INFLUENCE OF CERTAIN OPERATING AND GEOMETRICAL PARAMETERS ON THE FLOW STRUCTURE IN AN AIR VORTEX

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UDC 532.517.4

The results of measuring the tangential and axial velocity components in a laboratory model of an atmospheric vortex are presented for different values of the geometrical parameters and degrees of swirling of the stream.

Laboratory modeling of atmospheric vortex formations and the investigation of their hydrodynamic characteristics have attracted the interest of investigators for a long time. A number of experimental investigations were carried out fairly recently [1-6], and now an increase in interest and the appearance of many reports on this problem [7-9] are noted again.

The results of experimental measurements of radial profiles of the tangential and axial velocity components for different intensities of stream swirling and for different distances from the swirler to the underlying surface are given in the present article.

The scheme of the vortex generator is analogous to that presented in [8]. A steady air vortex is created by means of angular momentum through the rotation of a swirler and the convective axial flows generated in the working volume of the apparatus (between the deflector and the underlying surface). Increasing this volume and higher rotation rates of the swirler (from 2000 to 6000 rpm) permit an expansion of the range of conditions under which the experimental research is conducted.

The velocity field was measured with a miniature, five-channel, spherical probe, as in [8, 9]. The experimental procedure and the calculating equations for treating the results obtained are described in detail in [9, 10]. The measurement error was no worse than 8%.

In Fig. 1 we present radial profiles of the dimensionless tangential velocity component (normalized to the first maximum at $r_m = 4.5$ cm) (Fig. 1a) and the axial velocity component (Fig. 1b) for different horizontal cross sections of the vortex (the distance to the cross section is measured from the swirler) for a total vortex length $l = 23$ cm, $r_m = 4.5$ cm, and a swirler angular velocity $N = 6000$ rpm. In the cross section $z/r_m = 0.9$ (Fig. 1a) the profile of the tangential velocity component has two maxima: The first is located at a distance of about 4.5 cm from the axis of the vortex while the second is shifted toward the boundary of the vortex (the region of a sharp decrease in tangential velocity) and lies at a distance of about 8.5 cm from the axis. The experimental profiles of the tangential velocity in [8] have a similar character. With an increase in distance up to $z/r_m = 1.4$ the size of the first maximum and the radial distribution of tangential velocity in the region of it hardly vary, while the size of the second maximum decreases and its position shifts toward the axis. At $z/r_m = 2.6$ the second maximum of the tangential velocity is absent and one observes a decrease in the velocity, while the position of the first maximum remains unchanged. This indicates that the boundary of the vortex core, determined by the position of the first maximum of the tangential velocity, hardly varies over the height of the vortex in this case.

The variation of the profiles of the axial velocity component (Fig. 1b) with an increase in z/r_m has a more monotonic character: there is a general decrease in the axial velocity, for the regions of both the ascending and the descending (negative values of the axial velocity component) flow. In this case the maximum of the axial velocity of the ascending flow is located near the center of the vortex while its maximum for the descending flow is located at a distance of about 9.5 cm from the axis of the vortex, and its position, like the position of the zero point of the axial velocity component, does not vary as z/r_m increases from 0.9 to 2.6.

A. V. Lykov Institute of Heat and Mass Exchange, Academy of Sciences of the Belorussian SSR. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 45, No. 3, pp. 398-403, September, 1983. Original article submitted April 14, 1982.

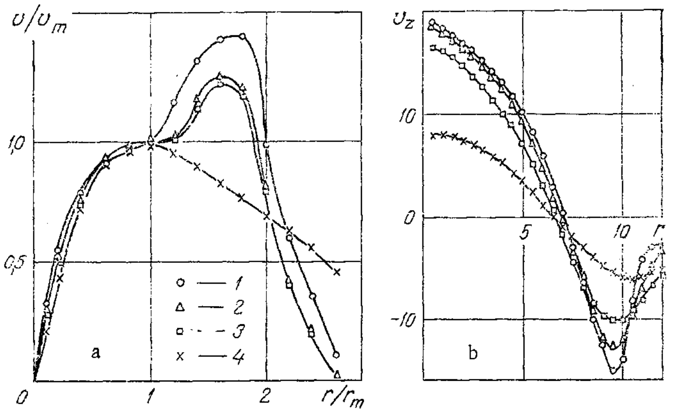

Fig. 1. Profiles of tangential (a) and axial (b) velocity components for N = 6000 rpm and l = 23 cm in different cross sections (z/r_m) of the vortex: 1) 0.9; 2) 1.2; 3) 1.4; 4) 2.6. v_z, m/sec; r, cm.

