Effect of Rotation on Convective Motion*

by

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Abstract

A simple, preliminary experiment on the effect of rotation on convective motion has been carried out by the method of rotating cylinder convection. Two different regimes of motion, i.e., mushroom regime and tornado regime motion, have been observed. By increasing the rotation (decreasing the Rossby number), the approaching transition of the mushroom regime to the tornado regime motion has been shown by means of two series of photographs.

1. Introduction

Although the use of models in studying fluid motion is not a new technique, its application to large scale atmospheric phenomena has shown considerable progress in recent years. For example, a number of groups of hydrodynamic experiments have been successfully run almost continuously over several years since 1947 on problems of the medium- and large-scale hydrodynamic phenomena of the atmosphere by Dr. FULTZ and his collaborators. A laboratory study of the primary ocean circulation was begun by VON ARX since 1950. Several works by Dr. LONG and Dr. SUZUKI (1953) represent an attempt to study experimentally the flow of an atmosphere with stratified fluids over mountain barriers. Experimental studies on free convection due to boundary sources have been carried out at Iowa Institute of Hydraulic Research. All these experimental studies have been summarized in several proceedings of the special symposium on fluid model experiments.

The present author intended to study experimentally the convective motion as well as the effect of rotation on convective motion in a quite primitive manner. This paper is partly devoted to experimental discussions on the mechanism of severe storms such as tornadoes and hurricanes.

2. Experimental arrangements

A cylinder made of glass, about 35 cm in diameter and about 36 cm in depth, is almost filled with a layer of water. SCORER and RONNE (1956) have released ready-made bubbles into a static tank of water and bubbles have been created by releasing a liquid denser than water. The denser fluid has been obtained by making a mud "slurry," whose tech-

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Fig. 1

nique was also employed in the present experiment.

To study experimentally the effect of rotation on the convective motion, the cylinder was mounted on a supporting frame on the rotating disc with variable speed. Observation and photographing of the convective motions were carried out directly. Photographic films were taken with standard cinema technique by Mr. M. SAITO (See Fig. 1).

3. Convection bubbles in a static tank of water

In the case of convection bubbles in a static tank it is absolutely the same as reported by SCORER and RONNE (1956). Five pictures of a bubble in succession after release are shown in Figs. 4 (a-e). We can see a well-developed mushroom regime motion in the course of convective motion. Mixing takes place between the liquid elements denser than water and their surroundings, and convective motions are finally damped out and are eroded.

Fig. 2. Five consecutive pictures of bubble after release show mushroom regime motion.

4. Rotating cylinder convection:

Mushroom regime motion with low speed rotation

Under suitable conditions, if the cylinder is rotated uniformly at a relatively low speed, say 14 revolutions per minute, the convective motion becomes more and more irregular and obscure, and makes an impression of rather turbulent flow. No theory at present can predict this type of irregular motion, concerning which any further theory must be more or less descriptive. Convection pattern after release is still of mushroom regime motion provided the speed of rotation remains sufficiently small.

It is evident that more mixing takes place between the buoyant elements and surroundings than in the case of a static tank of water. Figs. 3a-3e are shown to illustrate a mushroom regime motion with low speed rotation.

The most important type of characteristic parameter for the meteorological interpretation of such experiments is the Rossby number, which will be discussed in the next paragraph to explain two radically different regimes of motion.

Tornado regime motion with high speed rotation

If the cylinder is rotated uniformly at a higher speed, say 42 revolutions per minute, convective patterns make a sudden change from a mushroom regime to a tornado regime motion. The rotating pattern of bubbles after release becomes more narrow and systematic as shown in Figs. 4 (a-e).

The most powerful tool of experimenters on the fluid system is dimensional analysis.

Fig. 3. Mushroom regime motion with low speed rotation after release. Speed of rotation is about 14 revolutions per minute.

A quantitative form appropriate to the discussion of the rotating two-liquid experiments referred to above might be called a MARGULEAN form of the ROSSBY number

$$R = \frac{gS \cdot \Delta\rho}{2\Omega\rho_0 \cdot A\Omega}$$

where g is the acceleration of gravity, ρ_0 is a mean density, $\Delta\rho$ is the density difference between the two liquids, Ω is the basic rotation, A is a suitable length parameter, and S is a representative slope of the interface. In practice it is usually more convenient to adapt A as a definite quantity, normally a radius.

Many experimental results shown by Dr. FULTZ (1953) show that a series of radically different regimes of convective motions occurs across the Rossby number values. By increasing the speed of rotation (decreasing R), the approaching transition from a mushroom regime to a tornado regime motion can be found as shown in Figs. 3(a-e) and Figs. 4(a-e).

Understanding of the problem of a transition from a normal mushroom regime to a tornado regime motion seems to be very important in physical meteorology, and studies along this line will be continued by our collaborators.

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Fig. 4 Tornado regime motion with high speed rotation after release. Speed of rotation is about 42 revolutions per minute.

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対流に及ぼす回転の影響

荒川 秀俊

密度のやゝ大きな泥水を水槽中にたらし対流をおこすと きのご型の雲(倒立)に似た形になる。もしも水槽を回転すると回転の速度が小さいうちは対流は乱れをおこしながらもきのご型にとどまる。しかし回転の速度がある限度より大きくなると著者がトルネード型と呼んだ全く異質的な対流になる。この二種の異質的な対流は気象学的に大きな意味があると考えられる。