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Solution Of Dissipative Fluid Flow Of An Impulsively Started Infinite Vertical Plate.

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Abstract

A finite difference solution of dissipative fluid flow past an impulsively started infinite vertical plate in a rotating fluid. Axial and transverse velocity profiles, temperature profiles are shown for different values of Ekman number E_k, the Prandtl number Pr and the Eckert number Ec. The numerical values of Axial and transverse skin friction and the rate of heat transfer are entered in a table. It is observed that rotating speed increase axial velocity decrease and the transverse velocity is also decrease for all Prandlt number and there is rise in the temperature for low density fluid (Pr < 0.71) but when Pr is large temperature increase due to more rotation of the system near the plate and decreases far away from the plate.

Introduction

An exact solution of Navier-stokes equation which was concerned for the flow of viscous incompressible fluid past an infinite horizontal impulsively started plate, in a stationary mass of fluid was first presented by Stokes in 1851. Hall (1969) was presented by A finite difference solution to the flow past an impulsively started semi- infinite horizontal plate However instead of horizontal plate ,if an impulsive motion is given to an infinite vertical plate which is surrounded by an infinite mass of viscous incompressible fluid, how the flow is affected by free convection currents ?.This was first studied by Soundalgekar (1977) who presented an exact solution to coupled partial differential equations by the Laplace-transfer technique. The effect of heating or cooling of the plate by the free convection currents was studied by neglecting viscous dissipative heat .If the impulsive motion given to the plate is such that the velocity is rather high or the surrounding liquid is of high Prandtl number or the situation considered at high gravitational field, then the viscous dissipative heat cannot be neglected has been shown by Gabhart (1962). Soundalgekar et.al.(1979) considered this problem by taking the effect of viscous dissipative heat on the motion past an impulsively started infinite vertical isothermal plate. Now during last few years the flow around the bodies in rotating fluid is receiving good attention from researcher as it has many application in the engineering fields .Bachlor (1967) discussed the flow past an infinite horizontal plate in a rotating fluid.

What is the effect of rotation and free convection currents on the motion of the fluid near an impulsively started infinite vertical plate studied by Lahurikar R.M., (2010) who gave exact solution by Laplace transform technique.

It has been proposed to study the rotatory flow of dissipative fluid past an impulsively started infinite vertical plate. As the problem is governed now by coupled non-linear equations, exact solutions are not possible so we employ explicit finite difference method. In section 2 mathematical analysis is presented and in section 3 the conclusions are set out.

Mathematical Analysis

Consider an infinite vertical plate surrounded by an infinite mass of stationary viscous incompressible fluid .Let the x' -axis be in the plate in vertically upward direction and the y'-axis be in horizontal direction assumed to be at right angle to the x' -axis. Then z'- axis is taken normal to the $x'y'$ –plane.

The plate and the fluid are assumed to be at the same temperature T_∞' initially .Then at time $t' > 0$ the plate is given an impulsive motion in vertically upward direction with a velocity U_0, The dissipative fluid starts rotating about the Z' -axis with the angular speed $\Omega'$and the plate temperature raised to T'_ω. Then the physical variables are functions of z' and t' .We can then shown that the problem is governed under usual Boussinesq's approximation by the following system of coupled partial differential equation in non dimensional form

$$\frac{\partial u}{\partial t} - 2E_R v - \theta + \frac{\partial^2 u}{\partial z^2} \qquad (1)$$

$$\frac{\partial v}{\partial t} + 2E_R u - \frac{\partial^2 v}{\partial z^2} \qquad (2)$$

$$Pr\frac{\partial \theta}{\partial t} - \frac{\partial^2 \theta}{\partial z^2} + Pr\,E_c\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right] \qquad (3)$$

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and the initial boundary conditions are

$$u = 0, \quad v = 0 \quad \theta = 0, \quad for\ all\ z, t \leq 0$$

$$u = 1, \quad v = 0 \quad \theta = 1 \quad at\ z = 0 \quad t > 0$$

$$u = 0, \quad v = 0 \quad \theta = 0 \quad as\ \ z \to \infty\ ,\ t > 0 \qquad (4)$$

here the non-dimensional quantities are defined as follows.

