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Visualization of Turbulent Wakes Behind Large Particles

A.A. Mochalov[1,A,B], A.Yu. Varaksin[2,A,B]

[A] Bauman Moscow State Technical University, Moscow, Russia
[B] Joint Institute for High Temperatures RAS, Moscow, Russia

[1] ORCID: 0000-0003-3078-1277, artem.mochalov@yandex.ru
[2] ORCID: 0000-0002-8799-6378, varaksin_a@mail.ru

Abstract

An attempt was made to visualize the flow formed in the wake of large particles moving in a downward turbulent airflow in the channel. The paper also considers the possibilities of reconstructing velocity fields behind a large particle from visual data. A diagram of the experimental setup is shown (geometry of the working area, auxiliary and main equipment). The PIV (Particle Image Velocimetry) system is briefly described. A technique for visualizing multiphase flow "gas – solid particles" is proposed. The original images of large particles (spheres) are shown. The results of the experimental determination of the characteristics of the wake vortex behind the rear critical point of a large particle are presented.

Keywords: visualization, particle image velocimetry, two – phase flows, turbulent wake, turbulence.

1. Introduction

Features of the movement of dispersed impurities in the form of particles in turbulent gas flows and its reverse influence on the turbulence characteristics of the carrier phase are key problems in the theory of two – phase flows. The inverse problem is to study the influence of particles on the characteristics of the gas flow carrying them. Solving this problem involves determining the characteristics of a gas in the presence of particles: velocity and temperature fields, friction and heat transfer coefficients, etc. [1-7]. Pioneering studies that studied the dissipation of turbulence energy by relatively low-inertia particles and the generation of turbulence energy by large particles in vertical and horizontal pipes are the works [8,9]. There is a fairly large number of experimental studies in which the authors studied the features of the process of additional dissipation of turbulence energy due to the presence of particles [10-12]. At the same time, there are practically no experiments to establish the influence of large particles on the turbulence energy of the carrier gas. The purpose of this work is to visualize the moment of turbulence generation behind a large moving particle.

2. Experimental setup for visualizing turbulent wakes

The installation for studying two-phase flows with large particles (Fig. 1) is a vertical channel. A fog generator ***1*** is installed at the entrance to the channel, followed by a lemniscate nozzle ***2***, to which a large particle supply unit ***3*** is attached using special pylons, through which the dispersed phase is supplied. Next, the air flow passes through the initial section of circular section ***4*** (diameter – 100 mm, length – 1000 mm, material – PVC) and then enters working section ***5*** (square section – side 100 mm, length – 1000 mm, material organic glass). The outlet section of the working channel is a plug for capturing the dispersed phase. The airflow leaves the channel using an adjustable fan as part of a cyclone type filter ***7***. Lemniscate nozzle ***2***, large particle supply unit ***3*** and cyclone filter ***7*** are made using additive technologies (FDM) from polylactide (PLA).

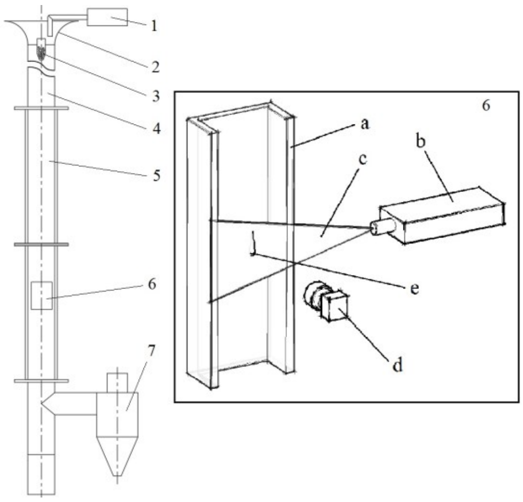


Fig. 1 Diagram of the experimental setup: 1 – fog generator; 2 – lemniscate nozzle; 3 – unit for supplying large particles; 4 – round pipe, initial section; 5 – square channel; 6 – measuring area and diagnostic tools; 6 (a) – measuring area of square section; 6 (b) – dual pulse laser; 6 (c) – plane of the laser "sheet"; 6 (d) – cross-correlation camera; 6 (e) – moving large particle; 7 – cyclone with adjustable fan.

Large spherical particles (Fig. 2) (material – plastic, physical density of particles – 1050 kg/m^3) with an average diameter of 6 mm are used as a dispersed phase in the experiment. The surface of the particles is blackened in order to reduce the effect of light reflection and flare of the receiving optics.

