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FINAL REPORT

on

HYDROMAGNETIC TURBULENCE

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Edward A. Spiegel
Edward A. Spiegel, Project Director

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Aims of the Program

The work performed during the past year has undergone a shift of interest and emphasis. We are now mainly concerned with fluid dynamical processes in stars and with making use of the knowledge gained from our previous studies in abstract theories of turbulence. These problems of astrophysical fluid dynamics are of direct importance to the understanding of stellar evaluation and to the interpretation of modern observations of the solar surface.

Personnel

The following persons have received at least partial support during the past year:

Dr. R.H. Kraichnan
Mr. S. Nagarajan
Mrs. M. Sestero
Dr. E.A. Spiegel

Mr. Nagarajan's work is expected to lead to a Ph.D. in physics and is the last thread to be taken up in the completion of the original work begun under the predecessor of the present contract. Dr. Kraichnan's official contact with the project terminated at the end of the first quarter.

In addition to these, Dr. D.W. Moore of the Department of Mathematics of Bristol University acted as consultant for one week during a visit to this country. He has continued in his collaboration with us on the problem of the solar oscillations.

Stellar Convection Theory

One of the essential problems of the theory of stellar evoluation is to provide a method for estimating the efficiency of convective heat transfer in stars.

At present, the method in use is the classical mixing-length theory which has a number of limitations. We have suggested a refined version of theory,[1] and this hopefully will improve the situation. The suggested improvement is now being applied to stellar evolution problems by Dr. A.G.W. Cameron of the Institute for Space Studies (NASA) and his students.

However, it is clear that an even deeper change in the prevalent convection theory is needed and we have been pursuing the development of such a new theory. The new line of approach is based on the formulation of convection theory outlined in reference(2). In this particular reference we showed that the Malkus theory which had provided some hope will not be suitable after all. In doing so, this work pointed the way to the approach based on a normal mode expansion and a suitable treatment of the nonlinear coupling terms. The work is still under way but its initial results seem to provide support for the newly devised mixing-length theory of reference (1).

Convective Instability in Stellar Atmospheres

Whatever theory of stellar convection is employed it is necessary to have a complete and accurate solution of the linearized equations of motion. The solution of these equations is tantamount to a determination of the convective instability of the star. This problem has been an adjunct to our stellar convection program for some time and we have been carefully studying the convective instability of a polytropic atmosphere. The problem has now been treated from four different points of view, the last being numerical solution on the IBM 7090 of the Institute for Space Studies. The tasks of making the results available in a series of about three papers has just been undertaken, Generation and Propagation of Waves in the Solar Atmosphere

The theory of generation of waves in a compressible atmosphere has been worked out for the case of a fluctuating force. Such a force will result from density variations in solar turbulence. The propagation of the waves is especially interesting; there is a discrete band of frequencies which cannot propagate. These nonpropagating frequencies provide an explanation of the recently discovered solar oscillations.

This work has been written up and the manuscript is in the last state of revision for publication.[3] It is intended to submit this paper to the Astrophysical Journal. The paper is also to be read at the forthcoming meeting of the American Astronomical Society in Tucson.

Radiative Fluid Dynamics

Work has continued on the damping of sound waves by photon losses. The theory devised during the past year has been under numerical evaluation. We have determined the damping of a sound wave for varying radiative properties. The extension of this work to the solar waves discussed in the former section has been undertaken.

A related study is the effect of photon losses on the convective instability in a polytrope. It has been possible to show that the existing literature on the subject contains some errors which have lead to a misinterpretation of the observed data. The new results indicate that small scale motions may exist in the solar atmosphere which have not been detected by the recent balloon observations.

Statistical Physics

During his last months at New York University Dr. Kraichnan continued his study of the quantum mechanical many-body problem. Mr. Nagarajan has studied the statistical mechanics of hydromagnetic turbulence. His aim has been to apply Kraichnan's methods to the problem and to shed some light on the knotty question of equipartition in hydromagnetic turbulence.

Papers Published and Prepared

1. "A Generalization of the Mixing-Length Theory of Turbulent Convection" by E.A. Spiegel. To appear in the July issue of the Astrophysical Journal.

2. "On the Malkus Theory of Turbulence" by E.A. Spiegel. Published by the Centre National de la Recherche Scientique of France in Mecanique de la Turbulence, 1962, P.181.

3. "The Generation and Propagation of Waves in a Compressible Atmosphere" by D.W. Moore and E.A. Spiegel. To be submitted to the Astrophysical Journal.

4. "Quantum Statistics and the Boltzmann Equation" by R.M. Lewis. Journal of Mathematical Physics, Vol. 3, P.1229, 1962.

5. "On Convective Growth-rates in a Polytropic Atmosphere" by E.A. Spiegel and W. Unno. Publications of the Astronomical Society of Japan, Vol. 14, P.28, 1962.

Other Activities

Once again Drs. Kraichnan and Spiegel participated in the Summer School of Geophysical Fluid Dynamics at the Woods Hole Oceanographic Institution. They presented seminars there on some of the work reported herein. Dr. Spiegel gave invited lecture series on turbulent convection at the International Meteorological Institute (Stockholm) and the National Center for Atmospheric Research (Boulder). Seminars on the Generalization of the Mixing-Length Theory" were presented at the Institute for Advanced Studies (Princeton), the Yale University Observatory, and the High Altitude Observatory (Boulder). Seminars on the "Generation and Propagation of Waves in a Compressible Atmosphere" were given at Harvard, Princeton, and Maryland Universities.