UNDERSTANDING TORNADOES AND MICROBURST

JP1.20

E. A. Farag *
Vice President, SNC-Lavalin Inc.
Montreal, Canada

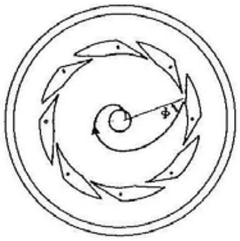
ABSTRACT

Tornadoes and microburst are violent columns of air in the atmosphere. Meteorologists do not yet fully understand the mechanisms that develop them from a thunderstorm. This paper provides a clear understanding of such mechanisms. It is based on earlier experimental and theoretical investigations of confined vortex flows by the author. In these investigations, flow pattern observations and analytical solutions of the boundary-layer thickness and flow are obtained. Their results are applied to tornadoes and microburst and prove that these natural phenomena are not the result of convective currents or descending cool air as commonly speculated. They are natural phenomena caused by swirls in the atmosphere. These swirls are created by wind shear. The presence of a cloud base under these conditions results into a confined swirling flow similar to that inside a vortex chamber. In other words, tornadoes and microburst are the result of concentric boundary-layer flows. These flows are separated into reverse flow, core flow and mantles flow.

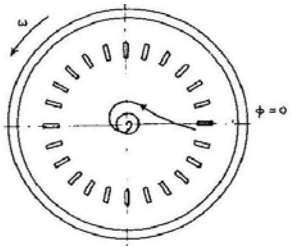
INTRODUCTION

Several studies, both theoretical and experimental, have been carried out on vortex or swirling flows. This is due to there being several useful applications such as in atomizers and cyclone separators. These devices are vortex chambers that have cylindrical configuration with central outlet and tangential inlet. Therefore, the swirl motion inside these stationary vortex chambers is introduced by supplying fluid to the interior of the chamber through tangential circumferential inlets. Another application of the vortex flow is the vortex rate sensor or the fluidic gyroscope that has cylindrical configuration with central outlet and radial circumferential inlets. The swirl motion, in this case is generated by the rotation of the vortex chamber. The configurations of stationary and rotating vortex chambers are shown schematically in Fig. 1-a and Fig. 1-b respectively.

Theoretical and experimental investigations of the swirling flow of liquids through vortex chambers were carried out by the author (1) and (2). This paper applies the results of these investigations to tornadoes and microburst and provides a clear understanding of these natural phenomena.



1-a Stationary vortex chamber



1-b Rotating vortex chamber

Fig. 1 Vortex chamber configurations

EXPERIMENTAL INVESTIGATION OF SWIRLING FLOWS

Two different apparatus are built for stationary and rotating vortex chambers. Their general arrangement is shown in Fig. 2. Each vortex chamber apparatus is placed in a glass tank and is belt driven by a D.C. motor through a reduction gear box. The flow rate into the glass tank is controlled by means of an inlet needle valve and the issuing discharge is channeled through a funnel-diverter system and its volume was measured using graded tanks. A cross section of the stationary vortex chamber apparatus is shown in Fig. 3-a where swirl is produced by admitting water under gravity through numerous holes in a vertical rotating cylinder made of Plexiglas. This cylinder forms the vertical walls of the vortex chamber. In this way, the magnitude of the swirl imposed on the water at the inlet could be directly measured and is equal to the tangential velocity of the inner surface of the rotating cylinder. It could be varied easily by changing the speed of rotation of the cylinder. Moreover, the effect of friction between the rotating liquid and the vertical wall of the cylinder is eliminated and only the frictional effect of the stationary bottom and top plates of the chamber is left to be investigated. The perforated cylinder is mounted on ball bearing and is belt driven in the cylindrical glass tank. A removable nozzle is located at the center of the stationary bottom plate. The total head on the nozzle is determined by the water level in the tank.

