Destructive atmospheric vortices and the Earth's rotation around its axis

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Abstract

Interesting atmospheric phenomena are often found in nature. These are ascending swirling flows of air, such as whirlwinds, tornadoes, tornado.The results of theoretical and experimental studies of the ascending twisting flows encountered in nature in the form of tornadoes and tropical cyclones [1-3] are represented.

Theorems on the existence and the uniqueness of the solutions to specific initial-boundary value problems that, in particular, set the rotation direction of tornadoes, tropical cyclones and fire vortices are proved for the system of gas dynamics equations.

There are the constructed numerically the solutions of indicated systems of partial differential equations that model the gas flow from the simple planar spiral currents to the three-dimensional nonstationary flows in general. The calculation results are consistent with both the data of natural observations and the results of laboratory experiments.

The results of theoretical studies of the ascending twisting flows encountered in nature in the form of tornadoes and tropical cyclones [1-3] are proven in this research. We consider the system of gas dynamics equations in dimensionless variables under the action of gravity and Coriolis forses [3, 4]:

$$\begin{cases} c_t + uc_r + \frac{v}{r}c_\varphi + wc_z + \frac{(\gamma-1)}{2}c\left(u_r + \frac{u}{r} + \frac{v_\varphi}{r} + w_z\right) = 0, \\ u_t + uu_r + \frac{v}{r}u_\varphi - \frac{v^2}{r} + wu_z + \frac{2}{(\gamma-1)}cc_r = av - bw\cos\varphi, \\ v_t + uv_r + \frac{uv}{r} + \frac{v}{r}v_\varphi + wv_z + \frac{2}{(\gamma-1)}\frac{c}{r}c_\varphi = -au + bw\sin\varphi, \\ w_t + uw_r + \frac{v}{r}w_\varphi + ww_z + \frac{2}{(\gamma-1)}cc_z = bu\cos\varphi - bv\sin\varphi - g. \end{cases} \tag{1}$$

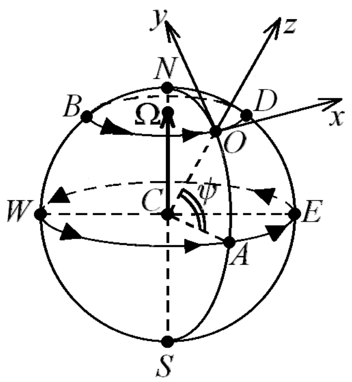

Fig. 1.

The symbols in system (1) are the following: ρ – is the density; u, v, w – are the projections of the velocity vector $\mathbf{V}$ on the axis of Cartesian coordinate system $Oxyz$ (see Fig.1) rotating together with the Earth and the beginning of which lies on the surface of the Earth at the point O on the parallels with the latitude ψ; $\mathbf{g}$ – is the acceleration vector of gravity; $a = 2\Omega \sin\psi$; $b = 2\Omega\cos\psi$; Ω – is the modulus of the angular velocity vector $\mathbf{\Omega}$ of the Earth's rotation.

The theorem on the smooth flow into the vertical cylinder. For the system of gas dynamics equations there are the specified conditions describing the initial time of the uniform, resting outside the cylinder $\sqrt{x^2+y^2} = r_0$, $r_0 > 0$ gas. Also the smooth radial flow into the cylinder are given. Then this problem has a unique solution in the neighbourhood of the given point $(t = 0, r = r_0, \varphi = \varphi_0, z = 0)$. Here r, φ – are the polar coordinates in the plane xOy.

The properties of the solution of this problem that since the time $t = 0$ in the gas flow occurs the twisting directed in the positive direction in the case of the Northern Hemisphere and the negative direction in the case of the Southern Hemisphere. This direction of rotation corresponds to the direction of air like tornadoes and tropical cyclones. If for the problem $\Omega = 0$, so the twisting does not arize.

The theorem on the smooth heating of the vertical cylinder. For the system of gas dynamics equations there are the specified conditions describing the initial time of the uniform, resting outside the cylinder $\sqrt{x^2+y^2} = r_0$, $r_0 > 0$ gas. Also the smooth heating of this cylinder are given. Then this problem has a unique solution in the neighbourhood of the given point $(t = 0, r = r_0, \varphi = \varphi_0, z = 0)$.

The properties of the solution of this problem that since the time $t = 0$ the twisting directed in the negative direction in the case of the Northern Hemisphere and the positive one in the case of the Southern Hemisphere appears in the gas flow. The air around the fire vortices has such direction of twisting. If for the problem $\Omega = 0$, the twisting in the flow is absent.

The paper provides examples of numerical construction of flows under the action of gravity and Coriolis forces for the system (1).

The geometric, speed and energy characteristics of stationary plane currents. The solution of problem (1) in the form convergent series, solves the corresponding characteristic Cauchy problem with data on an impenetrable plane $z = 0$. This solution describes a plane stationary spiral flow of gas when the Coriolis force is taken into account, which can be treated as a current in the bottom part of a tornado or a tropical cyclone. And, depending on the input data, such flows are obtained with different geometric, speed and energy characteristics. The aim of the paper is to construct and analyze flat stationary flows in a tornado different intensities and in a tropical cyclone, consistent with the data of full-scale observations.Coordination with the data of field observations of tornadoes and tropical cyclones is achieved using the Fujita scale and data on tropical cyclones (Table 1).

Table 1

Classes tornado, cyclone	$F_{-0.5}$	$F0$	$F_{0.5}$	$F1$	$F2$	$F3$	$F4$	$F5$	Cyclone
$d = 2r_0$, m	2.0	5.0	10.0	16.0	51.0	161	547	1609	60000
Wind speed $V(r_0)$, m/s	15	19	25.5	33	51	71	93	117	51

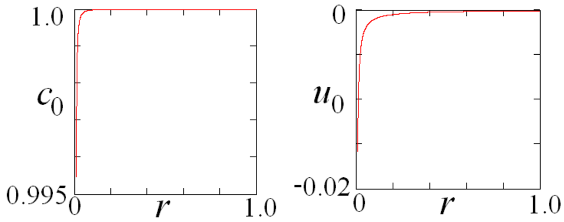

Fig. 2.

Based on the results of calculations on the left-hand side of Fig. 2 shows the graph of the function $c_0(r)$, and in right - the graph of the function $u_0(r)$ for a tornado of class $F3$

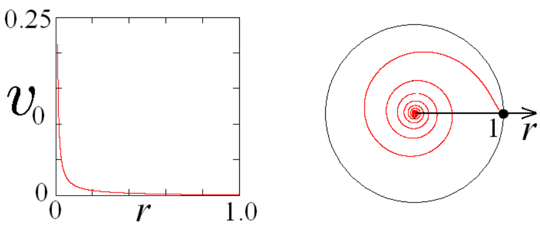

Fig. 3.

For this same tornado class on the left-hand side of Fig. 3 shows the graph of the function $v_0(r)$, and on the right an instantaneous streamline emerging from the point $(r = 1, \varphi = 0)$.

References

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