Magnetohydrodynamics - overview

Magnetohydrodynamics (MHD) is the study of the interaction of electrically conducting fluids and electromagnetic forces. MHD problems arise in a wide variety of situations ranging from the explanation of the origin of Earth's magnetic field and the prediction of space weather to the damping of turbulent fluctuations in semiconductor melts during crystal growth and even the measurement of the flow rates of beverages in the food industry. The description of MHD flows involves both the equations of fluid dynamics - the Navier-Stokes equations - and the equations of electrodynamics - Maxwell's equations - which are mutually coupled through the Lorentz force and Ohm's law for moving electrical conductors. Given the vast range of Reynolds numbers and magnetic Reynolds numbers characterising astrophysical, geophysical, and industrial MHD problems it is not feasible to devise an all-encompassing numerical code for the simulation of all MHD flows. The challenge in MHD is rather to combine a judicious application of analytical tools for the derivation of simplified equations with accurate numerical algorithms for the solution of the resulting mathematical models. The 2006 summer program provided a unique opportunity for scientists and engineers working in different sub-disciplines of MHD to interact with each other and benefit from the numerical capabilities available at the Center for Turbulence Research.

In materials processing such as the growth of semiconductor crystals or the continuous casting of steel turbulent flows are often undesirable. The application of steady magnetic fields provides a convenient means for the contactless damping of turbulent fluctuations and for the laminarisation of flows. However, the details of how a magnetic field affects the transition to turbulence are still poorly understood. Consequently, there is a dire need for fundamental investigations of the transition process. The papers by Boeck *et al.* and Sarris *et al.* help to fill this gap. The work of these two groups is complementary in several respects. Whereas Boeck *et al.* use stability theory to compute optimal perturbations in a channel flow with spanwise magnetic field, Sarris *et al.* employ large-eddy simulation to study transition from turbulent to laminar flow under the influence of a transverse magnetic field. An additional aspect of MHD flows concerns the behavior of particles in turbulent MHD flows and has been studied by Rouson *et al.*. This topic is not only of fundamental fluid-dynamical interest but is also of considerable importance for the prediction of the behavior of impurities in metallurgical flows. All three projects of the first subgroup have led to interesting new results that contribute to improvements of commercial codes for the simulation of metallurgical MHD processes.

MHD effects occur in many natural phenomena including the generation of the magnetic field of planets and stars, the interaction of Earth's magnetic field with the solar wind as well as lightning. Two of these topics were investigated by the second subgroup during the 2006 summer program. Hartlep *et al.* report the implementation of MHD waves into a code for the simulation of the solar interior. This work is not only an invaluable contribution to the improvement of helioseismological reconstruction methods but also adds a new facet to our general understanding of the physics of the sun. Ripoll *et al.*'s paper describes the development of a code for the modeling of lightning strikes. After careful verification using known exact solutions, the code is shown to improve the predictive capabilities in comparison to previous approaches considerably. The results will find their application in remote sensing for the monitoring of non-proliferation.

The third group of papers deals with applications of MHD. The reliable prediction of MHD flows under the influence of a strong magnetic field is a key ingredient for the design of liquid metal blankets in future fusion reactors. In their paper Smolentsev & Moreau describe a new approach to model these liquid metal flows by a set of two-dimensional equations involving a turbulence model that has been developed during the work of the summer program. Preliminary results of simulations indicate that the new model could become a useful tool in fusion applications. A second topic considered during the summer program were non-contact measurement techniques for liquid metal flows. The successful development of techniques that are suitable for high-temperature applications would have considerable impact. Thess et al have developed the theory of one such technique which is called Lorentz force velocimetry. The results involve analytical and numerical investigations and provide a rational framework for the development of signal processing algorithms for future industrial application of this technique. This project required, among other things, a direct numerical simulation of turbulent pipe flows. The fact that such a simulation (including sophisticated post-processing) was set up within only two weeks thanks to the invaluable help of the staff at CTR bears witness of the maturity of Computational Fluid Dynamics (CFD) in general and of CFD at CTR in particular.

Finally, it should be stressed that the results of the individual projects would not have been obtained without a fruitful interaction between all scientists from the MHD group and with the scientists of all other groups. This made the 2006 summer program an interesting and rewarding experience.

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