MAGNETOHYDRODYNAMIC FLOW PHENOMENA

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1. Introduction

The MHD group of the Institute of Safety Research performs basic studies on fluid dynamics and heat/mass transfer in fluids, particularly for electrically conducting fluids (liquid metals) exposed to external magnetic fields (Magnetohydrodynamics - MHD). Such a contactless influence on transport phenomena is of principal importance for a variety of applied problems including safety and design aspects in liquid metal cooled fusion reactors, fast reactors, and chemical systems. Any electrically conducting flow can be influenced without any contact by means of an external electromagnetic field. This, of course, can change the known hydromechanically flow patterns considerably. In the following two examples of such magnetic field influence are presented.

2. MHD Flow around a Cylinder

Fluid flows around obstacles determine in many applied cases the heat/mass transfer rates. The fluiddynamic standard problem of the flow around a circular cylinder serves as the generic problem for any studies in that field. This flow problem is extensively documented in literature. However, the relevance of 3d-effects along the cylinder axis was only recently detected and analysed.

We study this type of flow for the case of a liquid metal flow exposed to an external magnetic field [1]. In this situation there is besides the usual Reynolds number a second control parameter for the flow dynamics: The interaction parameter which is proportional to the square of the magnetic field strength. Depending on the magnetic field direction a variety of specific influences arises due to the magnetic field action. If the magnetic field is parallel to the oncoming flow a stabilization, i.e. the suppression of the Karman vortex street (Fig. 1a), is produced by the magnetic forces [2]. However, the magnetic field is not able to fully relaminarize the flow, standing eddies are always present how strong the magnetic field might be. This result is shown in Fig.1b. Only in the case of a magnetic field directed perpendicular to the flow and to the cylinder axis a full relaminarization is posssible as shown in Fig.1c. The results shown in Fig.1 were obtained by a 2d numerical simulation. They correct considerably the simulations available in literature up to now [2,4]. The most interesting aspects, however, are connected with a full 3d view on the problem [4]. In this case a list of interesting phenomena must be expected from general MHD principles:

- 3d-instabilities before 2d due to the break of the hydrodynamic Squire theorem,
- suppression of 3d instabilities if the magnetic field is parallel to the cylinder axis,
- occurence of new instabilities for a growing magnetic field strength in strong contradiction to the usually assumed damping action of steady magnetic fields transverse to cylinder axis.

The extension of the present 2d code to the general 3d case is the logical next step but requires huge calculating ressources.

In addition first MHD wake flow measurements were performed at the mercury facility of IMG Grenoble showing clearly the Karman vortex street suppression, but also an unexpected tendency for longwave instabilities [3].

