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MHD Couette Flow in a Rotating System in the Presence of an Inclined Magnetic Field

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Abstract

Steady hydromagnetic Couette flow of a viscous incompressible electrically conducting fluid in a rotating system in the presence of an inclined magnetic field is studied. Exact solution of the governing equations is obtained in closed form. The expressions for the shear stress at both the plates due to primary and secondary flows and mass flow rate in the primary and secondary flow directions are also derived. Mathematical formulation of the problem contains three pertinent parameters θ, K^2 and M^2. The asymptotic behavior of the solution is analysed for small as well as large values of K^2 and M^2. It is found that there arises modified hydromagnetic Ekman boundary layer for large values of K^2 and modified Hartmann boundary layer for large values of M^2 near the moving plate. It is found that the angle of inclination accelerates primary and secondary flows whereas it reduces primary and secondary induced magnetic fields. Rotation induces incipient reverse flow in primary flow direction near the stationary plate.

Mathematics Subject Classification: 76W05, 76U05

Keywords: MHD Couette flow, Hartmann number, rotation parameter, angle of inclination

1. Introduction

Hydromagnetic Couette flow in which the fluid motion is induced due to the movement of one of the plates is a well known problem in Magnetohydrodynamics due to its varied and wide applications in many areas of science and technology such as power generation, electromagnetic pumping, electromagnetic flow meters and accelerators, nuclear reactors utilizing liquid metals etc. Excellent literature related to the research works done on MHD Couette flow is well presented by Sutton and Sherman [8], Branover [9], Cramer and Pai [10], Pai [13] and Hughes and Young [15]. The problem of hydromagnetic Couette flow in a rotating system in the presence of an applied magnetic field has received attention of many research workers during past few decades due to its possible application in the areas of Geophysics, Astrophysics and Fluid Engineering. Kumar et al [1], Mandal et al [2], Mandal and Mandal [3], Seth and Maiti [4], Seth and Ahmad [5], Jana et al [11] and Jana and Datta [12], investigated steady MHD Couette flow of a viscous incompressible electrically conducting fluid in a rotating system in the presence of an applied magnetic field considering various variations in the problem. In all these investigations, applied magnetic field is considered acting parallel to the axis of rotation. However, in the problems of interest, it may not be possible to have applied magnetic field acting always parallel to the axis of rotation. Taking into account this fact, Seth and Ghosh [6] initiated the study of oscillatory Hartmann flow in a rotating channel in the presence of an inclined magnetic field neglecting induced magnetic field. Recently, Seth and Ghosh [7] and Ghosh and Bhattacharjee [14] investigated steady Hartmann flow of a viscous incompressible electrically conducting fluid in a rotating channel in the presence of an inclined magnetic field taking induced magnetic field into account considering different aspects of the problem.

The aim of the present paper is to study steady hydromagnetic Couette flow of a viscous incompressible electrically conducting fluid in a rotating system in the presence of an applied magnetic field which is inclined at an angle θ with the positive direction of the axis of rotation. Exact solution of the governing equations is obtained in closed form. Solution, in dimensionless form, contains three pertinent parameters viz. M^2 (Square of Hartmann number), K^2 (rotation parameter which is reciprocal of Ekman number) and θ (angle of inclination of applied magnetic field). Asymptotic behavior of the solution is analyzed for small as well as large values of K^2 and M^2 to gain some physical insight into the flow pattern. For small values of K^2 and M^2, primary velocity u and primary induced magnetic field B_x are independent of rotation whereas secondary velocity v and secondary induced magnetic field B_y are unaffected by the applied magnetic field for every value of θ. For large values of K^2 and M^2, flow becomes boundary layer type and fluid flow is confined to the boundary layer region only. The thickness of the boundary layers in both the cases are modified by the angle of inclination θ and it increases with the increase in θ. It may be noted that, for large K^2, there arises modified hydromagnetic Ekman boundary layer whereas, for large M^2, there appears modified Hartmann boundary layer near the moving plate. The expressions for the non-dimensional shear stress at both the plates due to primary and secondary flows and mass flow rates in primary and secondary flow directions are also obtained.

To study the effects of angle of inclination, rotation and magnetic field on flow-field and induced magnetic field, the numerical solution for the velocity and induced magnetic field, computed from analytical solution with the help MATLAB 7.5, is depicted graphically versus η for various values of θ, K^2 and M^2 while the numerical values of shear stress at the moving plate due to primary and secondary flows and mass flow rate in primary and secondary flow directions are presented in tabular form for various values of θ, K^2 and M^2. It is found that the angle of inclination accelerates primary and secondary flows whereas magnetic field retards it. Rotation retards primary flow throughout the channel whereas it accelerates secondary flow near the moving plate. Rotation induces incipient reverse flow, near the stationary plate, in primary flow direction. The angle of inclination and magnetic field reduce primary and secondary induced magnetic field whereas rotation reduces primary induced magnetic field and it increases secondary induced magnetic field.

2. Formulation of the Problem and its Solution

Consider steady flow of a viscous incompressible electrically conducting fluid between two infinite parallel plates when both the fluid and channel rotate in unison about an axis normal to the planes of the plates with a uniform angular velocity **Ω**. The origin of the coordinate system is considered at the lower plate z=0 with x-axis along the plate, z-axis perpendicular to it and y-axis normal to the xz-plane. A uniform magnetic flux density B_0 is applied in a direction which makes an angle θ with the positive direction of z-axis in xz-plane. Flow within the channel is induced due to the movement of the upper plate $z=L$ parallel to itself in x-direction with a uniform velocity U_0. The lower plate $z=0$ is kept fixed.