$$u = \frac{u'}{U_0} \qquad v = \frac{v'}{U_0}, \qquad t = \frac{t' Gr U_0^2}{\nu}, \qquad z = \frac{z'\sqrt{Gr}U_0}{\nu}\ , \quad Pr = \frac{\mu Cp}{k}$$

$$Gr = \frac{\nu g \beta (T'w - T'\infty)}{U_0^3}, \qquad \theta = \frac{T' - T'\infty}{T'w - T'\infty,} \quad E_K = \frac{\Omega'\nu}{Gr U_0^2},$$

$$Ec = \frac{U_0^2}{Cp(T'_w - T'_\infty)} \qquad (5)$$

An exact solutions of equations (1)-(3) are not possible, so we now solve them by explicit finite difference method .Then the set of finite difference equations corresponding to equation (1) to (3) gives.

$$u_{i,j+1} = u_{i,j} + \Delta t\{2\Omega'_K v_{i,j} + \theta_{i,j}\} + \frac{\Delta t}{(\Delta z)^2}\{u_{i+1,j} - 2u_{i,j} + u_{i-1,j}\} \qquad (6)$$

$$v_{i,j+1} = v_{i,j} + \frac{\Delta t}{(\Delta z)^2}\{v_{i+1,j} - 2v_{i,j} + v_{i+1,j}\} - 2\Delta t \Omega_K u_{i,j} \qquad (7)$$

$$\theta_{i,j+1} = \theta_{i,j} + \frac{\Delta t}{Pr(\Delta z)^2}\{\theta_{i+1,j} - 2\theta_{i,j} + \theta_{i-1,j}\} + E_c \frac{\Delta t}{(\Delta z)^2}\left[(u_{i+1,j} - u_{i,j})^2 + (v_{i+1,j} - v_{i,j})^2\right] \qquad (8)$$

with following initial and boundary conditions in the finite difference form.

Initial conditions.

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$u(0,0) = 0$, $\theta(0,0) = 1$, $v(0,0) = 0$

$u(i,0) = 0$, $\theta(i,0) = 0$, $v(i,0) = 0$ $\quad$ *for all i except $i = 0$* (9)

Boundary conditions.

$u(0,j) = 1$, $\theta(0,j) = 1$, $v(0,j) = 0$

$u(41,j) = 0$, $\theta(41,j) = 0$, $v(41,j) = 0$ (10)

here i corresponds to z and j corresponds to t

Here infinity is taken as z=4.1 because from the exact solutions of equations (1) to(3) for Ec=0 , it has been observed that u, v, θ tends to zero around $z=4$ for all values of Pr. Velocity and temperature distribution computed from equation (6) to (10) by chosenΔt=0.00125. To Judge the accuracy of the convergence and stability of the finite difference scheme the same program was run with smaller values of Δt i.e.Δt=0.0009 or 0.001 and no significant changes in the results hence, the scheme is stable and convergent. we calculate the skin friction and the rate of heat transfer defined by the following non-dimensional Quantities with the help of Newton five point interpolation formula and entered in the table.

$$\frac{\tau_{ax}}{\sqrt{Gr}} = -\frac{du}{dz}\Big|_{z=0}, \quad \frac{\tau_{tr}}{\sqrt{Gr}} = -\frac{dv}{dz}\Big|_{z=0}, \quad q = -\frac{d\theta}{dz}\Big|_{z=0} \qquad (11)$$

TABLE--I

t	Pr	Ec	E_k	$-\tau_{ax}$	$-\tau_{tr}$	q
0.2	0.2	0.1	1.0	0.946447	0.533975	0.550886
			0.2	1.055332	1.050618	0.549278
		0.05	0.5	0.919090	0.268060	0.557028
0.4	0.2	0.1	0.5	0.424913	0.400266	0.391399
		0.05	0.5	0.425558	0.400179	0.395114

