the flow core was rather stable over the initial jet length and the flow velocity in it equaled that at the nozzle exit. Besides, a fairly good agreement was observed between the experimental data obtained by two independent methods.

Taking into account similar results obtained for other flow velocities, a conclusion may be drawn that the developed technique, which ensures a minimum level of introduced disturbances, offers rather an effective probing tool for visualizing sub- and supersonic flows. However, further studies are required to examine whether this method can be applied or not to more complex flows such as essentially 3D flow structures.

REFERENCES

1. **Afonin Yu.A., Petrov A.P., Nalivaichenko D.G.** Application of a high-voltage multichannel pulse generator for visualization and measurement of the gas flow velocity // Thermophysics and Aeromechanics. 2002. Vol. 9, No. 1, P. 143–149.
2. **Zapryagaev V.I., Solotchin A.V.** Three-dimensional structural features of an under-expanded supersonic jet // J. Appl. Mech. Tech. Phys. 1991. No. 4. P. 42-47.