Fig. 2 Spherical particles

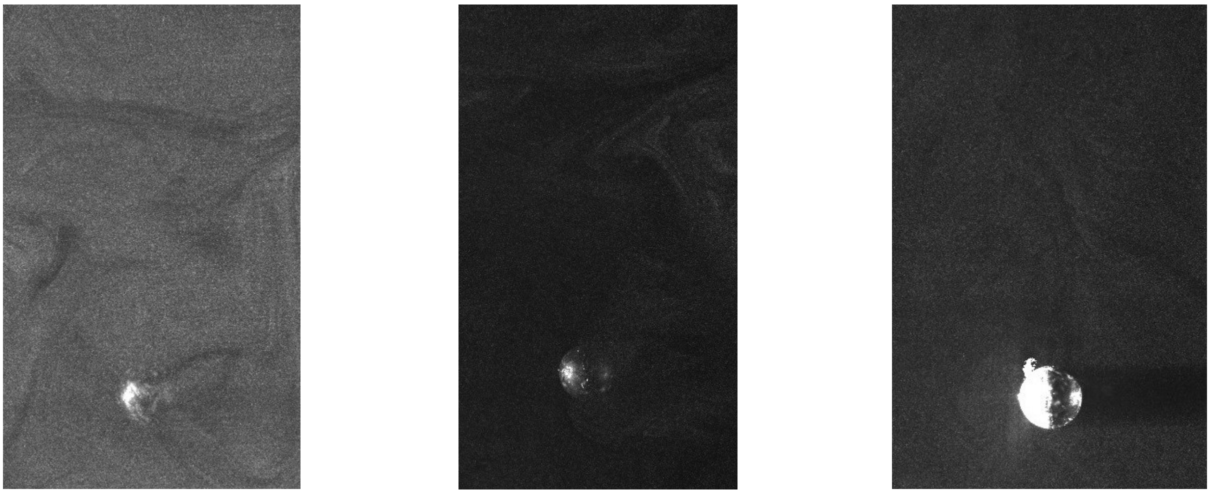
Also, as a dispersed phase, in order to visualize the air flow, microdroplets (substance - glycerol, physical density - 1260 kg/m^3) were introduced into the flow using a fog generator (model Safex F2010) with a diameter of 1 to 5 μm (Fig. 3).

Fig.3 Micro drops of glycerin

Photography of turbulent wakes behind large moving particles was carried out using the PIV (Particle Image Velocimetry) anemometry complex based on particle images. The measuring complex includes: cross-correlation camera ***6 (d)***, (model Flow Sense EO 2M) with a resolution of 1600 x 1200 pixels and an installed lens (model Zeiss 50 mm f/1.4 ZF.2) and dual pulse laser ***6 (b)*** (Dual Power model 145 – 15) with an energy of 145 mJ and a wavelength of 532 nm.

3. Visualization of turbulent wakes behind large particles

Visualization of turbulent wakes behind large moving particles was carried out as follows. From the large particle supply unit, plastic spheres enter the initial section of the round section, then enter the transparent measuring area of the square section, where they accelerate to a speed of V_p = 5,2 m/s. At the same time, micro drops of glycerol in the form of a mist enter the working channel through the lemniscate nozzle and take on the velocity of the carrier gas, which on the channel axis is about$V$ = 1,8 m/s. When the plastic sphere reaches the measuring area, it is illuminated with a flat laser "sheet" and then photographed. Figure 4 shows characteristic images of moving large particles caught in the frame, surrounded by micro drops of glycerin. It is worth noting that there are not many successfully photographed particles; in fig. 4(a) and fig. 4(b) shows particles that did not fall into the plane of the laser "sheet" and into the focus of the camera. While, in fig. 4(c) shows the case of a successfully photographed particle; the shadow of the laser "sheet" is clearly visible in the frame.