TABLE--II

t	Pr	Ec	E_k	$-\tau_{ax}$	$-\tau_{tr}$	q
0.2	0.71	0.1	0.1	0.979506	0.0525695	1.020298
-	-	-	0.5	0.988141	0.262508	1.019897

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-	-	-	1.0	1.014978	0.522902	1.01186571
-	-	-	2.0	1.120123	1.029164	1.013778
-	-	0.05	0.5	0.989231	0.262449	1.038861
0.4	0.71	0.1	0.5	0.525372	0.383581	0.723700
0.2	7	0.1	0.5	1.119609	0.255202	3.076963
-	100	0.1	0.5	1.2199475	0.252926	13.157520
0.2	7	0.1	0.1	1.111306	0.0510594	3.079280
-	-	-	2.0	1.246502	0.000680	3.041466
-	-	0.05	0.5	1.123003	0.255080	3.209859
0.4	7	-	0.5	0.708723	0.363153	2.165163

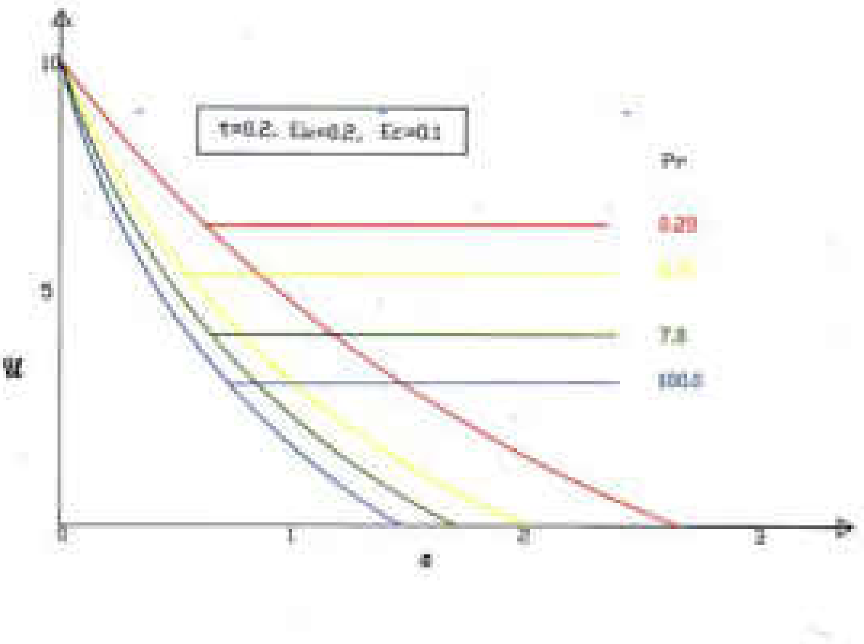

FIG.7: AXIALVELOCITY PROFILES

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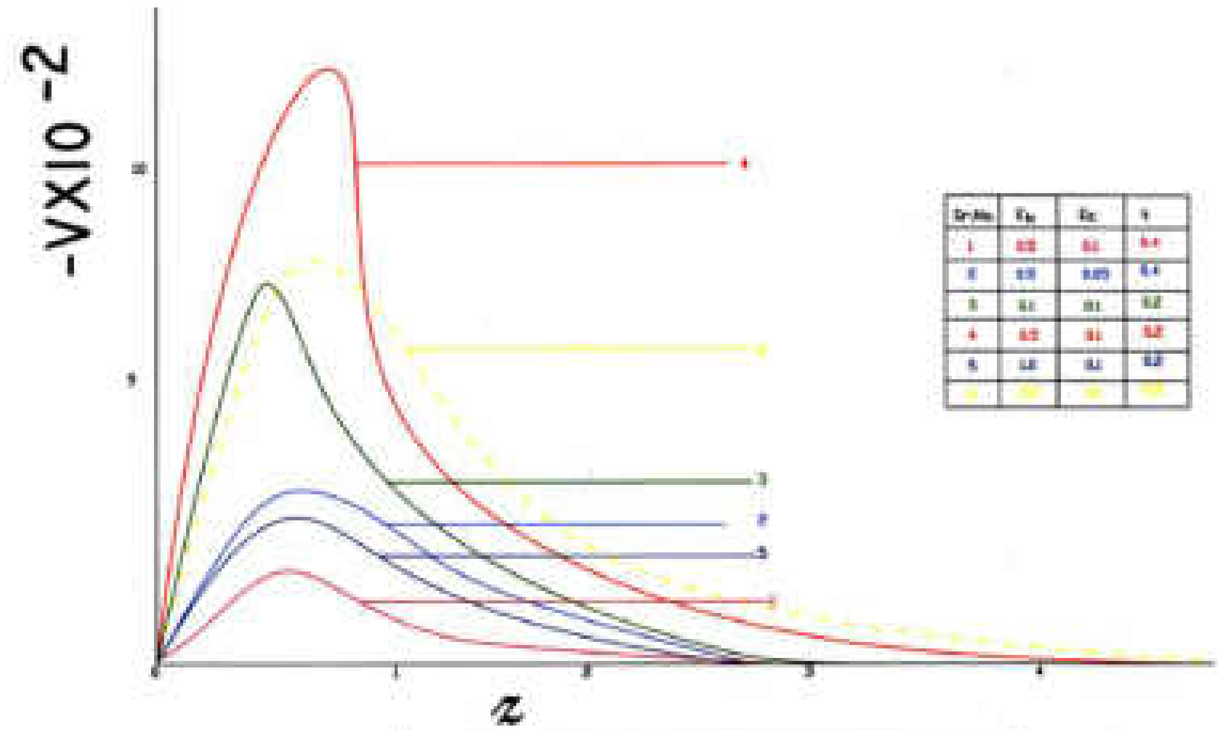

FIG.-2: TRANSVERSE VELOCITY PROFILES, Pr=0.2

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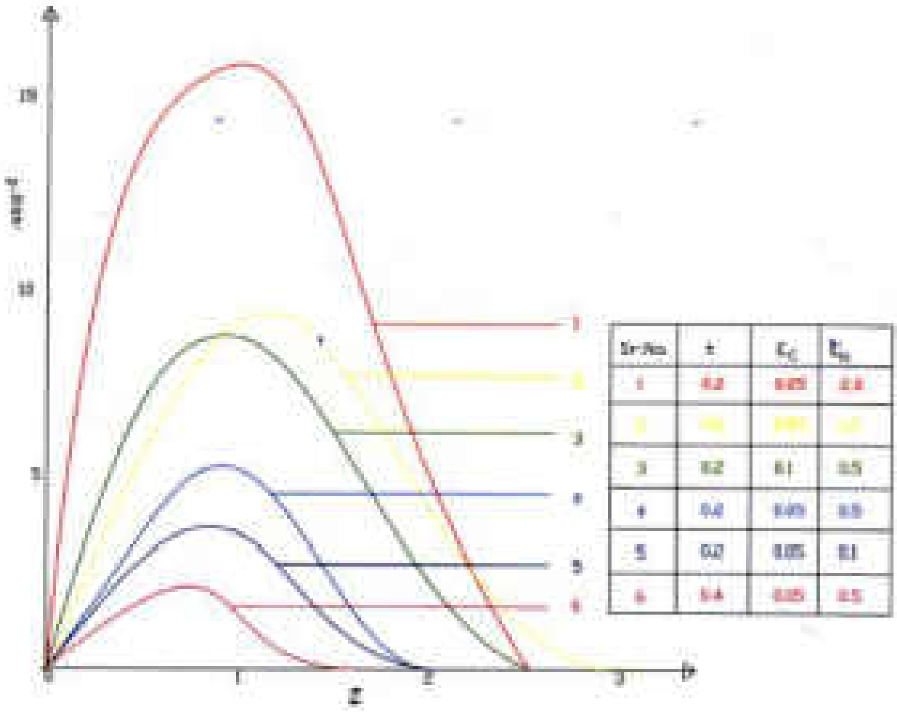

