九州大学学術情報リポジトリ
Kyushu University Institutional Repository

Plane Wakes behind a Moving Magnetic-Field Source

Honji, Hiroyuki
Department of Earth System Science and Technology, Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

https://doi.org/10.15017/17291

出版情報：九州大学大学院総合理工学報告. 14 (4), pp.411-414, 1993-03-01. Interdisciplinary Graduate School of Engineering Sciences, Kyushu University
バージョン：
権利関係：

KYUSHU UNIVERSITY

九州大学大学院総合理工学研究科報告
第14巻 第4号441-414頁 平成5年3月

Engineering Sciences Reports, Kyushu University
(KYUSHU DAIGAKU SOGORIKOGAKU KENKYUKA HOKOKU)
Vol. 14, No. 4, pp. 411-414, Mar. 1993

Plane Wakes behind a Moving Magnetic-Field Source

Hiroyuki HONJI*

(Received November 30, 1992)

The structure and evolution of plane wake flows induced magnetohydrodynamically behind a moving magnetic-field source are investigated experimentally. This paper, a sequel to a preceding one[1], presents some supplementary laboratory results.

Introduction

In a preceding paper[1], it was reported that a plane wavy wake forms downstream of a localized magnetic field. The field source is a permanent-magnet unit moving at a constant velocity along a shallow water tank filled with electrolytes. As is well-known, wavy wakes form downstream of a "submerged" rigid body at high Reynolds numbers. The formation is due to periodic separation of the boundary layers from the body. In the magnetohydrodynamic system composed of a combination of electrolytes and constant magnetic fields as described above, no boundary layer separation from bodies is concerned; the waviness of the wakes in this case appears solely as a result of their inherent instability. The preceding paper thus showed that the wavy wake formation is not necessarily connected with periodic boundary layer separation from bodies.

In this paper, some supplementary laboratory results are reported as well as a few technical details concerning the magnetohydrodynamically driven system of flow of electrolytes.

Experimental Setup

The experimental apparatus is similar to that used in the preceding study[1]. A water tank made of transparent acrylic resin plates is 20.0 cm wide, 100 cm long, and 1.50 cm deep. The experimental setup and procedure are almost the same as before. Instead of salt water used previously, however, a 1.5 % solution of sodium hydrogen carbonate ($NaHCO_3$) was used as a safer working fluid. The shallow tank was filled with this solution up to the depth of 1.10 cm. A unit of permanent magnets as a constant magnetic-field source was arranged similarly as displayed in **Fig. 1** of the preceding paper[1]. The maximum magnetic flux density (B) was normally 0.095 T.

Similar types of electrolyte flow systems have been employed to set up periodic 2D streamings, of which the instabilities have become a subject of interest[2-8]. The systems may also provide a simple method of setting up diverse types of incompressible MHD flows, of which active studies have revived in recent years[9-13].

*Department of Earth System Science and Technology

In the previous experiment, the distribution of the electric current density was determined by measuring a total current supplied for electrolyzation; the current distribution along the tank was left unknown. In the present experiment, an exploratory measurement was made of the distribution of local electric current (I_0) across the tank, using a hand-made device consisting of two small pieces of probing electrodes. The result is shown in **Fig. 1**. The current distribution is hardly uniform; the maximum deviation of I_0 from its mean reaches more than 8 %. It should be noted, however, that the submergence of the probing electrodes may, in itself, have affected the orginal current distribution.

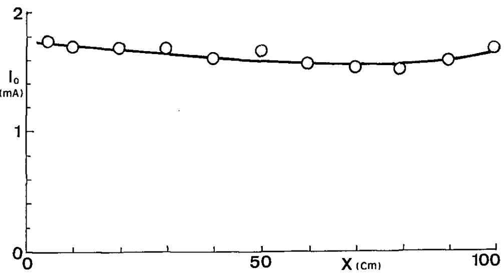


Fig. 1 Electric current (I_0) distribution with distance x measured from one end of tank.

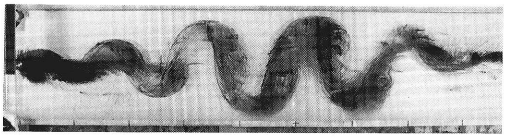
Electrodes for supplying a constant electric current were made of brass cylinders having nearly the same length as the inside length of the tank. It has been found that, for producing plane wakes, such long electrodes are not always needed but small pieces of them moving together with the nearby magnetic-field source can do. In the latter setup, however, it is hard to evaluate the actual current distribution around the magnetic-field source, because no current lines may be straight except a dividing line connecting the electrode centers.

