Visualization of the aerodynamic vortices by Background Oriented Schlieren

Sergey I. Inshakov [1], Nadezhda M. Skornyakova [2], Anton Yu. Poroykov [2], Dmitry G. Sychev [2]

[1]Central Aerohydrodynamic Institute, Moscow, Russia
[2] V.A.Fabrikant Physics Department, National Research University "MPEI", Moscow, Russia
*corresponding author: nmskorn@mail.ru

Abstract Investigating of toroidal vortices (vortex rings) currently arouses growing interest. Their presence reveals in various fields of science and technology: the effect of a vortex ring while helicopter decreasing, vortex rings in the ventricle of the heart, the internal structure of ball lightning and more.
Background Oriented Schlieren (BOS) – one of the relatively young methods of diagnostic of optical inhomogeneities based on the use of the reference and distorted images of a background pattern. This method is commonly used in aerodynamics, hydrodynamics and heat transfer. The main advantages of this method are the simplicity of implementation and an almost unlimited field of view.
In this work laboratory testing of the applicability of the Background Oriented Schlieren method for aerodynamic problems was carried out. For result verifying simultaneous registration via shearing interferometer was used. Field of view of the camera for the Background Oriented Schlieren and the interferometer were situated close and at a small angle to each other. Toroidal vortex was recorded directly at the output of the generator. Background pattern for Background Oriented Schlieren and interferometer mirror were located in the same plane. For achieving better contrast background pattern was illuminated by LED spotlight.
Keywords: toroidal vortices, Background Oriented Schlieren method, shearing interferometer

1 Introduction

Large amount of the information may be obtained by visual observation. But not every physical phenomenon is easy for observation by the human eye. The fact that it is not visible does not mean that it can be neglected and does not diminish its importance. For example, without studying the air flows around the aircrafts, problem of optimization of its form would have remained unresolved. The need for research in these areas is obvious. To obtain qualitative and quantitative results of the experiment are used optical imaging techniques [1]. One of these methods is described in this article.

This work is devoted to the Background Oriented Schlieren method [2]. This method is relatively young, but it is widely used in various fields. The undeniable advantages of this method are relatively modest requirements for the equipment used in experimental setup, the possibility of using this method in field conditions [3], an unlimited field of view, high sensitivity and fast calculations. Background Oriented Schlieren can measure all the parameters of the test flow that determine the gradient of the refractive index [4, 5].

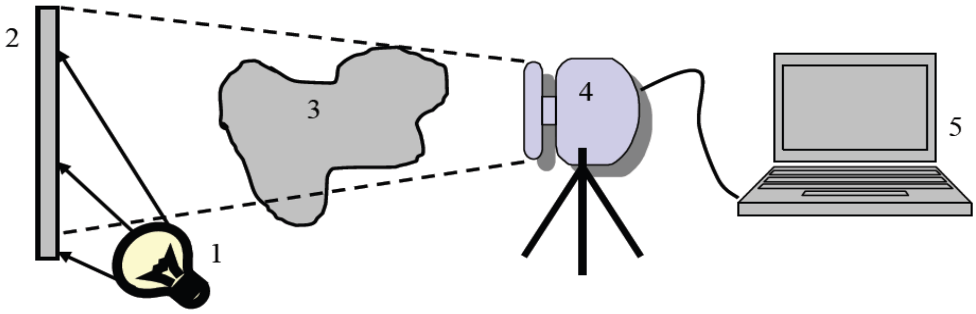
The investigation of the applicability of Background Oriented Schlieren for aerodynamic experiment was conducted. As a test object was chosen toroidal vortex which was created by a special generator.

2 Principle of Background Oriented Schlieren method

The principle of visualization of Background Oriented Schlieren (BOS) method images is quite simple. It consists of using distorted images of special structured picture – background pattern (or simply pattern). The first image (the reference) is recorded in the absence of any perturbation between the pattern and the camera, the second (the measuring) – in the presence of perturbations. The heterogeneity of the refractive index gradient in the test medium leads to distortion of image of pattern captured by the camera.

Further processing of the images is done in standard or specially designed programs with a cross-correlation method on PC.

After analyzing the displacement of the characteristic elements of the background pattern on captured images, quantitative information on the integral refractive index of the test medium can be obtained. Figure 1 shows a scheme of experimental setup for capturing images of Background Oriented Schlieren method visualization.



1 – incoherent light source, 2 – background pattern, 3 – test medium, 4 – camera, 5 – PC with software
Fig. 1 Scheme of experimental setup for capturing images of background oriented schlieren method visualization

3 Toroidal vortex

Toroidal vortex (vortex ring) – a phenomenon in which an area of a rotating liquid or gas moves through the same or another area of the liquid or gas, and the flow takes the form of a toroid. The friction between the moving air flow and stationary air slows down air layers relative to its core. Simultaneously the forward flow movement forms the low pressure area behind it. The layers of stationary air bend around moving flow and gather behind him, and then fall directly into the vortex. Where layers addicted forward by faster inside part. This results is a vortex ring. Schem[illegible] toroidal vortex is shown in Figure 2.

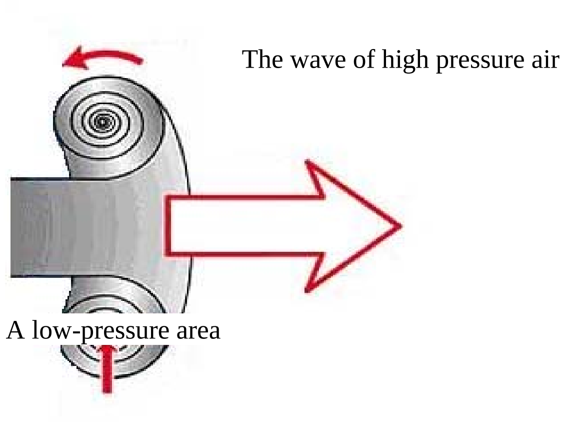


Fig. 2 Schematic representation of the toroidal vortex

Known fact that the landing helicopters cause appearance of toroidal vortices. The flow of air which moves through the blade wraps outwardly and further rises and dragging inward again goes through the blade. Such air circulation can lead to catastrophic loss of height of the helicopter and creates the possibility of its collapse. The presence of the phenomenon and the probability of catastrophic consequences of its occurrence show the relevance of studies of this problem.

4 Experimental setup and the results of experimental studies

Images for Background Oriented Schlieren method were obtained by a high-speed camera model Fastec HiSpec 1 at 1000 frames per second. To improve quality of visualization air inside the vortices generator was heated to a temperature of about 50° C by combustion of acetone, at ambient temperature 23° C. For processing two images were used: one without a vortex in the camera field of view, the second – in his presence. As a result, qualitative visualizations of toroidal vortex since moment of its inception to moment of appearing flow after its passage were obtained.