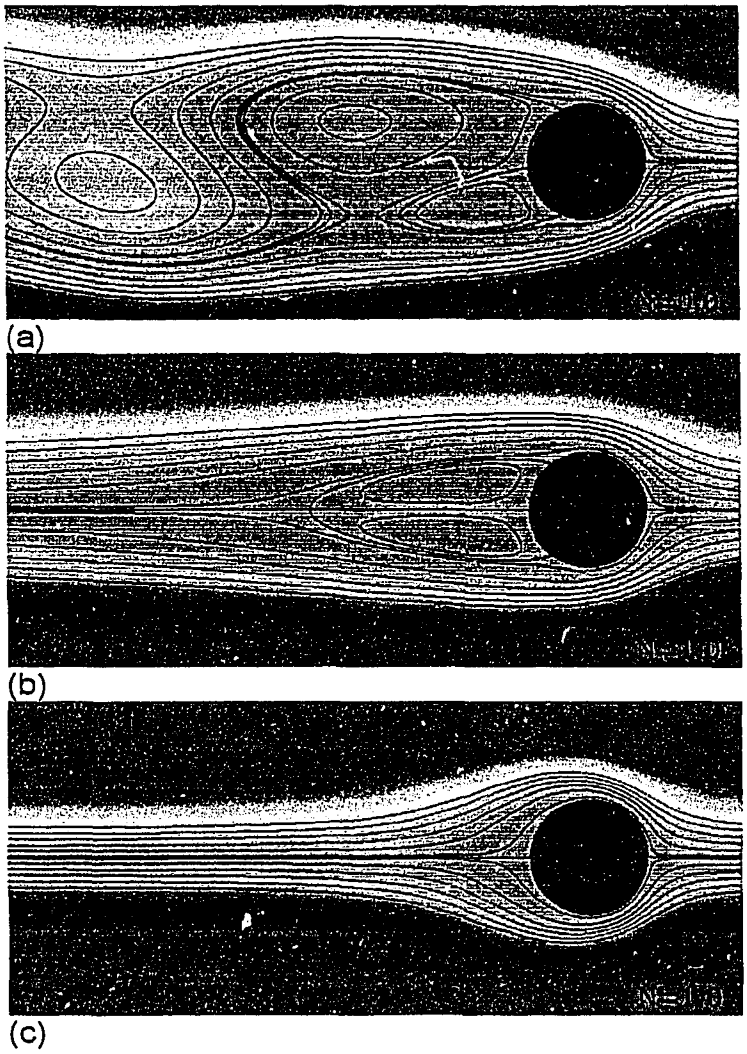
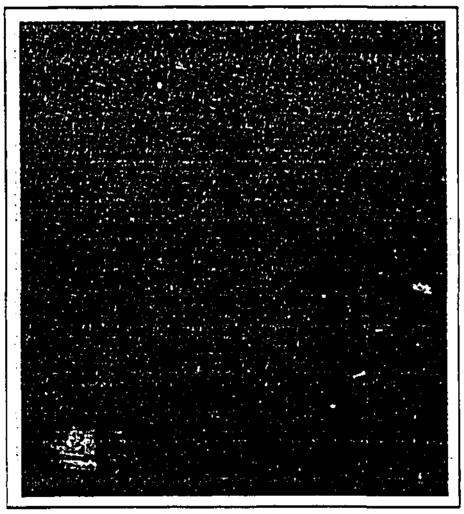
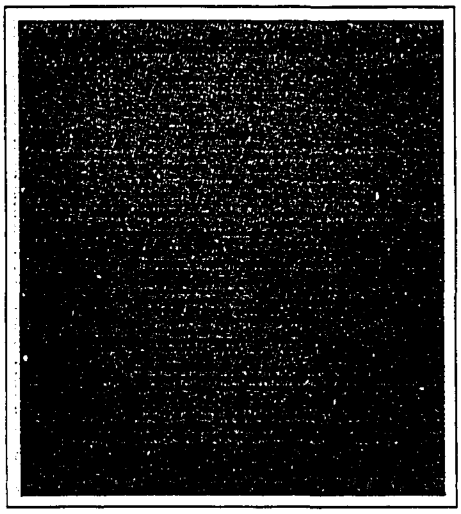


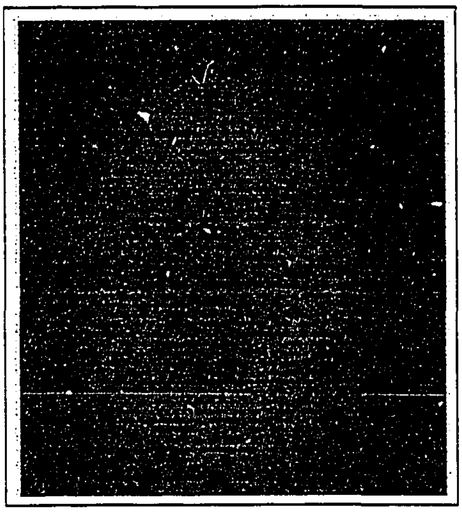
Fig. 1: 2d MHD flow around a circular cylinder at Re = 100
(a) unsteady flow, N = 0
(b) steady flow, aligned field, N = 1
(c) steady flow, transverse field, N = 1