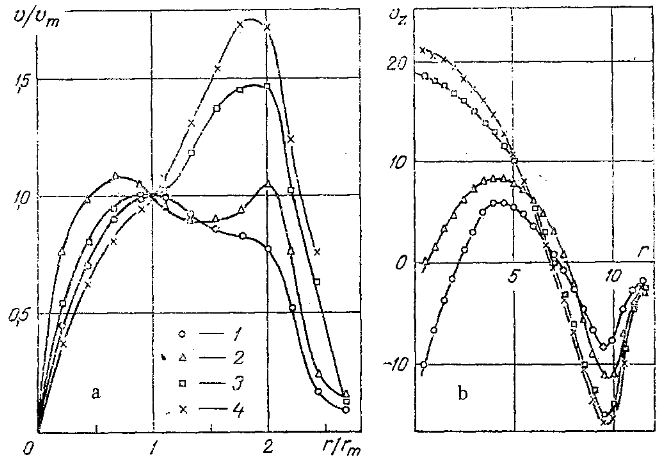

Fig. 2. Profiles of tangential (a) and axial (b) velocity components for N = 6000 rpm and z/r_m = 0.9 for different vortex lengths (l, cm): 1) 8.0; 2) 13.0; 3) 23.0; 4) 33.0

In Fig. 2 we present profiles of the dimensionless tangential and axial velocity components for the cross section z/r_m = 0.9 and N = 6000 rpm for different vortex lengths (the distance from the swirler to the underlying surface).

For a vortex length l = 8 cm the tangential velocity profile (Fig. 2a) has one characteristic maximum. With an increase in l the character of the radial velocity distribution changes considerably: For l = 13 cm the curve has two maxima of about the same size, while with a further increase in the vortex length to l = 23 cm and l = 33 cm the tangential velocity profile is transformed into a curve with one maximum near the boundary of the vortex column.

Radial distributions of the axial velocity component for different values of l are shown in Fig. 2b. For small l ($r_m/l \approx 1$) the axial velocity changes sign twice, forming two regions of descending motion (the central part and the periphery) and a region of ascending flow (a vortex structure of the tornado type), and with a further increase in l such a structure is retained, starting with $r_m/l \approx 0.5$.

The influence of variation of the angular velocity of rotation of the swirler on the tangential and axial velocity components for a vortex column 8 cm long is shown in Fig. 3. As N varies from 6000 to 2000 rpm the tangential velocity (Fig. 3a) decreases approximately linearly in magnitude while the position of its maximum hardly varies. The profiles of the axial velocity component behave similarly: With a decrease in swirling the maximum values of the axial velocity decrease linearly with N for both the ascending and the descending flows, while the positions of its zero values remain unchanged.

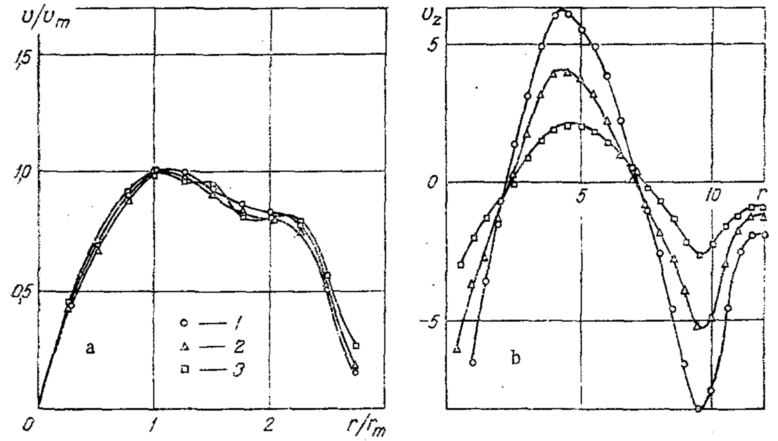

Fig. 3. Profiles of tangential (a) and axial (b) velocity components for $z/r_m = 0.9$, $l = 8$ cm, and different N (rpm): 1) 6000; 2) 4000; 3) 2000.

