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Three-dimensional stagnation point flow of a second grade fluid towards a moving plate

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Abstract

The problem dealing with the steady three-dimensional flow of a second grade fluid near the stagnation point of an infinite plate moving parallel to itself with constant velocity has been investigated. By using the appropriate transformations for the velocity components and temperature, the basic equations governing flow and heat transfer have been reduced to a set of ordinary differential equations. These equations have been solved approximately subject to the relevant boundary conditions by employing a numerical technique. The effect of a nondimensional elastic parameter on the velocity components, wall shear stress, temperature and heat transfer has been examined carefully.

Keywords: Stagnation point; Viscoelasticity; Second grade fluid

1. Introduction

Most problems involving two- and three-dimensional stagnation point flow have similarity solutions in the sense that the number of independent variables is reduced by one or more. These similarity solutions may be derived using the group-theoretic method. The analysis of such flows is very important in both theory and practice. From a theoretical point of view, flows of this type are fundamental in fluid mechanics and forced convective heat transfer. From a practical point of view, these flows have applications in many manufacturing processes in industry such as the boundary layer along material handling conveyers, the aerodynamic extrusion of plastic sheet, and the cooling of an infinite metallic plate in a cooling bath.

The classical two-dimensional Hiemenz [1] and axisymmetric Homann [2] stagnation point flows describe situations where fluid impinges normally onto a flat surface and spreads out bidirectionally or radially along the surface, away from a single stagnation point. Both two-dimensional and axisymmetric flows were extended

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to three dimensions by Howarth [3] and Davey [4]. Two-dimensional oblique stagnation flow was solved by Stuart [5] and later by Tamada [6] and Dorrepaal [7].

Authors like Stuart [8], Rott [9], and Glauert [10] analyzed the two-dimensional stagnation point flow against a plate that is oscillating in its own plane. Yang [11] investigated the two-dimensional unsteady stagnation point flow towards a plate. Yang's work was extended by Williams [12] for the case of axisymmetric flow and then Cheng et al. [13] for the case of three-dimensional flow. The three-dimensional stagnation point flow on a moving plate was considered by Wang [14] and Liby [15]. Wang [16] studied the unsteady oblique stagnation point flow. Weidman and Mahalingam [17] solved the problem of axisymmetric stagnation point flow impinging on a flat plate oscillating in its own plane with suction and blowing by reduction of the Navier–Stokes equations to a set of coupled ordinary differential equations and subsequent numerical integration. Laminar incompressible mixed convection boundary layer flow with large injection rates at the stagnation point of a three-dimensional body was examined by Eswara and Nath [18].

All the above investigations are, however, confined to flows of Newtonian fluids. In recent years, it has generally been recognized that in industrial applications non-Newtonian fluids are more appropriate than Newtonian fluids. For instance, in certain polymer processing applications, one deals with the flow of a non-Newtonian fluid over a moving surface. That non-Newtonian fluids are finding increasing application in industry has given impetus to many researchers. Srivastava [19] obtained an approximate solution for an axisymmetric flow of a Reiner–Rivlin fluid near a stagnation point adopting the Karman–Pohlhausen method used for the study of boundary layer equations in Newtonian fluids. Maiti [20] re-examined the same flow problem by replacing Reiner–Rivlin fluid by power-law fluid. For second-order Rivlin–Ericksen fluid, Rajeswari and Rathna [21] studied the two-dimensional and axisymmetric flows near a stagnation point by using an extension of the Karman–Pohlhausen technique. The Prandtl boundary layer theory was extended by Beard and Walters [22] for an idealized elastico-viscous fluid, more specifically such a fluid is called a Walter's B' fluid, and then by Sarpkaya and Rainey [23] for a second-order viscoelastic fluid. They obtained the approximate solution valid for sufficiently small values of the elastic parameter by employing a perturbation procedure, using the coefficient that multiplies the highest order term in the equation as the perturbation parameter, thereby lowering the order of the equation. Soundalgekar and Vighnesam [24] used the same perturbation scheme in order to obtain a solution to the heat transfer problem related to the two-dimensional stagnation point flow of Walter's B' fluid. Garg and Rajagopal [25] considered the two-dimensional stagnation point flow of thermodynamically compatible second-order fluid, where only the velocity field was studied. They obtained solutions valid for all values of an elastic parameter by using an additional boundary condition at infinity. The heat transfer aspect of this problem was investigated Massoudi and Ramezan [26] and Garg [27]. Dorrepaal et al. [28] examined the behaviour of a viscoelastic fluid impinging on a flat rigid wall at an arbitrary angle of incidence. Labropulu et al. [29] studied the orthogonal and oblique flows of a second grade fluid impinging on a wall with suction or blowing. Ariel [30] examined the generalized three-dimensional stagnation point flow of a Walter's B' fluid against a stationary flat plate by using the transformations proposed by Howarth [3] for the velocity components. He has demonstrated on the basis of his exact numerical solutions that the solutions can be obtained only up to some critical value of the elastic parameter, and that for values less than this critical value dual solutions exist. In his subsequent study [31], he investigated the laminar, steady stagnation point flow of a Walter's B' fluid towards a moving plate by considering both the cases of two-dimensional and axisymmetric flow. Seshadri et al. [32] studied the unsteady three-dimensional stagnation point flow of a viscoelastic fluid of second grade. The two-dimensional stagnation point flow of a second grade fluid was investigated by Ariel [33]. In this study, it is shown that without augmenting the boundary conditions at infinity it is possible to obtain a numerical solution of the problem for all values of the dimensionless viscoelastic fluid parameter. Recently, Mahapatra and Gupta [34] have made an analysis of the steady two-dimensional stagnation point flow of an incompressible viscoelastic fluid of short memory (obeying Walter's B' model) over a flat deformable surface when the surface is stretched in its own plane with a velocity proportional to the distance from the stagnation point. In another study Labropulu and Chinichian [35] have analyzed the unsteady stagnation point flow of the Walter's B' fluid impinging obliquely on a flat plate oscillating in its own plane.

In the present paper, our concern is to investigate the steady three-dimensional flow of a second grade fluid towards a stagnation point at an infinite plate moving parallel to itself with constant velocity. The problem