Experimental Results

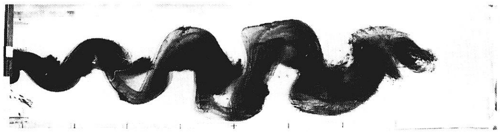
The wake flow fields may be governed approximately by the Navier-Stokes type equations including the $\mathbf{j} \times \mathbf{B}$ body force term, because the electromagnetic and hydrodynamic equations are well decoupled in the present experimental condition; **j** and **B** are the electric current and magnetic flux densities, respectively. The similarity reasoning gives that the flow on full scale depends on such parameters as the Reynolds number R $(= Ud/\nu)$, the non-dimensional "Lorentz" force Q $(= jBd/\rho U^2)$, and the reduced time Ut/d, where U, d, ν, ρ, and t and the magnet speed, the magnet diameter, the kinematic fluid viscosity, the fluid density, and the time measured from the start of magnet-unit motion.

In **Fig. 2** are displayed two typical plane wake patterns: (a) shows a wavy wake formed when the long stationary electrodes were put in a NaCl solution, and (b) shows one formed when the short electrodes were moved together with the permanent magnet unit in a $NaHCO_3$ solution. The total current applied is denoted as I. Both wake patterns look similar, and the wavy wakes thus can set up with either of the two electrode configurations. The value of Q for **Fig. 2 (b)** is only approximate because of the difficulty of precise evaluation of j. The maximum values of B for each field-source configuration are used to determine Q.

The measurement of mean wavelengths (L) for the wavy wakes was made when the long electrodes and 3.5 % salt water as a working fluid were employed. The result is shown in **Fig. 3**, in which L/d is plotted against R for Q between 0.77 and 1.04. The wavelength decreases monotonically when R is smaller and approaches to about 8.2 as R



(a)



(b)

Fig. 2 Plane wavy wakes behind a moving magnetic-field source.
(a) With long stationary electrodes in 3.5 % salt water:
R=260, Q=0.994, U=1.53 cm/s, I=1.25A, d=2.00 cm
(b) With short moving electrodes in 1.5 % $NaHCO_3$ solution:
R=299, Q=4.83, U=1.28 cm/s, I=0.250A, d=2.00 cm

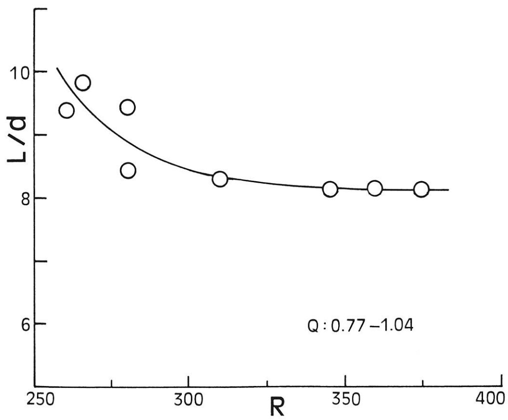
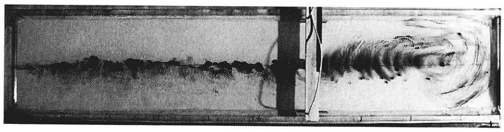
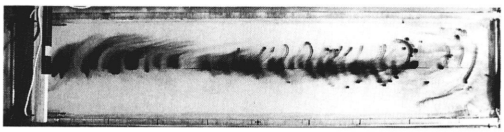


Fig. 3 Reynolds number dependence of mean wavelength of plane wavy wakes at nearly constant Q.



(a)



(b)

Fig. 4 Wakes with cross flow at R=57.0 and Q=154.

increases in the range of R examined.

The effects of cross flows on a plane wake were investigated with several different arrangements of the magnets. It was observed that, when an initially straight wake was blown off from the side by a localized cross wind in the middle of the tank, the wake became unstable and wavy after the blowing. It was also observed that, when a cross wind blew constantly, the basic wake remained straight while a circulatory flow set up in the tank. An example is shown in **Fig. 4**. In this case, the elctrodes were located on the left and right ends of the tank so that the body force continued to cause a cross flow during the run. In **Fig. 4 (a)**, the leftward-moving magnet unit is still in the middle of the tank and a clockwise-rotating circulation is established behind the unit. **Figure 4 (b)** shows the wake formed after the whole tank has been traversed. As will be seen from the picture, the basic wake pattern remains straight to suffer no wavy distortion.