In another arm of the measuring device mirror interferometer IT-228 with lateral shift was used. The field of view of this type of interferometer is determined by the size of the spherical mirror. Mirror with diameter 220 mm and the focal length 3 m was used. The experiments were conducted with a small vertical shift of 2 mm (0.01 field of view) with setting to the zero band of infinite width. Images of toroidal vortex was obtained by high-speed camera FASTCAM SA5 model 775K-M1, with the rate of 1000 frames per second and the exposure of 1 ms.

On photos (Figures 3, 4) the developed experimental setup for visualization of laboratory generated toroidal vortices is presented. Figure 5 is shown optical scheme of the shearing interferometer IT-228.

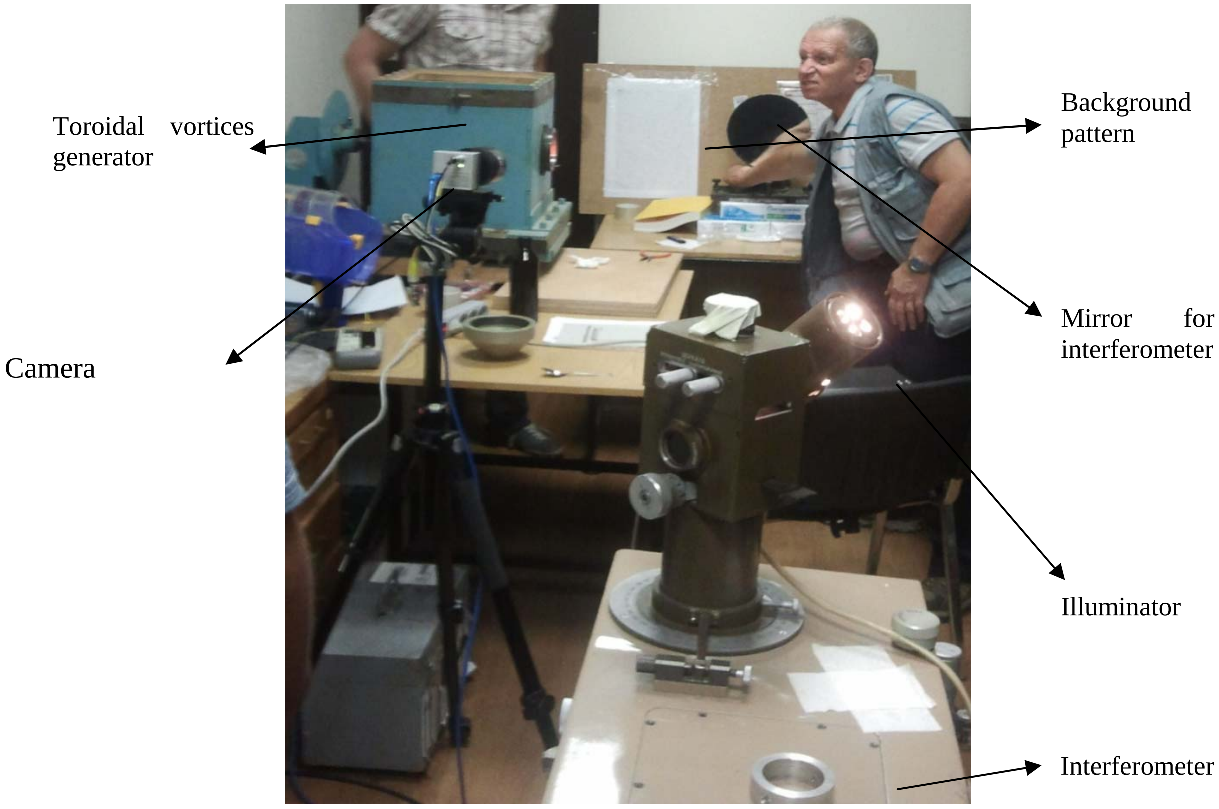


Fig. 3 The part of experimental setup for realization Background Oriented Schlieren method

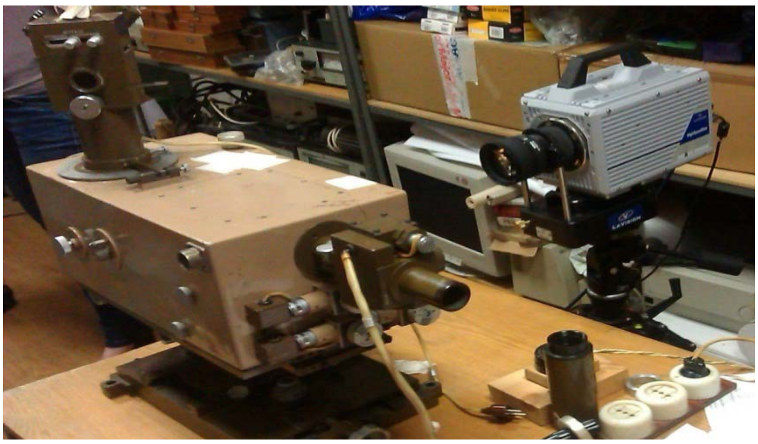


Fig. 4 The part of experimental setup with interferometer for control measurements