TRANSVERSE VELOCITY PROFILES

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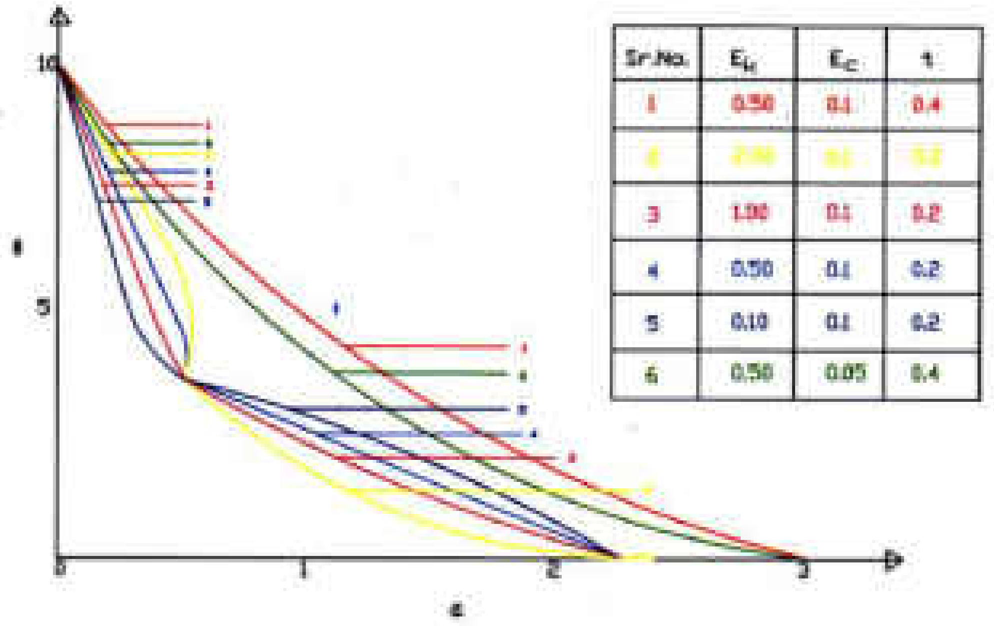

Fig:4 Tempreture profile

Nomenclature

Cp : Specific heat at constant pressure.

Ec : Eckert number.

Ek : Ekman number.

g : Acceleration due to gravity.

K : Thermal conductivity.

Pr : Prandtl number.

T' : Temperature of the plate.

$T'w$: Temperature of the plate.

$T'\infty$: Temperature of the fluid for away from the plate.

t' : Time.

U_0 : Impulsive Velocity of the plate.

(u', v') : Velocity components in x' and y' axis respectively.

Greek Symbols

τ : skin friction.

μ : Viscosity.

β : Coefficient of volume expansion.

ρ : Density.

Ω' : Angular velocity.

Conclusions

From above fig and Table

It is observed that

1. As Prandtl number Pr increase or the density of fluid increases there is fall in axial velocity, temperature, transverse skin friction and rise in transverse velocity ,axial skin friction and rate of heat transfer

2. Greater viscous dissipative heat causes rise in the axial velocity ,transverse velocity, temperature, transverse skin friction and fall in axial skin friction and rate of heat transfer for Pr=0.2. Also Greater viscous dissipative heat causes rise in the axial velocity , temperature, transverse skin friction and fall in transverse velocity, axial skin friction and rate of heat transfer for air and water i.e. when Pr=0.71 and 7.0.

.

3. 4.Rotation parameters Ω' increases axial velocity, transverse velocity decreases for all Pr.

Rotation speed increases there is rise in temperature for Pr= 0.2 But when Pr=0.71 and 7 temperature increases due to more rotation of the system near the plate and temperature decreases far away from the plate .

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4. As time t increases there is rise in axial velocity, transverse velocity, and temperature for Pr=0.2 and 0.71. But for Pr = 7.0 there is fall in transverse velocity, As t increases axial skin friction and rate of heat transfer decreases and transverse skin friction increases for all Pr.

5. As E_c increases the rate of heat transfer decreases and axial skin friction increases for large Pr and decreases for small Pr, transverse skin friction increases for small Pr and decreases for large Pr.

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