---

* *Corresponding author address*: Essam A. Farag, SNC-Lavalin Inc., 1801 McGill College Avenue, Suite 1200, Montreal (Quebec) Canada, H3A 2N4; email: essam.farag@hedahorizons.com

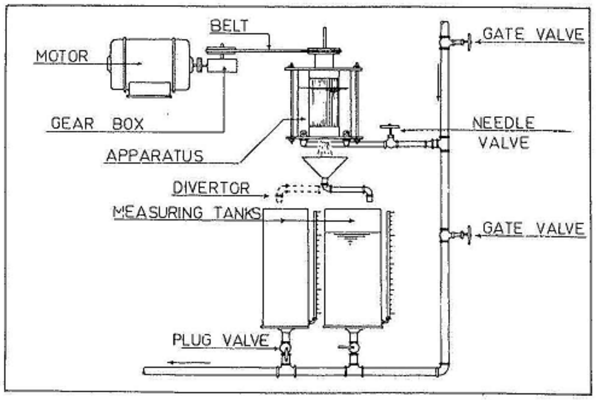


Fig. 2 General lay-out of the apparatus

A cross section of the rotating vortex chamber apparatus is shown in Fig. 3-b where swirl is produced by rotating radial plastic vanes. The radial vanes, the bottom plate and the top plate are mounted on ball bearing and are belt driven in the cylindrical glass tank. A removable nozzle is located at the center of the rotating bottom.

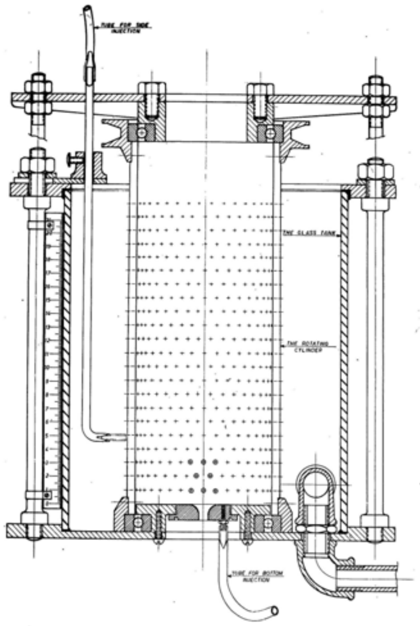


Fig. 3-a Stationary vortex chamber apparatus

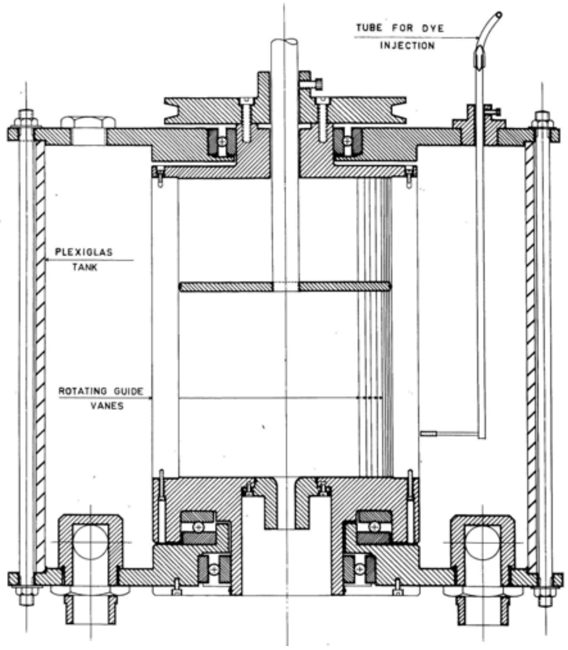


Fig. 3-b Rotating vortex chamber apparatus

The investigated parameters include nozzle diameter, top plate roughness and speed of rotation. Typical results are shown in Figs. 4, 5 and 6 for the discharge coefficient "K" under different swirl coefficient "X". These are defined by:

$$K = Q / \pi a^2 (2 g H)^{1/2} \qquad (1)$$

and

$$X = \Omega / \ a \quad (2 g H)^{1/2} \qquad (2)$$

where:

a = nozzle diameter
g = gravitational acceleration
H = gross head above nozzle
K = discharge coefficient
X = swirl coefficient
Q = rate of discharge through nozzle
Ω = angular velocity of cylinder/vanes

The points at which the air core and the reverse flow were firstly observed are marked on the figures. An inclined stroke across the point indicates the point at which the air core is first established at the nozzle, and the cross corresponds to the point at which the air core is fully developed along the chamber axis. The vertical stroke indicates the point at which reverse flow was first observed.