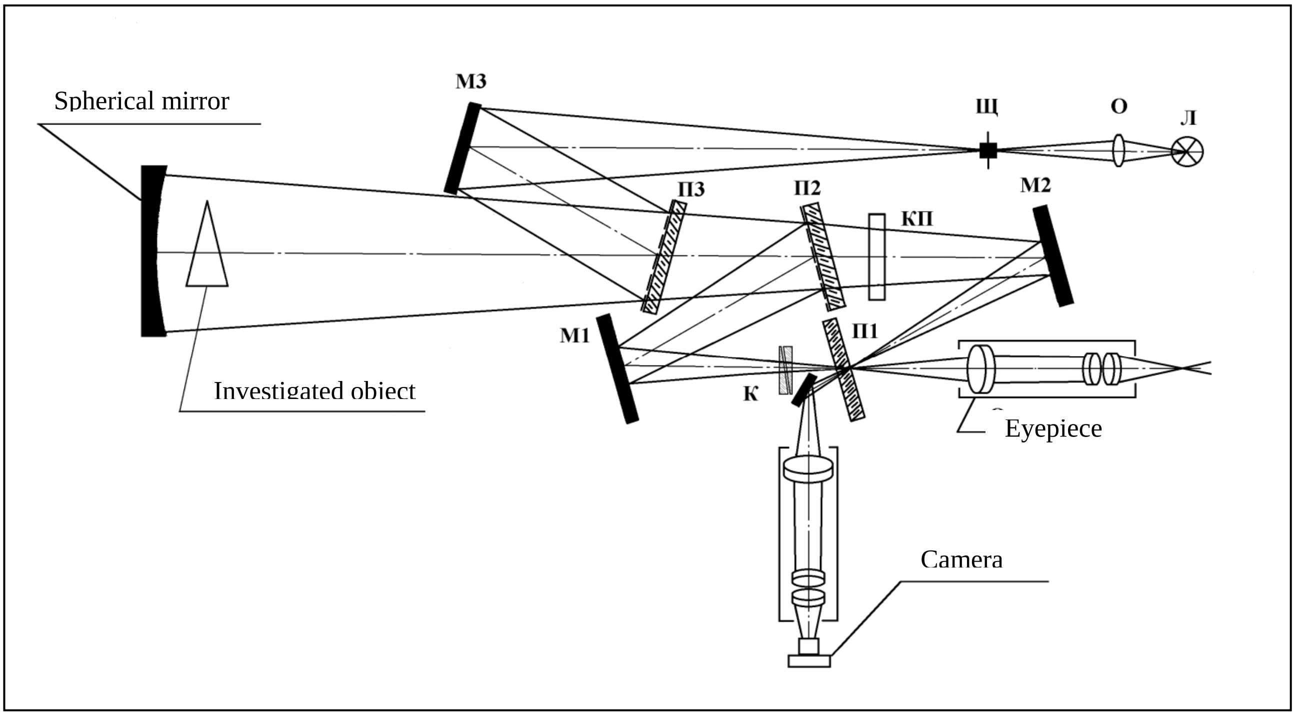


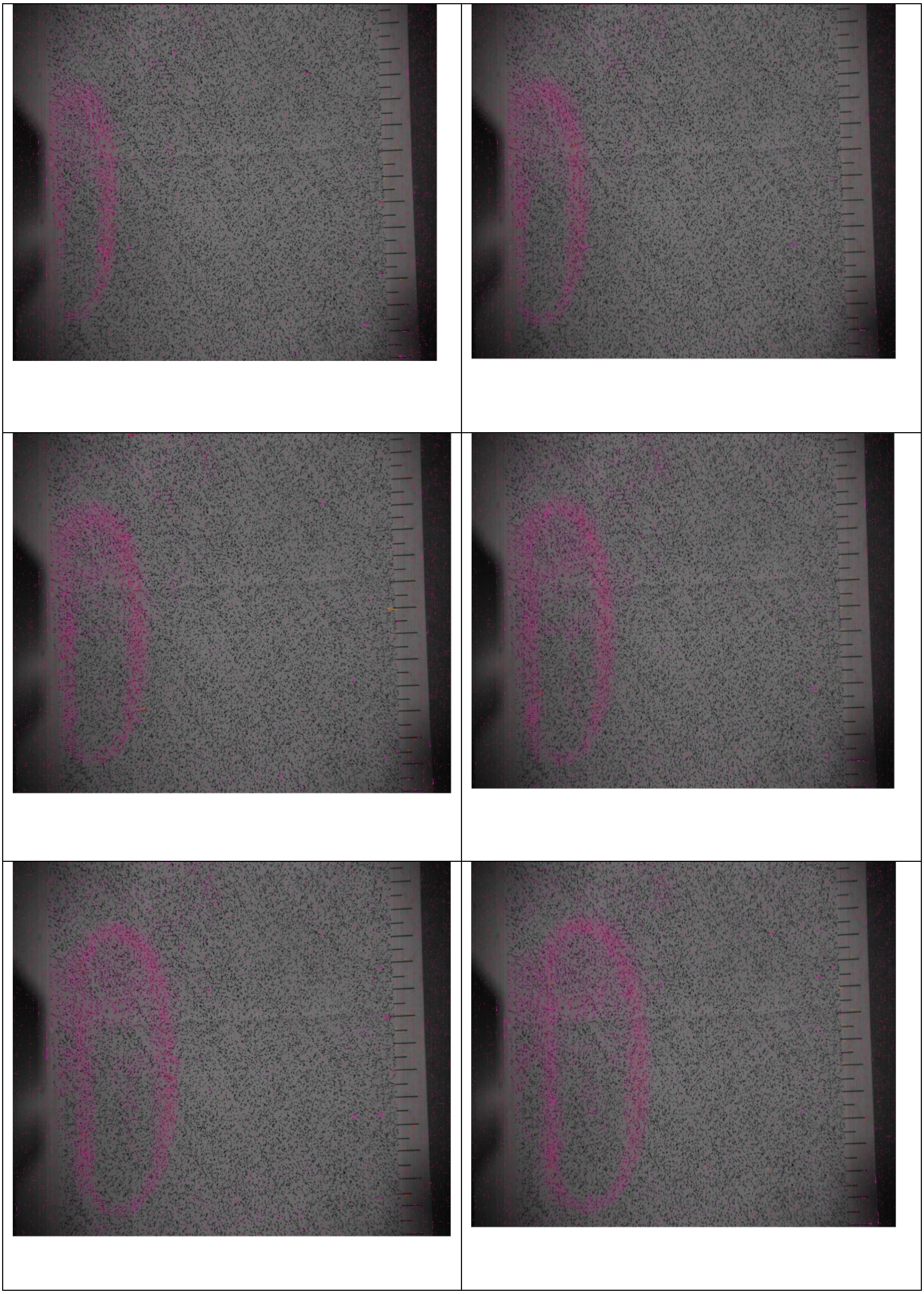
Fig. 5 Optical scheme of the shearing interferometer IT-228