(a) (b) (c)

Fig. 4 Characteristic images of moving large particles, frame size 25x40 mm: (a) – particle behind the plane of the laser "sheet"; (b) – particle in front of the plane of the laser "sheet"; (c) – particle in the plane of the laser "sheet"

4. Characteristics of a turbulent wake behind a large particle

The use of the optical method of diagnostics of velocity fields "PIV" in the experiment makes it possible to determine the main characteristics of the vortex wake behind a large particle. During the experiments, the diagnostic system was controlled from a computer using the "Dynamic Studio" software package. Diagnostics were carried out with a frequency of 10 Hz. The thickness of the laser "sheet" formed by a cylindrical lens was about 1.5 mm in the measuring area. The measuring area coincided with the central section of the working channel. The size of the measuring area was about 100 x 100 mm. An adaptive PIV algorithm was used to calculate the instantaneous velocity field. To find the characteristics of the flow in the wake of a particle, the maximum spatial resolution of a vector map with a size of computational areas of 16 x 16 pixels has been determined, which corresponds to a physical size of 0.5

x 0.5 mm². The threshold signal/noise value was 6.5. The threshold value for the height of the correlation peak was 0.45. The limit for detecting a particle against the background of "noise" was 5. The nominal number of particles in each of the calculation areas was 10.

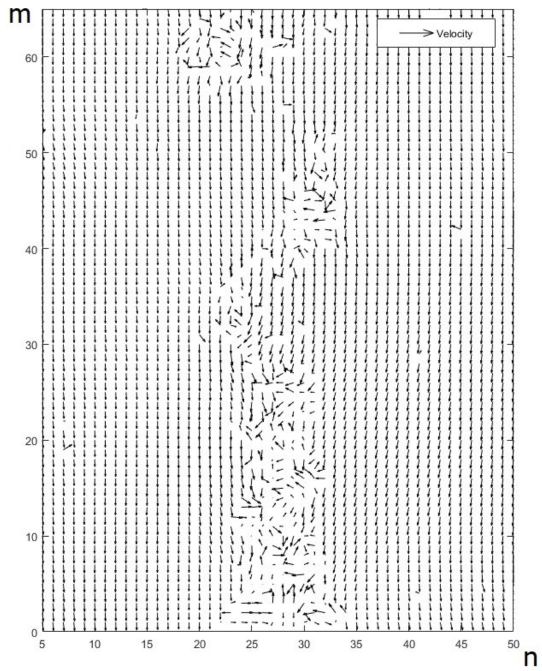


Fig. 5 Vector map of the wake vortex behind a large particle

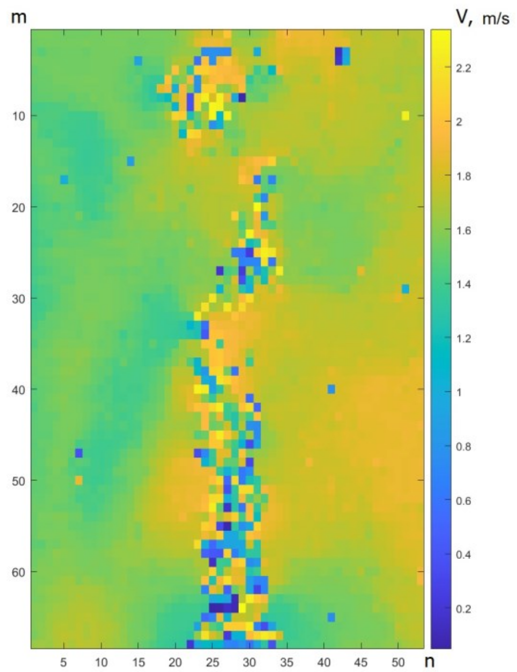


Fig. 6 Velocity map of a vortex wake behind a large particle

Figure 5 shows a vector map of the wake vortex behind a large particle. The vector map is of size m x n vectors, approximately 3000 vectors. Figure 6 shows a velocity map of the wake vortex behind a large particle. Unlike figure 5, figure 6 shows a map of scalar quantities. From the data presented, one can see two characteristic regions of the vortex wake behind a large particle - the region of attached vortex structures and the region of a detached vortex. The first of the mentioned areas has a length (in the longitudinal direction) of approximately 5 particle diameters. The second characteristic area has a diameter approximately equal to the diameter of the particle.

5. Conclusion

The authors demonstrated the possibility of visualizing and measuring the characteristics of the flow in the wake of large moving particles in a downward airflow using a fog generator and a PIV velocity field diagnostic system. Velocity distributions in the region of the rear critical point of the particle are obtained. Further visual interpretation of the velocity fields showed the presence of both a region of attached vortices and the presence of detached large vortices in the flow in the wake of the particle. The proposed visualization technique can be useful in studying the contribution of large particles to the characteristics of turbulent and eddy multiphase flows [13-15].

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