TORNADO-LIKE VORTICES GENERATION DUE TO AIR TURBULENT CONVECTION

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Abstract The purpose of the paper is to demonstrate the possibility of studying the dynamics of wall-free non-stationary air vortices by using of video filming, various visualization methods and particle image velocimetry. These vortices were generated over underlying surface of aluminum sheet due to its controlled heating from below as a result of development of buoyancy-driven turbulent convection of air. It is strictly emphasized that in contrary of previous studies no mechanical rotation devices and/or underlying surface rotation were used for the vortices generation. The experiments on establishing how vertical nets placed in the travel line of a sufficiently non-stationary laboratory vortex affect its dynamics have been conducted. We have distinguished several fundamental mechanisms of how nets affect a non-stationary vortex. Among these mechanisms is the action of small-scale turbulence generated behind the net with large-scale turbulence of the model vortex, leading to violation of its symmetry.

INTRODUCTION AND RESULTS

Vortex (swirling) flows are widely occurring in nature (atmospheric cyclones, tornadoes [1-6], dusty devils) and find numerous engineering applications. Simulating dust devils and tornadoes in laboratory environments is not a new concept. Many laboratory simulator designs were built for meteorological purposes to understand the parameters influencing dust devil and tornado formation (for example, [7, 8].

This study continues the investigation [9], where the principal possibility was demonstrated of generating and studying of wall-free non-stationary concentrated tornado-like vortices under laboratory conditions without using of mechanical swirling devices. Varaksin et al. [9] studied the thermal modes of heating (cooling) of underlying surface, in which vortices are formed and their integral parameters (geometric dimensions, lifetime, velocity of travel, and others).
In this study we use the simple experimental setup allowing to make controlled heating of aluminum plate top surface (called here as underlying surface) and to generate the wall-free non-stationary swirl structures over the plate due to the unstable air stratification (the warm air near the top surface and the cold air over him). It is strictly emphasized that in contrary of previous studies no mechanical swirling devices (ventilators, guide swirl vanes, screws, internal spiral ribbing, and the like) and/or underlying surface rotation were used for the vortices generation.

The photography, video filming and PIV measurements made it possible to visualize (using tracer particles) the wall-free non-stationary air vortex structures arising over the underlying surface and to test the net structures of influencing their behavior.

Figure 1 is a typical frame of a relatively long-lived (lifetime of about 40 s) air vortex structure of visible (by means of tracer particles) height of about 1.5 m and diameter of 0.1 m. The typical experimentally observed vortex structure is given also in a Fig.2a for the purpose of detailing its basic parts (vortex core, peripheral region, vortex cascade). Given in Fig.2b for comparison is a photograph of real air tornadoes on June 6, 2009 in northern Lincoln County, Washington. Initially only one tornado was visible, but it appeared to split into two twisters.

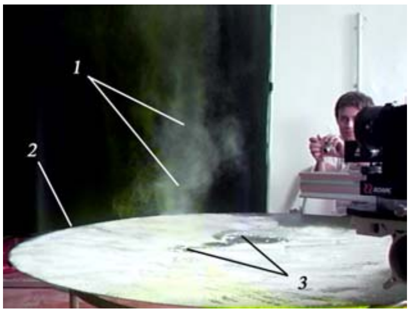

Figure 1. Photograph of the model laboratory vortex (the visible height of the vortex is 1.5 m), mode no.6, $\tau_h = 150$ s: (1) vortex, (2) edge of the underlying surface, (3) vortex trail.

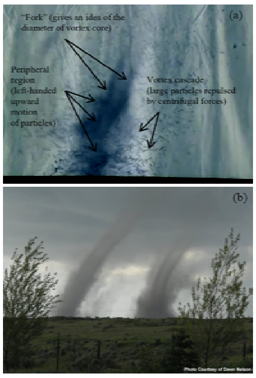

Figure 2. Photographs of vortex structures: (a) typical frame with recorded wall-free non-stationary vortex (negative), 1.68 s after generation, (magnesia particles visualization, the image size is 0.66 by 0.41 m); (b) air tornadoes in northern Lincoln County, Washington (photo by Dawn Nelson, www.wrh.noaa.gov).

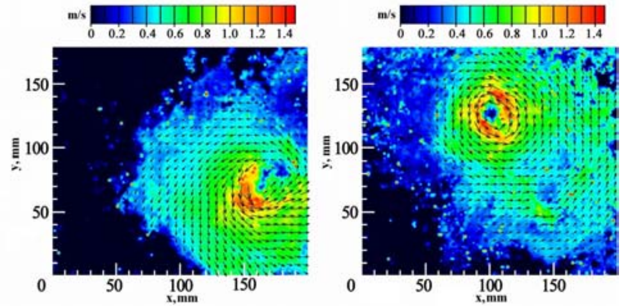

Figure 3. Typical pattern of the instant velocities over the cross section of the vortex funnel (the distance from the laser knife to the surface equals 200 mm): (a) the time moment $\tau = 0$, (b) $\tau = 0.8$ s.

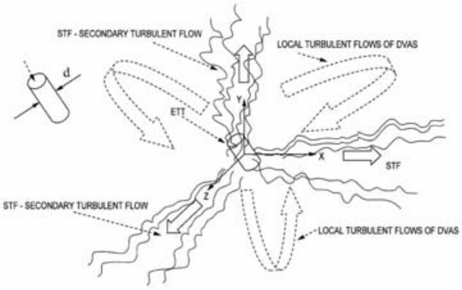

Figure 4. Schematic illustration the directions of small-scale turbulent fluctuations (secondary turbulent flow (STF)) by a single mechanical element of net structure (elementary turbulent transformer (ETT)) interaction with local turbulent flow of dynamic vortex atmospheric structure (DVAS).

We have conducted the experiments on establishing how vertical nets placed in the travel line of a unsteady wall-free laboratory vortex affect its dynamics (see Fig.3). These net obstacles carry out the transformation of energy of the local turbulent flow of the atmospheric vortex to energy of small-scale turbulent fluctuations (secondary turbulent flow) (see Fig.4). Secondary small-scale turbulent flow moves towards the arriving vortex structure and leads to its destabilization. Thus the energy required for the destruction of the vortex structure is taken from the energy from the vortex structure itself.

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