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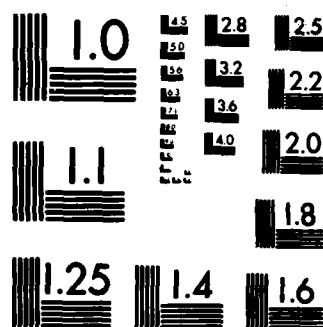
VORTICES IN NON-NEWTONIAN FLUIDS(US) LEHIGH UNIV
BETHLEHEM PA R S RIVLIN FEB 85 ARO-18595.5-MA
DAG29-82-K-0026

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20. ABSTRACT CONTINUED:

The fluids considered are such that for shearing flows the shear stress at an instant of time t depends linearly on the history of the velocity gradient in the fluid for all times up to and including t . Although in the problems considered most of the analysis is carried out for arbitrary linear dependence of the shear stress on the velocity gradient history, illustrative numerical results are obtained for the case when the fluid is Maxwellian and, for purposes of comparison, when it is Newtonian.

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FINAL REPORT

ARO Proposal Number: 18595 - MA
Contract Number: DAAG29-82-K-00
Period Covered: December 14, 1981 - December 13, 1984
Title: Vortices in Non-Newtonian Fluids
Principal Investigator: R. S. Rivlin
Name of Institution: Lehigh University
Personnel Supported: R. S. Rivlin

PROGRESS REPORT

The research carried out under the subject contract has been directed to the analysis of the manner in which vorticity in an incompressible viscoelastic fluid propagates and decays.

The fluids considered are such that for shearing flows the shear stress at an instant of time t depends linearly on the history of the velocity gradient in the fluid for all times up to and including t . Although in the problems considered most of the analysis is carried out for arbitrary linear dependence of the shear stress on the velocity gradient history, illustrative numerical results are obtained for the case when the fluid is Maxwellian and, for purposes of comparison, when it is Newtonian.

In the first problem considered, the fluid fills the region between two fixed infinite parallel plates and is initially at rest. It is subjected at time $t=0$ to a uniform pressure gradient, in a direction parallel to the plates, which is subsequently held constant. The time-dependent development of the final steady-state Poiseuille flow is calculated. It is found that, in the case when the fluid is Newtonian, at each instant of time the velocity profile in the fluid varies smoothly from zero at the plates to a maximum on the mid-plane. As time proceeds the velocity at each position between the plates increases monotonically until, asymptotically at infinite time, the parabolic velocity distribution associated with steady Poiseuille flow of a Newtonian fluid is attained.

In contrast, when the fluid is Maxwellian quite different behavior is obtained. Shear layers in which the vorticity is nearly constant are developed at the walls. These have initially zero thickness. As time proceeds the thickness of the layers increases, but the vorticity (i.e. the velocity gradient) in them increases only slightly. At each instant the fluid

between these shear layers moves forward as a rigid body with a velocity which increases with time. This region becomes narrower and narrower as time progresses and at its interface with the shear layers there is a discontinuity in the velocity gradient. When the shear layers reach the mid-plane, the velocity on the mid-plane exceeds that corresponding to the final steady state and subsequently oscillates about the latter value, the amplitude of these oscillations decaying with time until the steady-state value of the velocity is attained asymptotically.

These results are easily applied to obtain the time-dependent flow field which results when the initial flow is steady-state plane Poiseuille flow and the pressure gradient which maintains it is suddenly removed. This is given by the complement of the time-dependent flow already obtained with respect to the steady plane Poiseuille flow.

The problem of the propagation and decay of an initially existing shear layer or vortex sheet in a viscoelastic fluid has been considered from two points of view. In Ref. 2 a pair of symmetrically disposed shear layers are assumed to exist in the region between two stationary parallel plates and at time $t=0$ the forces maintaining them are removed. The equation of motion governing the resulting time-dependent velocity field is set up. Its Laplace transform is formed and solved for the Laplace transform of the velocity, subject to appropriate conditions at the bounding plates. To this point the analysis is carried out for arbitrary linear dependence of the shear stress on the history of the velocity gradient. The Laplace transform of the velocity is inverted to yield the velocity in the particular cases when the fluid is Maxwellian and, for purposes of comparison, when it is Newtonian. In the latter case the shear layers broaden smoothly in a diffusive manner and simultaneously decay. In contrast, when the fluid

is Maxwellian, on removal of the forces maintaining the shear layers, there is a jump in velocity at the boundary of each shear layer. As time progresses each of these jumps propagates as a pair of wave-fronts with equal and opposite velocities and decaying amplitudes. Ahead of the fronts the flow field is unchanged. Since the assumed constitutive equation of the fluid is linear, the effects of the waves as they pass each other is additive. When the waves reach the rigid boundaries they are reflected and the superposition of the resulting flow fields leads to a complicated decaying oscillatory flow field in the fluid. From the calculated time-dependent velocity field in the fluid, the velocity gradient field (i.e. the vorticity field) can be easily obtained.

The time-dependent velocity field in the case when the initial shear layers exist in an unbounded space of fluid is derived as a limiting case. The predicted behavior is basically similar to that obtained for a bounded domain with the difference that the waves resulting from reflections at the boundaries are missing.

The velocity field which results when the initial field consists of a pair of vortex sheets of equal and opposite vorticities is also obtained as a limiting case by allowing the width of the initial shear layers to tend to zero while the velocity gradient in them tends to infinity, the product of these two quantities remaining constant.

In Ref. 3 a somewhat different approach has been taken to the same problem in the case when the initial velocity field exists in an unbounded space of the fluid. Instead of solving the equation of motion for the velocity field, the differential equation governing the vorticity is first obtained from the equation of motion by spatial differentiation. The resulting vorticity equation is then solved subject to the condition that the

vorticity is zero at infinity, again using a Laplace transform method. The calculations are carried out with the assumption that the initial flow field is one in which there is a single shear layer, i.e. a single layer or constant vorticity. From the results obtained, corresponding results for any number of initial parallel shear layers can be easily obtained by superposition.

In Ref. 3 explicit illustrative results are obtained for Newtonian and Maxwellian fluids. In both cases the results agree with those obtained in Ref. 2. However, a clearer picture emerges of the behavior of the vorticity than that obtained in the earlier paper. When the fluid is Maxwellian, immediately after removal of the forces maintaining the layer of constant vorticity, there is a jump in the vorticity to half its initial value at each boundary of the layer. This jump propagates from the boundary in both directions with equal speeds and decays as it progresses. The result when the initial flow field in the fluid consists of a vortex sheet, rather than a layer, is derived as a limiting case.

The method employed in Ref. 3 has also been applied to the calculation of the time-dependent vorticity distribution which results from an initial vortex tube, or, as a limiting case, an initial vortex line, in an unbounded space of viscoelastic fluid. Although the results obtained are physically reasonable, and are consonant with those which might be expected from the calculations on the propagation and decay of vortex layers and sheets, a certain technical detail in the calculation is open to question. It is hoped to resolve this matter by using a procedure similar to that employed in the case of shear layers in Ref. 2.

PAPERS PUBLISHED

- (1) "Run-up and Decay of Plane Poiseuille Flow" by R.S. Rivlin, J. Non-Newtonian Fluid Mechanics, 14, 203-217 (1984)
- (2) "Decay of Shear Layers and Vortex Sheets" by R.S. Rivlin, J. Non-Newtonian Fluid Mechanics, 15, 199-226 (1984)
- (3) "The Propagation of Vorticity in a Viscoelastic Fluid" by R.S. Rivlin, J. Non-Newtonian Fluids Mechanics (in the press)

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