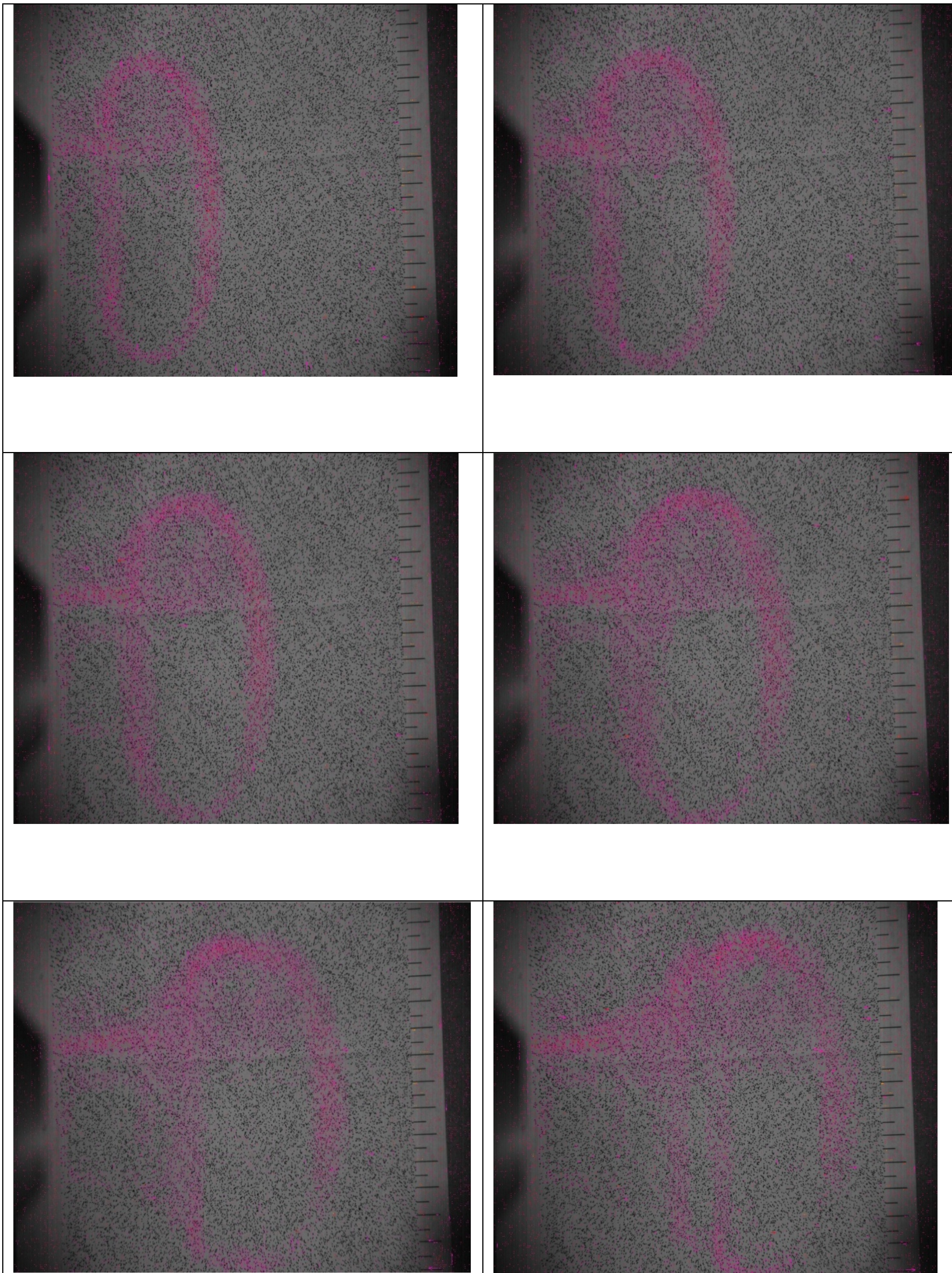
Field of view of the camera for Background Oriented Schlieren method and the interferometer were close and at a small angle to each other. Toroidal vortex recorded directly at the output of the generator. Pattern of Background Oriented Schlieren method and mirror of interferometer were located in the same plane. For getting best contrast background pattern was additionally illuminated.

Image registration was performed using a high-speed camera model Fastec HiSpec 1 with a frequency of 500 or 1,000 frames per second and a resolution of 1280×1024 pixels. The field of view was 220×175 mm.

For increasing sensitivity of Background Oriented Schlieren air inside the vortex generator was heated by combustion of acetone to a temperature of about 50 C.

The experimental setup allowed to obtain consecutive images of the origin and spread of the toroidal vortex in space. Figure 6 shows the results of the processing of the Background Oriented Schlieren method images. Images were captured with the speed 500 frames per second, that is, 2 ms between two consecutive images. Full time of the vortex observing was 28 ms, after this time it came out of the camera field of view.





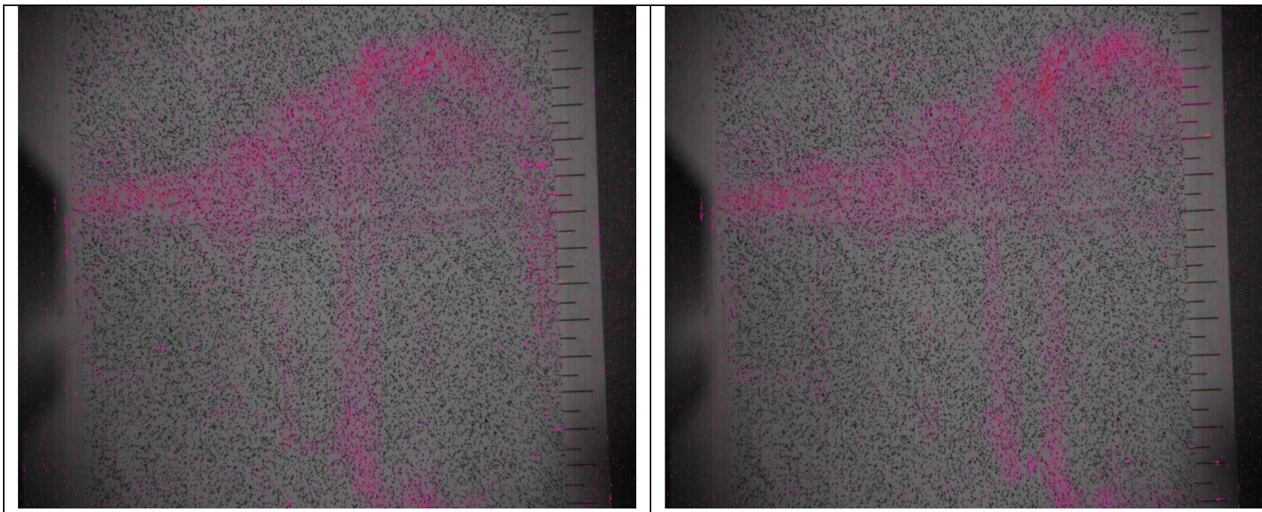
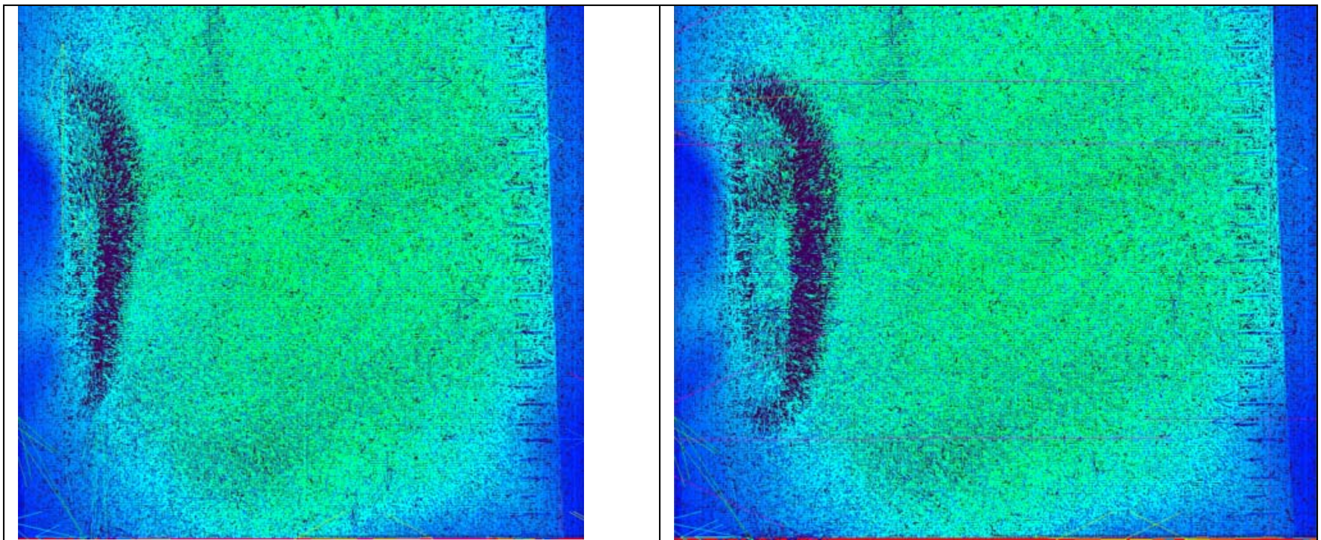
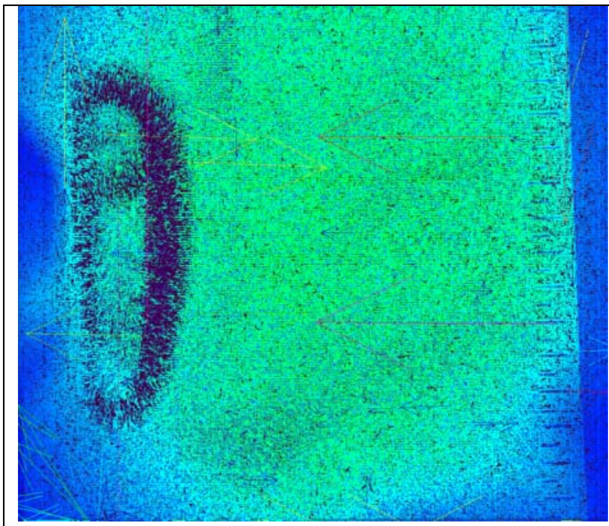