The interference of the wake with a more complicated cross flow was investigated exploratively. **Figure 5** shows a symmetric flow induced by the magnets alining, behind the bottom of the tank, equidistantly with alternating polarities. With the use of a pair of two magnets, a single pair of standing mushroom vortices as shown in **Fig. 5** was selected in

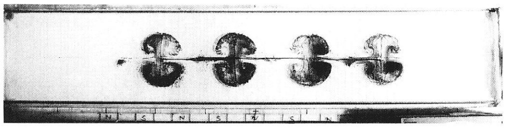
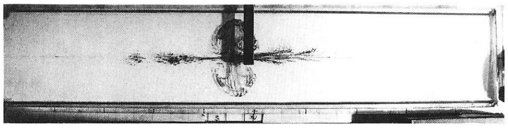
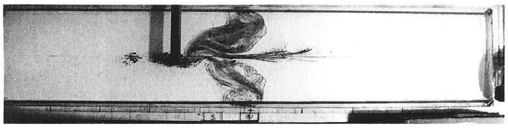


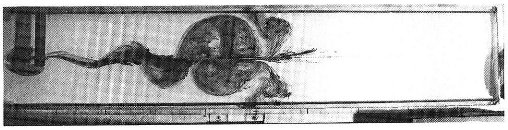
Fig. 5 Mushroom vortices induced on alined magnets arranged equidistantly with alternating polarities at B=0.100 T and I=1.00 A.



(a)



(b)



(c)

Fig. 6 Interference of plane wake with a vortex pair standing in the middle of tank at R=67.5, Q =0.164, U=1.00 cm/s, d=0.600 cm, B= 0.0300 T, and j=90.0 A/m^2.
(a) Ut/d=35.0
(b) Ut/d=61.7
(c) Ut/d=138

the middle of the tank, and made to interfere with a progressing plane wake originally formed due to the moving magnetic-field source. The result is displayed in **Fig. 6**. **Figure 6(a)** shows the encounter of the wake with the vortex pair. **Figures 6 (b)** and **(c)** show the subsequent development of the interfering flow pattern. **Figure 6 (c)** shows that the wake has become wavy after the encounter and a large block of symmetrical vortices is formed in the far wake. A cross flow thus distorts the plane wakes substantially.

In conclusion, the Reynolds number dependence of the mean wavelength of the plane wavy wakes induced by the Lorentz force is established for the range $250 < R < 400$. The plane wakes are substantially affected by cross flows.

This work was supported by the Grant-In-Aid for Scientific Research (No. 04804025) from the Ministry of Education, Science, & Culture, which is gratefully acknowledeged.

References

1) H. Honji: J. Phys. Soc. Jpn. **60**, 4 (1991) 1161-1164.
2) Ye. Z. Gak and G. R. Rik: Dokl. AN-SSSR, **175**, 4 (1967) 556-588.
3) S. O. Belotserkovskii, A. P. Mirabel, and M. A. Chusov: Izvest. Atmos. Oceanic Phys. **14**, 1 (1978) 6-12.
4) N. F. Bondarenko and M. Z. Gak: Izvest. Atmos. Oceanic Phys. **14**, 2 (1978) 146-150.
5) N. F. Bondarenko, M. Z. Gak, and F. V Dolzhansky: Izvest. Atmos. Oceanic Phys. **15**, 10 (1979) 711-716.
6) O. Cardoso, H. Willaime, and P. Tabeling: Phys. Rev. Lett. **65**, 15 (1990) 1869-1872.
7) K. Gotoh: Proc. Autumnal Meeting Phys. Soc. Jpn. (Tokyo Univ. Sept. 25, 1992) p. 77.
8) A. Thess: Phys. Fluids **A4**, 7 (1922) Pt. 1, 1385-1395; Pt. 2, 1396-1407.
9) V. Bojarevics, Ya. Freibergs, E. I. Shilova and E. V. Shcherbinin: *Electrically Induced Vortical Flows*, Kluwer Academic Publ., Dordrecht, 1989.
10) A. E. Lifshitz: *Magnetohydrodynamics and Spectral Theory*, Kluwer Academic Publ., Dordrecht, 1989.
11) A. M. Anile: *Relativistic fluids and magneto-fluids*, Cambridge Univ. Pr., Cambridge, 1989.
12) R. Moreau: *Magnetohydrodynamics*, Kluwer Academic Publ., Dordrecht, 1990.
13) R. V. Polovin and V. P. Demutskii: *Fundamentals of Magnetohydrodynamics.*, Consultants Bureau, N. Y., 1990.