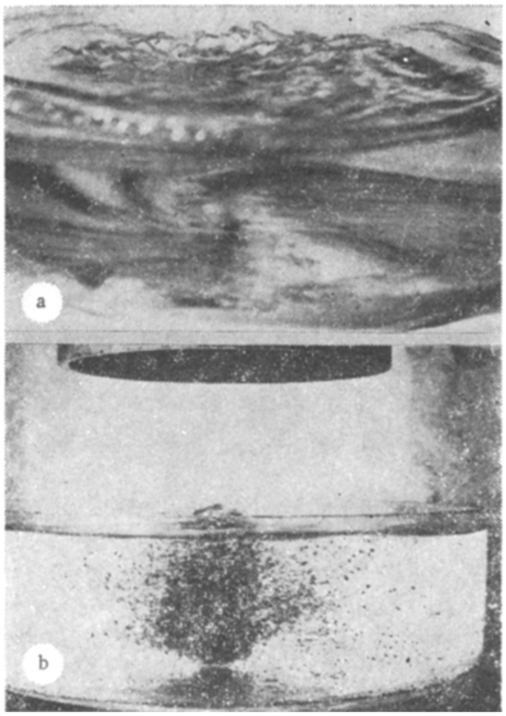

Fig. 4. Interaction of a vortex with a water surface for N = 1400 rpm and $l = 10$ cm: a) steady conditions; b) 2 sec after turning on the swirler.

The results obtained allow us to draw a number of conclusions: 1) The hydrodynamic structure of vortex flow varies considerably over the height of the vortex, with the most complicated flow pattern being observed near the deflector; 2) the total length of a vortex is one of the most important parameters determining the flow structure, and it is possible to obtain structures of the tropical cyclone type ($r_m/l \approx 1$) and structures of the tornado type ($r_m/l \approx 0.5$), while an increase in l to values above 33 cm ($r_m/l \approx 0.15$ for the given apparatus) results in a certain limiting flow pattern which is influenced insignificantly by the presence of the underlying surface; 3) variation of the swirling velocity, at least in the range from 2000 to 6000 rpm, results in linear variation of the investigated hydrodynamic parameters.

The results of these experiments also allow us to make certain assumptions about a possible laboratory model for imitating the interaction of an atmospheric vortex with a water surface. For example, if the interaction of a vortex of the tornado type is being modeled, then one must choose those distances from the swirler to the water surface for which the condition $r_m/l \leqslant 0.5$ is satisfied, where r_m depends on the geometrical size of the swirler. Modeling the interaction of a vortex of the tropical cyclone type with a water surface requires that the condition $r_m/l \geqslant 1$ be satisfied. Since the angular velocity of the swirler does not noticeably affect the flow structure in the vortex in the investigated range, it is possible to regulate the intensity of its interaction with the water surface.

The surface and internal flows in the volume occupied by the liquid are seen in Fig. 4; they are formed in the interaction with the water surface of a vortex of the tornado type ($r_m/l < 0.5$) (Fig. 4a) and a vortex of the tropical cyclone type ($r_m/l \approx 1$) (Fig. 4b). The dark particles in the water are potassium permanganate crystals used to make the flow pattern visible.

NOTATION

N, angular velocity of rotation of the swirler; r_m, radial coordinate of the first maximum of tangential velocity; v_m, magnitude of the first maximum of tangential velocity; z, vertical coordinate (distance from the swirler to the horizontal cross section of the vortex in which the measurements are made); l, vortex length (distance from the swirler to the underlying surface).

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