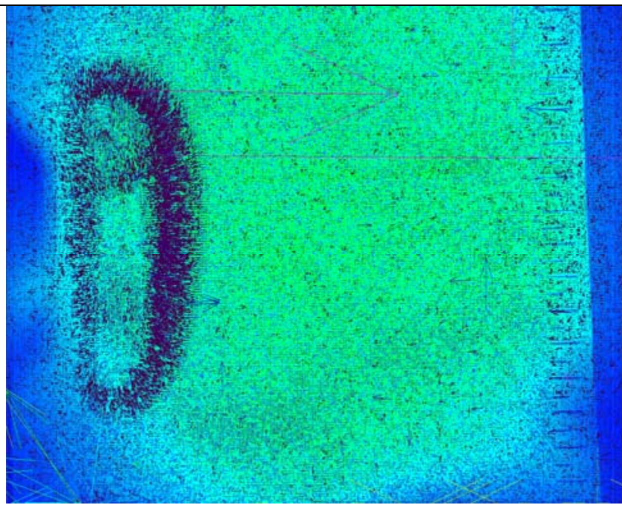
Fig. 6 Consecutive visualization of toroidal vortex origin and spreading (BOS)

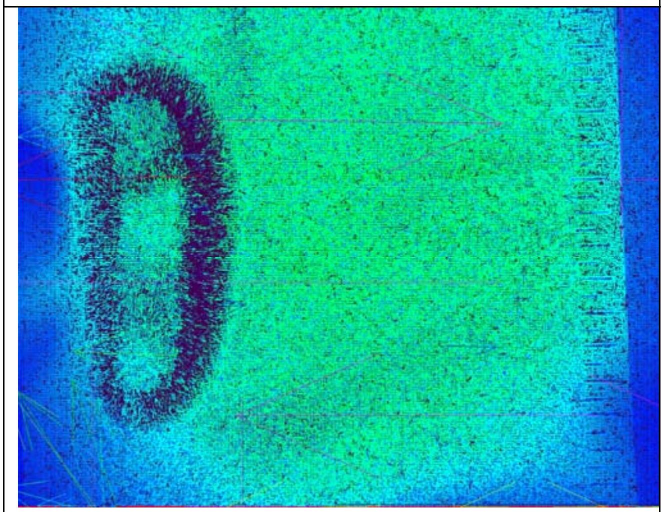
Figure 6 shows images with the structure of the vortex. It is also possible to assess the geometric parameters of the vortex structure using a normalization line located on the right side of each frame. Dividing price of line is 5 mm.

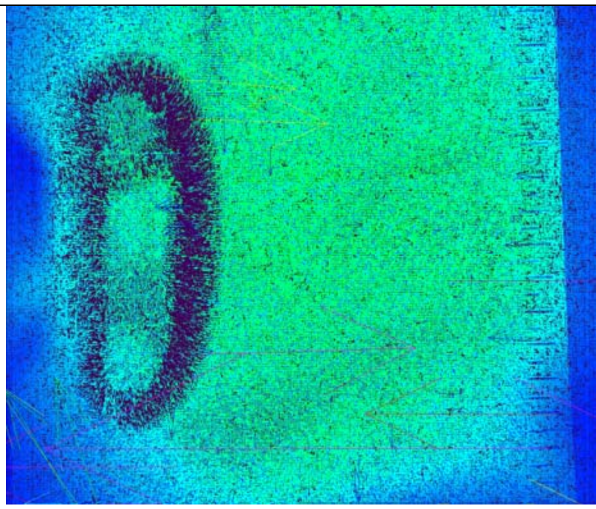
The results of another generated vortex shown in Figure 7. Images were captured at speed of 500 frames per second, the time of the vortex observation was 32 ms. On Figure 7 was chosen another way to display the results, the background pattern is not visible, but the structure of the vortex is shown more clearly. Normalization line in the right part of the image is still displayed and allows to determine the geometric parameters.