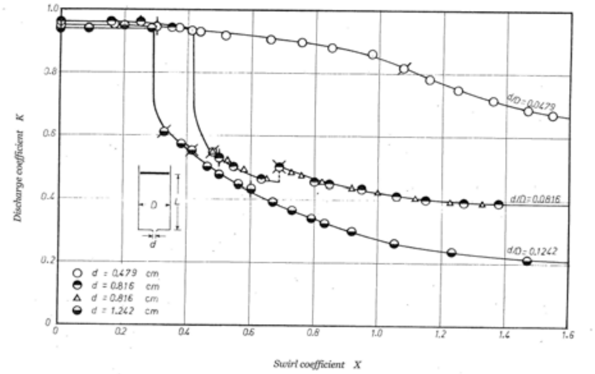


Fig. 4 Typical results for different nozzle diameters

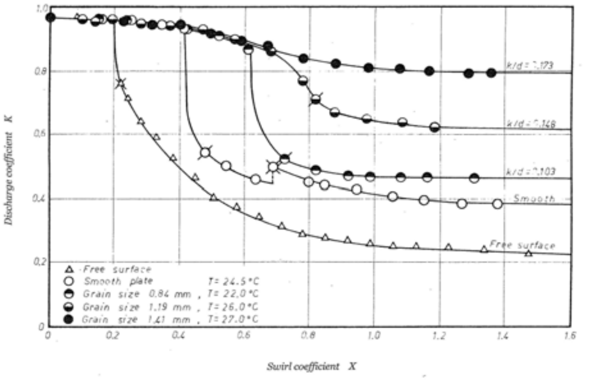


Fig. 5 Typical results for different roughness of top boundary

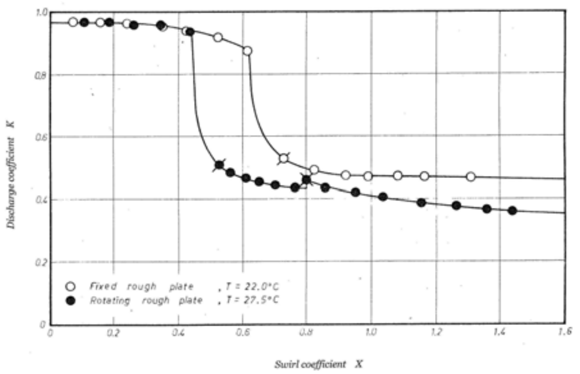


Fig. 6 Typical results for fixed vs. rotating top boundary

These figures show the same trend of variation of "K" with "X", i.e., the value of "K" remained at nearly constant value till an air core is formed, and then it decreases with the increase of "X". Fig. 4 shows that the smaller the nozzle diameter, the bigger is the coefficient of discharge. Fig. 5 shows that the coefficient of discharge increases with surface roughness of the top plate. Fig. 6 shows that the friction effects of the top plate are reduced when the top plate is rotated and therefore the coefficient of discharge is lowered and the air core is formed at lower values of swirl coefficients.

