Approbation of the Laser Doppler Anemometer under Kinematic Flow Parameters Diagnostics during Spray Formation in a Laboratory Wind-Wave Interaction Modelling

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Abstract. The sea spray, a typical feature of the marine atmospheric boundary layer, is one of the most uncertain factors among those controlling hurricanes and severe storms [1]. To investigate how extremely strong winds tear off spray from wave crests, to classify such events, and to quantify the efficiency of the disclosed mechanisms, the high-speed wind-wave flume was constructed. For development of understanding of spray formation under hurricane wind condition the information about velocity distribution is required. The flow kinematics inside the wind-wave was studied using a laser Doppler anemometer (LDA) with an adaptive temporal selection of the velocity vector (LAD-08).

1. Introduction

The sea spray, a typical feature of the marine atmospheric boundary layer, is one of the most uncertain factors among those controlling hurricanes and severe storms [1]. To investigate how extremely strong winds tear off spray from wave crests, to classify such events, and to quantify the efficiency of the disclosed mechanisms, the Thermostratified Wind-Wave Tank (TSWiWaT) was designed at the Institute of Applied Physics RAS (IAP RAS).

Tree main mechanisms of generation of droplets for hurricane winds were identified and a statistical analysis of their frequency was performed [2], basing on results of laboratory experiments on TSWiWaT, aimed at studying the mechanisms of droplets generation using optical methods with shadow visualization technique and highspeed video filming from different viewpoints. It is shown that the greatest efficiency in generating sprays is associated with the phenomenon of bag breakup type instability and fragmentation of water surface. Moreover, near the crests of surface waves on the surface of the water, objects are formed and develop, which are thin-walled “membranes” with thick rim inflated by the air flow. Then, bursting of the film produces small droplets and fragmentation of the “rim” large droplets, correspondingly. It has been shown that large droplets generated by fragmentation of parachutes make a large contribution to the momentum, heat, moisture flows, and
can also make a significant contribution to gas exchange between the atmosphere and the ocean, especially under stormy conditions [3].

For the development, understanding of spray formation under hurricane wind condition the information about velocity distribution is required. Optical velocity measurement techniques are demanded. So the purpose of the experiments was to verify the technical capabilities of a modern non-contact optical method for diagnosing two-phase flows: the laser Doppler anemometry (LDA) method. The LAD-08 meter based on the LDA method was developed and manufactured at the Institute of Thermophysics SB RAS in Novosibirsk.

2. Experimental stand
The laboratory experiments were performed on TSWiWaT IAP RAS. The length of the recently modified air channel is 12 m. The cross section of air channel is 0.7 x 0.7 m at the inlet and increased to 0.7 x 0.9 m at the outlet due the inclined ceiling. This feature of the construction avoids the air velocity gradient along the channel. Centerline mean wind velocity was controlled with Pitot gauge and varied from 10 to 35 m/s during experiments (it corresponds to the range of up to 45 m/s for the wind speed on the 10-m height for real marine conditions). A detailed description of the previous modifications of facility and principles of design and control for the air flow are presented in [2, 3]. The photo of facility is presented in Figure 1.

![Figure 1.a](image1a.png)  
**Figure 1.a.** The photo of wind-wave flume (top view).

![Figure 1.b](image1b.png)  
**Figure 1.b.** The photo of wind-wave flume (side view).

![Figure 1.c](image1c.png)  
**Figure 1.c.** The photo of LAD-08 on the experimental stand during droplet velocity measurement.
3. Velocity measuring in the experiment

The flow kinematics inside the air channel of TSWiWaT was studied using a laser Doppler anemometer (LDA) with an adaptive temporal selection of the velocity vector LAD-08. The measuring device was designed and manufactured at the Kutateladze Institute of Thermophysics SB RAS, in Novosibirsk. The diagram illustrating the LAD-08 complex operation principle is shown in Figure 2. The laser-optic velocity measuring circuit contains a laser, two orthogonally oriented acoustic light modulators with traveling waves, a transmitting-receiving optical system, consisting of a series of mirrors and lenses arranged at the optical unit, and a photomultiplier tube. The photomultiplier tube transmits the signal to the quadroture mixer. The quadroture mixer passes the signal to the Doppler signal processor, which transmits the processed data to the computer. The test volume is scanned by moving the optical unit by a coordinate spacer. LAD-08 operates as follows. After passing through the acoustic light modulators the laser beam is diffracted into the zero and minus first orders. The split beams pass through a series of optical elements of the system and then are sent to the tested area of the flow by the lenses. Intersecting in that area, laser beams form an interference pattern with the known space-time periodic structure. The particle moving through the intersection area scatters the light. The photocurrent appears at the output of the detector, producing a frequency pulse in the radio range with the Doppler frequency shift, which is the known linear function of particle velocity. The signal duration is equal to the time of particle passage through the volume of intersection. The LAD-08 measures two projections of the velocity vector in the range of 0.001-400 m/s with a relative error of no more than 0.5%. The size of the intersection area is 0.1x0.1x0.5 (mm). The coordinate spacer moves the measurement unit in the area of 250 x 250 x 250 (mm) with an accuracy of 0.1 mm. The measuring system was mounted on height of 10 cm over the water level at the absence of the wind.

4. Flow control

In curved channels, due to the curvature of the flow, centrifugal forces, directed from the center of curvature to the outer wall of the pipe, appear. This determines the increase in pressure at the outer wall and its decrease at the inner wall when the flow passes from a straight section of the pipeline to a bent one. Therefore, the flow rate will accordingly be lower at the outer wall and higher at the inner. At this point, a diffuser effect appears near the outer wall, and a confuser effect appears near the inner wall. The transition of the flow from the curved part to the rectilinear (after rotation) is accompanied by the inverse phenomena: the diffuser effect near the inner wall and the confuser effect near the outer one [9]. Flow resistance can be reduced by installing guide vanes. The big advantage of this method is preservation of installation compactness.
5. Results
The meter was located at a height of 10 cm above the water level in the absence of wind at a distance of 8 m from the inlet cross-section.

All three components of droplets were measured. The axial component of the velocity Vx of spray speed varied from 10 to 45 m/s. The number of recorded events reached up to 45 000 events per minute. The vertical component of the velocity Vz of spray speed varied from 0 to 15 m/s. The number of recorded events reached up to 1000 events per minute. The traverse component of the velocity Vy of spray speed varied from 0 to 3 m/s. The number of recorded events reached up to 2400 events per minute.

It is necessary to note that events were recorded even at wind speeds above 30 m/s, when intense aerosol formation was observed, and water fell on the walls and flowed in the form of rivulets.

The axial component of the wind velocity was measured when smoke particles were added as tracers. The recorded values of instantaneous wind velocities varied from 1 to 45 m/s. The number of recorded events reached up to 100 000 events per minute.

Conclusions
Preliminary experiments on measuring the velocity of aerosol droplets with a Doppler laser meter LAD-08 on the Wind Wave Channel of the Institute of Applied Physics RAS were carried out. It is shown that the measuring system allows us to measure all three components of the velocity of the air flow in the range of 10 to 45 m/s. The possibility of diagnosing wind speed when smoke particles are added to the flow is shown. It is necessary to note that events were recorded even at wind speeds above 30 m/s, when intense aerosol formation was observed, and water fell on the walls and flowed in the form of rivulets.

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