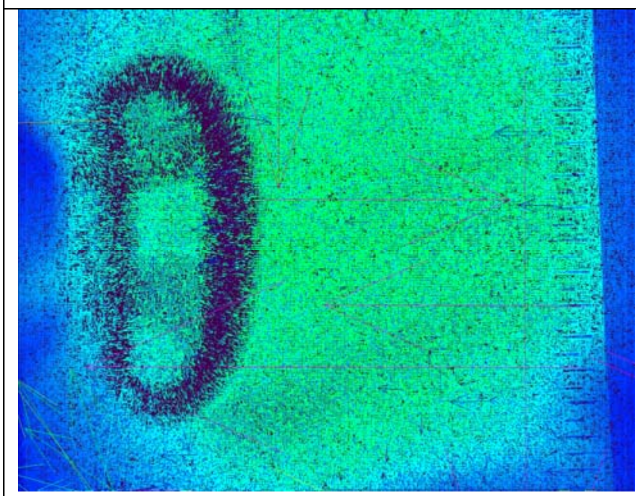


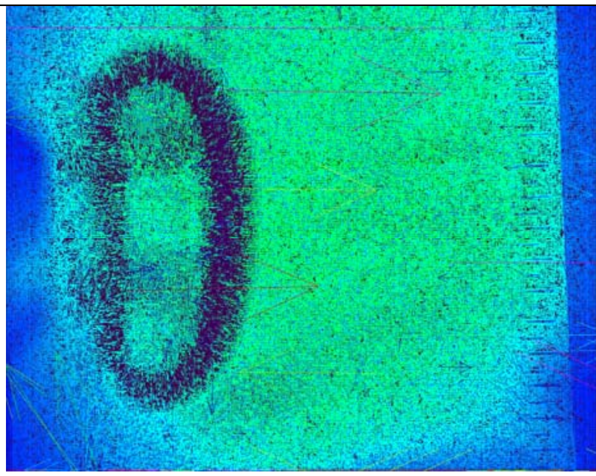


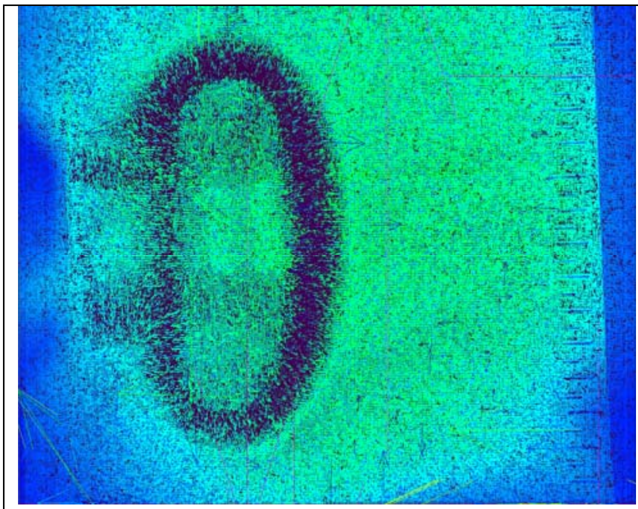


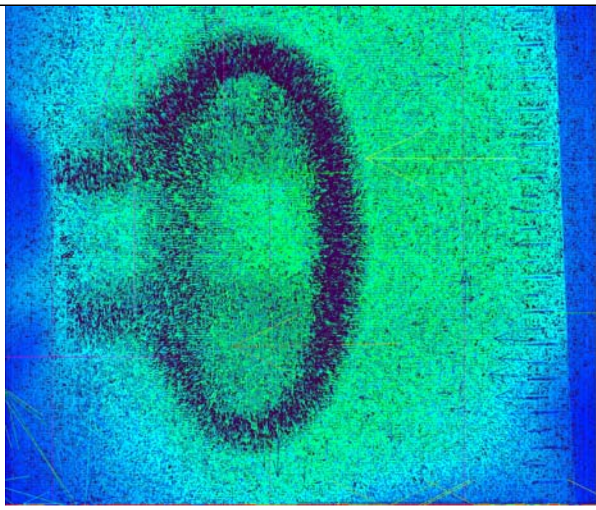


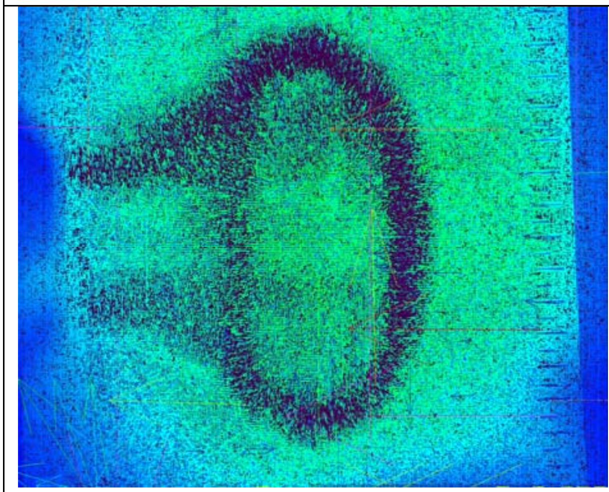


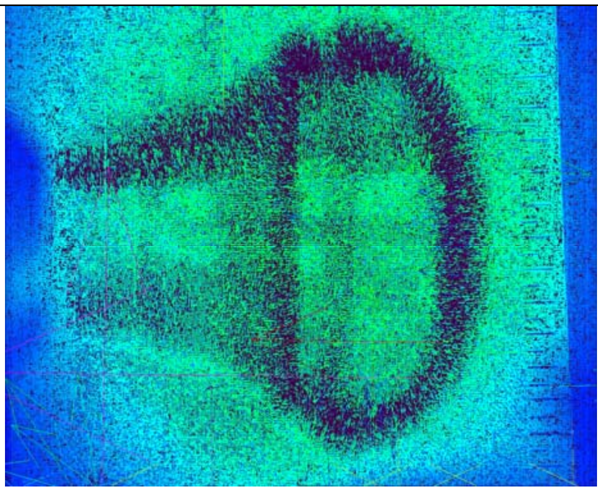