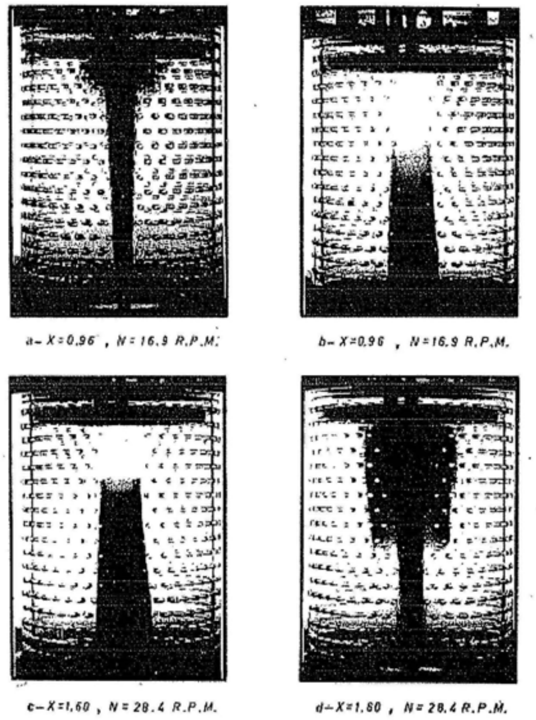
FLOW PATTERN

The flow pattern inside the stationary vortex chamber apparatus is examined by injecting colored phosphoric dye by means of an L-shaped tube. This tube can be located very close to the rotating cylinder at different levels inside the glass tank. These examinations of the flow pattern are carried out for different outlets at various degrees of swirl with different top plate roughness.

At zero swirl, the pattern was simple and the streamlines converged from all points towards the outlet. At weak swirl, the dye injected at different levels showed helical streamlines converging from all points towards the outlet. This confirms that at low swirl the flow configuration is similar to that of the pure radial flow while inward radial flow component exists at all points within the chamber.

As the swirl increases, a small part of the dye injected near the top plate moves inward into the boundary-layer flow and then downward to the outlet through the center core. This core flow is unsteady in beginning due to an air core trying to establish itself at the outlet. When the air core establishes itself at the outlet, the core flow is clearly visible and steady as shown in Plate "a". The dye injected near the bottom moves inward through the boundary-layer current and is discharged directly through the outlet. The dye injected at intermediate levels of the vortex chamber apparatus does not show any definite pattern but when the injection stops, the dye is eventually washed away indicating that part of the outflow is being fed by potential flow as well.

At medium swirl, when the dye is injected near the bottom of the chamber, a part of the bottom-boundary layer flow separates and moves upwards around the core flow showing the existence of reverse flow as shown in Plates "b". At high swirls the reverse flow intensifies as shown in Plate "c" and when the dye is injected near the top of the chamber, a part of the top boundary-layer current separates at a bigger radius and moves downwards in a mantle form around the reverse flow as shown in Plate "d". Injection of dye into the potential flow region during high swirl shows no definite pattern and when the injection stopped, the dye remains. This strongly suggests that the potential flow does not feed the outlet. When the air core is fully developed inside the chamber, the core flow surrounds the air flow. The flow pattern under low, medium and high swirls is shown diagrammatically in Fig. 7.



a- X=0.96 , N=16.9 R.P.M.

b- X=0.96 , N=16.9 R.P.M.

c- X=1.60 , N=28.4 R.P.M.

d- X=1.60 , N=28.4 R.P.M.

