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Pattern selection, wave formation, turbulence, and vortex breakdown in spiral flows

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13. ABSTRACT (Maximum 200 words)

(1) Landau type amplitude equations for the small-gap Taylor problem were derived and analyzed; the equations obtained are global and are more complete than those determined by a formal two-timing analysis. Transition solutions (i.e., heteroclinic orbits) connecting the trivial Couette flow with bifurcating steady flows were obtained by solving singular evolution equations in infinite-dimensional spaces. (2) The existence of a continuum of periodic waves for a class of spiral flow problems was established; the general method was applied to rotating plane Couette flow to obtain an analytic description of turbulent-like flows. The usual Hopf bifurcation theory does not apply to such problems and new methods using singular evolution equations were developed. It was shown that such methods apply also to Langmuir circulations in upper-ocean mixing problems and that the use of such methods leads to a number of new results for Langmuir circulations including mixing problems where the Stokes drift has a cross-wind component. The work in (2) is joint with Prof. George H. Knightly of the University of Massachusetts.

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FINAL TECHNICAL REPORT

I. Summary of Research Activities.

(1) Landau type amplitude equations for the small-gap Taylor problem were derived and analyzed in [3] (see the list of publications in II). The equations obtained are global and are more complete than those determined by a formal two-timing analysis. Transition solutions (i.e., heteroclinic orbits) connecting the trivial Couette flow with bifurcating steady flows were obtained by solving singular evolution equations in infinite-dimensional spaces. The results obtained lead to the first analytic description of the difference between primary and secondary flows of a viscous fluid.

The work in (2)-(4) is joint with George H. Knightly of the University of Massachusetts.

(2) The bifurcation and stability properties of spiral flows for a variety of Couette-Poiseuille problems were obtained in [1]. These are the first complete results on the bifurcation and stability of viscous spiral flows.

(3) Periodic waves were shown to exist and their expansions obtained in [2; 5; 6] for various Couette-Poiseuille problems for viscous spiral flows. The existence of periodic waves in such problems has been conjectured but never proved.

(4) A continuum of periodic waves bifurcating supercritically from the basic spiral flow was obtained in [4] for rotating plane Couette flow. Results of this type provide a simple explanation for the occurrence of turbulent-like flows in spiral flow problems and

also the first analytic description of turbulent-like flows. The usual Hopf bifurcation theory does not apply to such problems and new methods using singular evolution equations were developed.

(5) It was shown that the methods used in (4) apply also to Langmuir circulations in upper-ocean mixing problems and that the use of such methods leads to a number of new results for Langmuir circulations including mixing problems in which the Stokes drift has a cross-wind component. There are no other results for Langmuir circulations of this nature in the literature to date. These results will be reported on in a series of papers in preparation.

II. Publications and Papers in Preparation.

The following papers were completed and accepted for publication during the period of the grant. Preprints and reprints have been forwarded to ONR.

- [1] *Bifurcation and stability problems in rotating plane Couette-Poiseuille flow*, Contemporary Math. 108 (1990), 79-91, (joint with George H. Knightly).
- [2] *Time-periodic states in problems containing a structure parameter*, Proc. 1st European Conference on Elliptic and Parabolic Problems, 1991, to appear (joint with George H. Knightly).

The following paper has been submitted to the Archive for Rational Mechanics and Analysis. A preprint has been forwarded to ONR.

- [3] *Transition solutions in the Taylor problem*, University of Colorado Report, August 1991, (39 pages).

The following papers are in the final stages of preparation. Preprints will be forwarded to ONR within the next two months.

- [4] *Continua of periodic waves in rotating plane Couette flow*, (joint with George H. Knightly).
- [5] *Families of periodic waves in rotating Couette-Poiseuille flow*, Proc. of the Conference on Nonlinear Dynamics, University of Massachusetts, October 1990, to appear (joint with George H. Knightly).
- [6] *Periodic waves in rotating plane Couette flow*, Conference on Applied Dynamics and Bifurcation Theory, January 1992, to be submitted to ZAMP (joint with George H. Knightly).

III. Invited Symposia Lectures.

A * denotes invitations not accepted.

- (1) Fluid Dynamics Stability, SIAM Annual Meeting, Chicago, July 16-20, 1990.
- (2) Partial Differential Equations, Cornell University, October 5-7, 1990.
- (3) Nonlinear Dynamics in Mathematics and Science, AMS Meeting, Amherst, October 20-21, 1990.
- (4)* Bifurcation and Symmetry, University of Marburg, Germany, June 2-7, 1991.
- (5) Applied Dynamics and Bifurcation Theory, Oberwolfach, Germany, January 12-18, 1992.
- (6) First World Congress of Nonlinear Analysts, Florida Inst. of Technology, Melbourne, August 19-26, 1992.