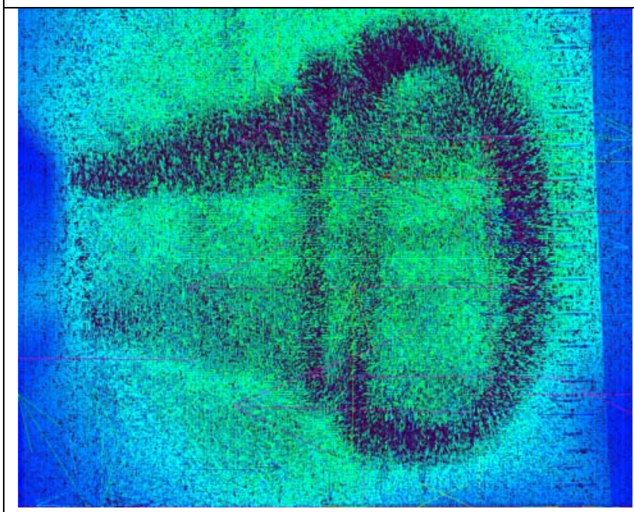


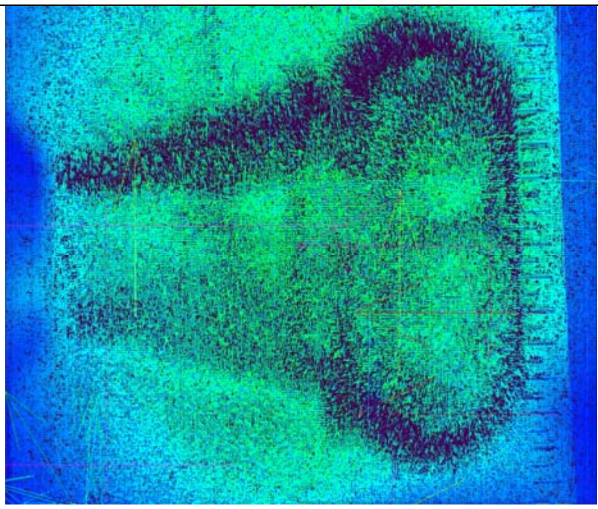












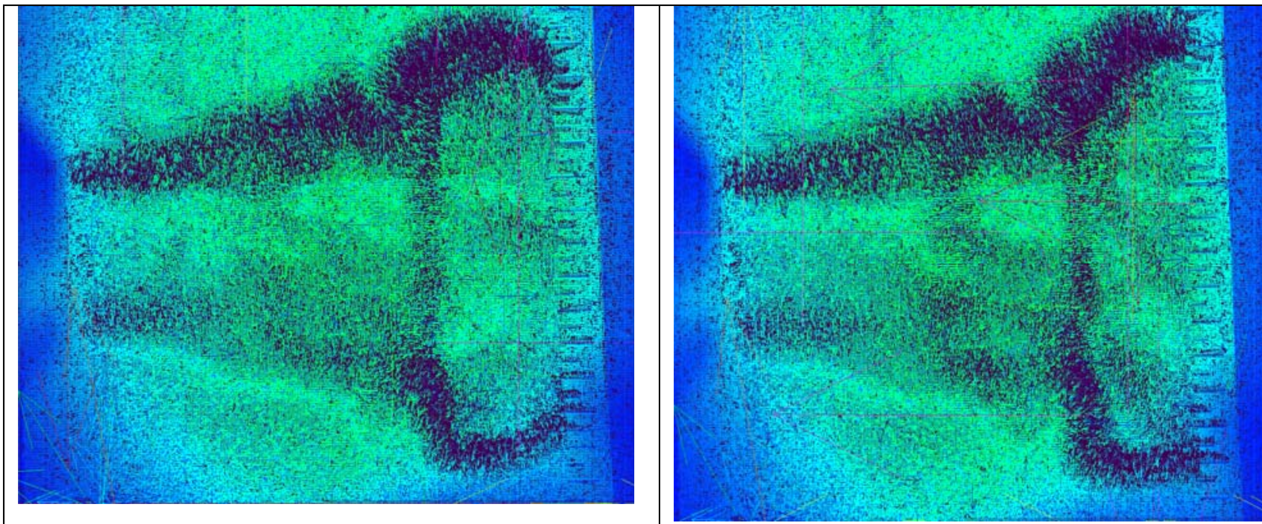
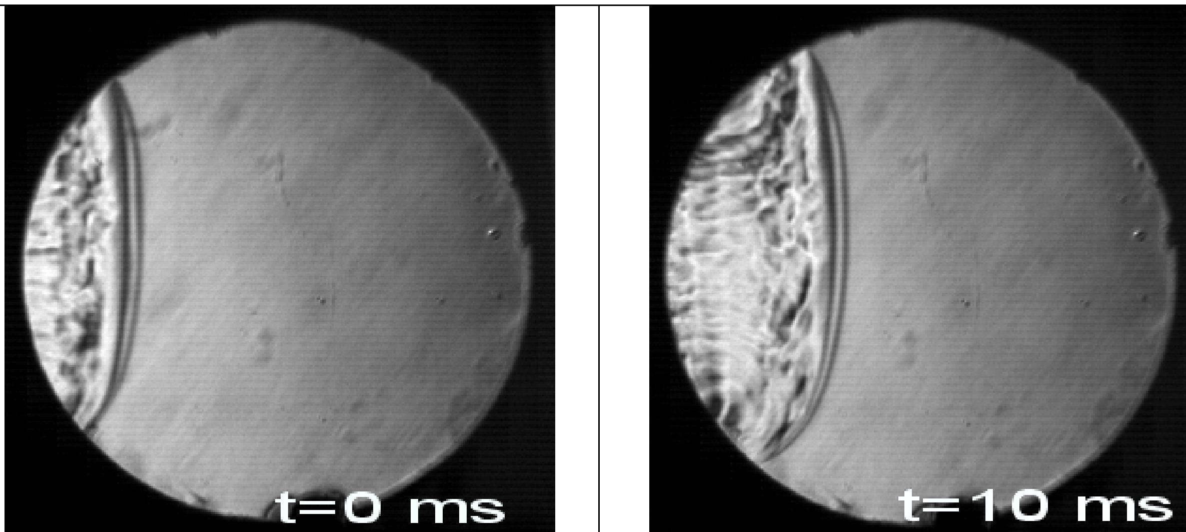
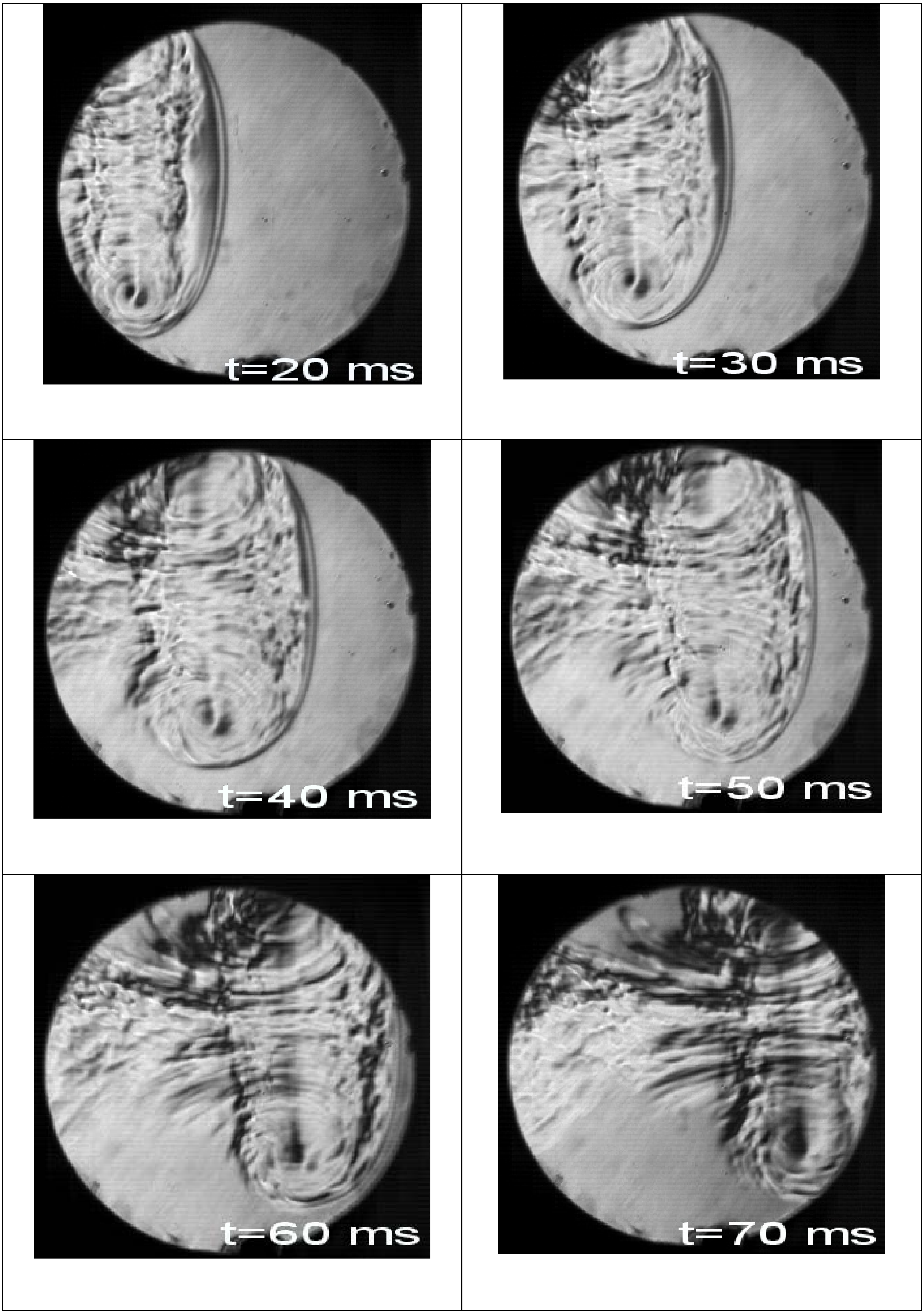