Dye injection plates

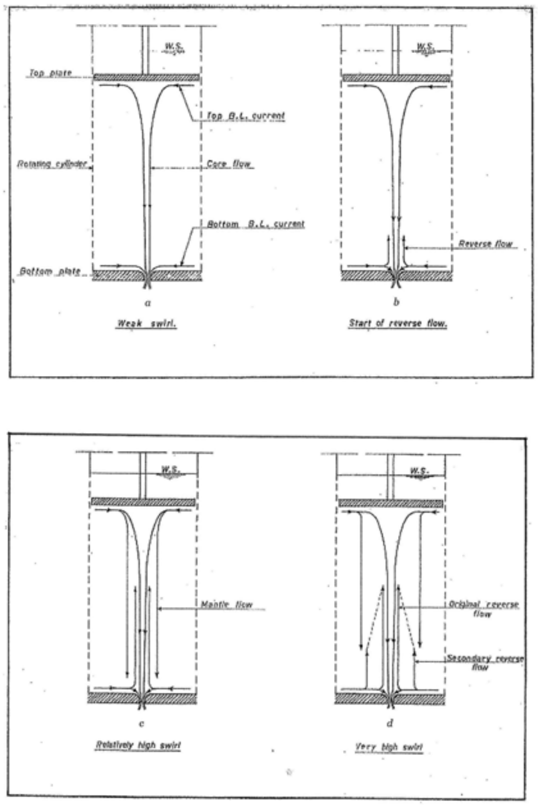


Fig. 7 Diagrammatic sketch of flow pattern

TORNEDOES AND MICROBURST

Tornadoes and microburst are the result of swirling flow of air in the atmosphere. Such swirl is caused by wind shear. Wind shear is a difference in wind speed and direction over a short distance in the atmosphere. They occur only under a cloud base that resembles the top plate of a vortex chamber while the ground forms the bottom plate of that chamber. The circular motion imparted by wind shear creates two concentric boundary-layer flows. The first boundary-layer flow is at the cloud base and the second boundary-layer flow is at the ground. With no outlet at the bottom, the latter boundary-layer flow is separated upwards in its entirety in the form of a reverse flow around a center core as demonstrated in plates “b” and “c” of the experimental model. The latter center core originates from the top boundary-layer at the cloud base and joins the reverse flow at the ground. Excessive top boundary layer flow and reverse flow may join again at the top to flow downwards in the form of mantles around the reverse flow as demonstrated in Plate “d” of the experimental model and observed with some tornadoes.

Microburst is the result of high altitude wind shear. Such wind shear imparts circular motion in the atmosphere and can develop a concentric boundary-layer flow under a cloud base. This boundary-layer flow is then separated and diverted downwards in the form of a core flow as demonstrated in Plate “a” of the experimental model.

BOUNDARY-LAYER FLOW OF TORNADOES AND MICROBURST

A comprehensive theoretical investigation of confined swirling flows was carried out by the author (2). In this investigation, approximate analytical solutions of the boundary-layer thickness are obtained by solving the boundary-layer momentum integral equations and the following expression is derived:

$$\delta \;=\; 2\,\xi\,(\gamma / \omega)^{1/2} \left\{\left[(301/4) - (203/2)\,\xi + 28\,\xi^{2} - (7/4)\,\xi^{4}\right] / \left[1 + \xi^{4}\right]^{2}\right\} \qquad (3)$$

The radial and tangential velocity distributions are expressed in power series where the constants of these series are determined by the boundary conditions. The solutions are applied to predict the boundary-layer flow at various swirl conditions:

$$Q_{B.L.} = (\,\pi / 24\,\gamma\,)\;\delta_{a}^{3}\;(\omega\,R / \xi_{a}\,)^{2} \qquad (4)$$

Where:

a = the outlet radius
R = the vortex chamber radius
γ = the kinematics viscosity of the fluid
δ = the boundary-layer thickness
ω = the angular velocity
$\xi = a/R$

In the case of tornadoes and microburst, “a” tends to zero and “γ” is small. On the other hand, “R” is infinitely large and “ω” is relatively high. This lends a very high boundary-layer flow that is characteristic of tornadoes and microburst. The boundary-layer thickness increases towards the center of rotation. With no nozzle to discharge, the ground boundary-layer flow separates in its entirety into an upwards reverse flow around the downwards core flow. The latter core flow originates in a similar manner from the cloud base boundary-layer flow. With no outlet to discharge, it joins the reverse flow and together form the violent column of the tornado.

CONCLUSIONS

Tornadoes and microburst are not the result of convective currents or descending cool air as commonly speculated. They are natural phenomena caused by swirls in the atmosphere. These swirls are created by wind shear or differences in wind speed and direction over a short distance in the atmosphere. The presence of a cloud base under these conditions results into a confined swirling flow similar to that inside a vortex chamber. In other words, tornadoes and microburst are the result of concentric boundary-layer flows. These flows are separated into reverse flow, core flow and mantles flow due to their convergence.

REFERENCES

1. Kamel, M.Y.M. and Farag, E.A. “The Swirling Flow of Liquids Through Vortex Chambers.” ASME Publications, Paper No. 73-WA/FE-12, 1973.

2. Kwok, C.K. and Farag, E.A. “Investigation of Swirling Flows of Liquids Through Rotating Vortex Chambers” ASME Publications, Paper No. 73-WA/Flcs-8, 1973.