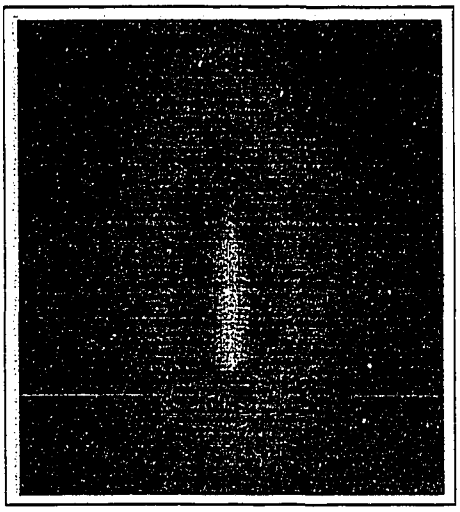
(a) Ha = 0, N = 0



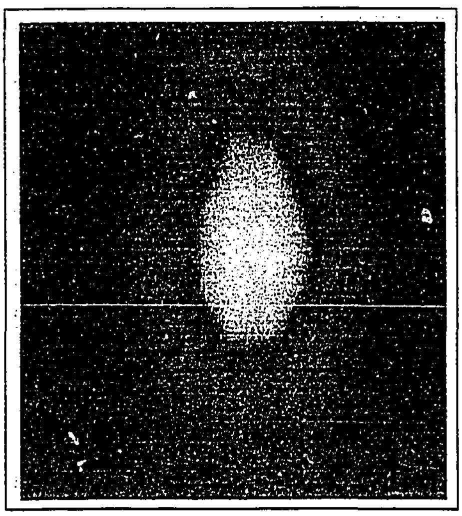
(b) Ha = 600, N = 19



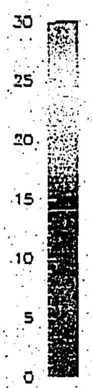
(c) Ha = 1200, N = 78



(d) Ha = 1505, N = 122



(e) Ha = 2110, N = 239



→ direction of the B-field →

Fig. 2:
Meas. void fraction distributions in a vertical sodium/argon flow at Re =18600,
strong anisotropic dispersion due to the magnetic field action

3. Anisotropic transport in strong magnetic fields

Application of an external magnetic field can change the transport mechanism drastically. Usually an overall damping effect is assumed, but this is not correct. The magnetic field redistributes the vortices leading to a highly anisotropic turbulence structure. This phenomenon is known in literature as two-dimensional MHD turbulence [7]. It could have a distinctive and even crucial influence on the Blanket design of a liquid metal cooled fusion reactor. The possibility of a self-cooled liquid metal (Li) Blanket for a Fusion Reactor strongly depends on the problem which rate of heat transport away from the first wall can be realized. Due to the strong magnetic fields in a TOKAMAK the liquid metal Blanket design was based on the assumption of a fully relaminarized flow due to the turbulence damping of the magnetic forces. In that case a liquid metal Blanket is not possible since the required flow rates would lead to extraordinary pressure drops in the flow channels. However, this picture was not a correct one: Even in very strong magnetic fields turbulence can persist, namely, vortices parallel to the magnetic field direction. Based on a physical understanding of this remaining turbulence special means for its intensification can be proposed.

To measure these transport phenomena experiments were performed and prepared at the sodium test facility of the MHD group [5-7]. At one test section bubbles are injected through a single orifice into the center of the vertical test section. Local measurements of the void fraction appr. 30cm above the injection point give a clear picture of the magnetic field influence on the bubble dispersion. Fig. 2 shows such measuring results, particularly the anisotropic action of the magnetic field. A more sophisticated heat transport test section is in preparation now. The goal is to demonstrate that the heat transport rate away from a heated wall can be higher compared to the fully relaminarized case by a factor of 3...6. The bubble measurements are in accordance with such a transport enhancement.

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