Figure 7 – Consecutive visualization of toroidal vortex origin and spreading (BOS). Dividing price of line is 5 mm.

This vortex is also visualized by means of shearing interferometer. Mirror diameter was 220 mm, focal length was 3 m. The experiments were conducted with a small vertical shift of the order of 2 mm (0.01 field of view) with setting the on the line of infinite width. Capturing toroidal vortex made by high-speed camera FASTCAM SA5 model 775K-M1 at the speed of 1000 frames per second, the exposure was 1 ms. Figure 9 shows the sequence of images of vortex passage in front of the mirror, the interval between images is 10 ms.




t=20 ms
t=30 ms
t=40 ms
t=50 ms
t=60 ms
t=70 ms

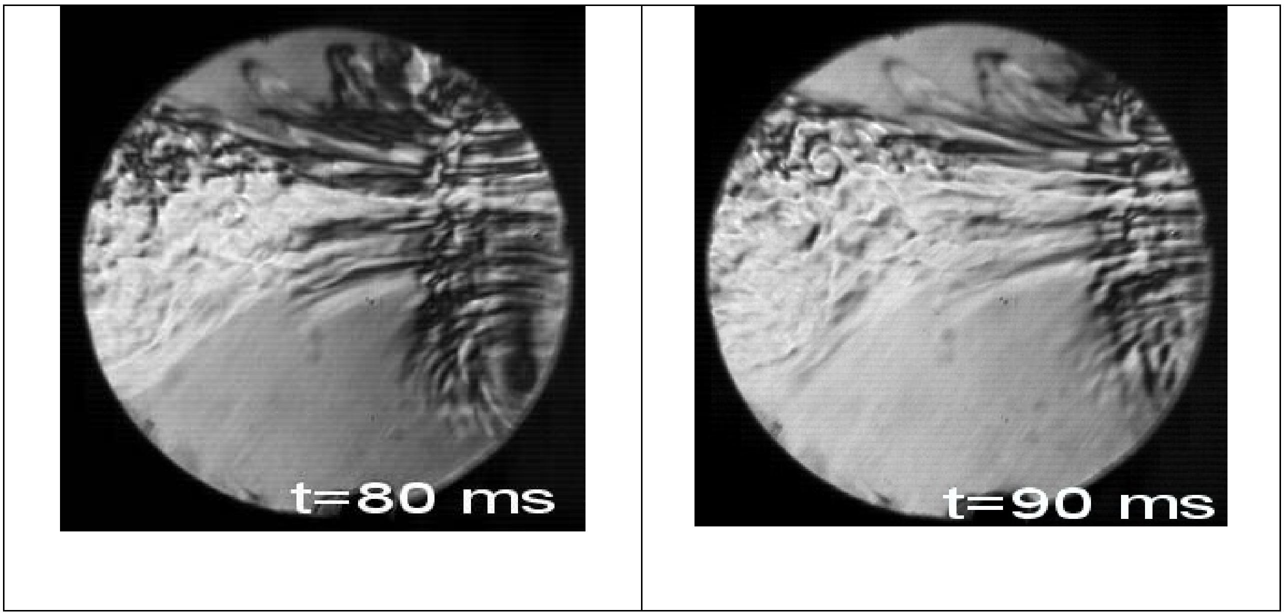


Figure 8 – The sequence of images of toroidal vortex passage in front of the spherical mirror (Shearing interferometer)

CONCLUSION

One of the main advantages of BOS compared to other optical methods of flow investigation is the simplicity of its implementation. This method makes it possible to measure all the parameters of the test flow that determine the gradient of the refractive index. The BOS experimental setup consists of incoherent light source, background pattern, test flow, camera, computer and software. At the same time, with the optimal parameters of the installation high resolution and sensitivity can be obtained. As an additional advantages of this method unlimited field of view and, consequently, unlimited size of the object, considerable speed computer image processing, high accuracy, fast computation and two-way sensitivity can be named.
In this work laboratory testing the applicability of the Background Oriented Schlieren method for aerodynamic problems was carried out. To confirm the results of BOS simultaneously measurements by shearing interferometer was used. Field of view of the camera for Background Oriented Schlieren method and the interferometer were close and at a small angle to each other. Toroidal vortex recorded directly at the output of the generator. Pattern of Background Oriented Schlieren method and mirror of interferometer were located in the same plane. For getting best contrast background pattern was additionally illuminated.

Comparison of the obtained results shows that BOS sufficiently reliable visualizes the basic elements of a toroidal vortex, in particular, its outer surface and its track. As the field of view of Background Oriented Schlieren method is determined only by the field of the recording camera, and the classical imaging techniques (shadow and interferometric) have a relatively small field of view (no more than a meter), the Background Oriented Schlieren method is very promising for use in large wind tunnels for optical inhomogeneities visualization in size of several meters at a the flow around test models.

References

[1] Settles G.S. (2001) Schlieren and shadowgraph techniques: visualizing phenomena in transparent media. Berlin: Springer-Verlag.

[2] Meier G. E. A. (2002) Computerized background-oriented schlieren. *Experiments in Fluids*. Vol. 33. pp. 181 – 187.

[3] Rinkevichyus B.S., Skornyakova N.M., Mikhaleva E.M., Mikhalev A.S., Poroykov A.Yu., Udalov A.V.

(2013) Chapter 18. Investigation of background pattern for the outdoor application of the BOS method / In: Advanced In-Flight measurement Techniques. Eds.: Boden, F.; Lawson, N.; Jentink, H.W.; Kompenhans, J. Springer. pp. 305-320.

[4] Mikhalev A.S., Skornyakova N.M. (2011) A refraction system for studying evaporation of liquid drops from a solid surface. *Measurement technique*, Vol. 53, No. 12, pp. 1337–1341.

[5] Skornyakova N.M. (2012) Module of complex contactless monitoring of the environment on the basis of the background oriented schlieren method. In: Laser, measurement, information. S.-Pb. Polytechnical University, Vol.3, pp. 46-54.