Since plates are infinite along x and y directions and flow is steady so all physical quantities, except pressure, will be function of z only. The fluid velocity $\vec{q}$ and induced magnetic field $\vec{B}$ are assumed as

$$\vec{q} \equiv \left(u_x, u_y, 0\right),\ \vec{B} \equiv \left(B_x' + B_0 \sin\theta, B_y', B_0 \cos\theta\right), \tag{1}$$

which is in agreement with the fundamental equations of Magnetohydrodynamics.

Under the above assumptions, equation of motion and induction equation for magnetic field reduce to

$$-2u_y\Omega = \upsilon \frac{d^2 u_x}{dz^2} + \frac{B_0 \cos\theta}{\mu_e \rho} \frac{dB_x'}{dz}, \tag{2}$$

$$2u_x\Omega = \upsilon \frac{d^2 u_y}{dz^2} + \frac{B_0 \cos\theta}{\mu_e \rho} \frac{dB_y'}{dz}, \tag{3}$$

$$0 = -\frac{1}{\rho}\frac{\partial}{\partial z}\left[p' + \frac{1}{2\mu_e}\left\{ \left(B_x' + B_0 \sin\theta \right)^2 + B_y'^2 \right\} \right], \tag{4}$$

$$0 = B_0 \cos\theta \frac{du_x}{dz} + \frac{1}{\sigma\mu_e}\frac{d^2 B_x'}{dz^2}, \tag{5}$$

$$0 = B_0 \cos\theta \frac{du_y}{dz} + \frac{1}{\sigma\mu_e}\frac{d^2 B_y'}{dz^2}, \tag{6}$$

where ρ, σ, μ_e, υ, and p' are, respectively, fluid density, electrical conductivity of fluid, magnetic permeability, kinematic coefficient of viscosity and hydrodynamic pressure including centrifugal force.

Equation (4) shows the constancy of the pressure along z-axis i.e. axis of rotation and the absence of $\partial p'/\partial y$ in equation (3) indicates that there is a net cross flow in y-direction. $\partial p'/\partial x$ is absent in equation (2) because flow is induced due to the movement of the upper plate.

The upper plate of the channel, which is moving with the uniform velocity U_0, is considered as non-conducting while the lower plate, which is kept fixed, is assumed as perfectly conducting. The boundary conditions for velocity and induced magnetic field are

$$u_x = u_y = 0 \text{ at } z = 0 \text{ and } u_x = U_0,\ u_y = 0 \text{ at } z = L, \tag{7}$$

$$\frac{dB_x'}{dz} = \frac{dB_y'}{dz} = 0 \text{ at } z = 0 \text{ and } B_x' = B_y' = 0 \text{ at } z = L. \tag{8}$$

Introducing non-dimensional variables $\eta = z/L$, $(u, v) = (u_x, u_y)/U_0$, $(B_x, B_y) = (B_x', B_y')/B_0$, $p = p'/\rho U_0^2$, the equations (2) to (6), in non-dimensional form, become

$$-2K^2 v = \frac{d^2 u}{d\eta^2} + \frac{M^2 \cos\theta}{R_m}\frac{dB_x}{d\eta}, \tag{9}$$

$$2K^2 u = \frac{d^2 v}{d\eta^2} + \frac{M^2 \cos\theta}{R_m}\frac{dB_y}{d\eta}, \tag{10}$$

$$0 = -\frac{\partial}{\partial\eta}\left[p + \frac{M^2 \cos\theta}{2R_e R_m}\left\{ \left(B_x + \sin\theta \right)^2 + B_y^2 \right\} \right], \tag{11}$$

$$0 = \cos\theta \frac{du}{d\eta} + \frac{1}{R_m}\frac{d^2 B_x}{d\eta^2}, \tag{12}$$

$$0=\cos\theta\frac{dv}{d\eta}+\frac{1}{R_m}\frac{d^2B_y}{d\eta^2}, \tag{13}$$

where $R_e=U_0L/\upsilon$ is Reynolds number, $R_m=\sigma\mu_e U_0 L$ is magnetic Reynolds number, $M=B_0L(\sigma/\rho\upsilon)^{1/2}$ is Hartmann number and $K^2=\Omega L^2/\upsilon$ is rotation parameter which is reciprocal of Ekman number.

The boundary conditions (7) and (8) in, non-dimensional form, are

$$u=v=0 \text{ at } \eta=0 \text{ and } u=1, v=0 \text{ at } \eta=1, \tag{14}$$

$$\frac{dB_x}{d\eta}=\frac{dB_y}{d\eta}=0 \text{ at } \eta=0 \text{ and } B_x=B_y=0 \text{ at } \eta=1. \tag{15}$$

The Equations (9), (10), (12) and (13) subject to the boundary conditions (14) and (15) can now be solved. The solution for the velocity and induced magnetic field may be expressed in the following form

$$u=a_1\sinh\alpha\eta\cos\beta\eta+b_1\cosh\alpha\eta\sin\beta\eta, \tag{16}$$

$$v=a_1\cosh\alpha\eta\sin\beta\eta-b_1\sinh\alpha\eta\cos\beta\eta, \tag{17}$$

$$B_x/R_m=a_2\left(\cosh\alpha\cos\beta-\cosh\alpha\eta\cos\beta\eta\right)+b_2\left(\sinh\alpha\sin\beta-\sinh\alpha\eta\sin\beta\eta\right), \tag{18}$$

$$B_y/R_m=a_2\left(\sinh\alpha\sin\beta-\sinh\alpha\eta\sin\beta\eta\right)-b_2\left(\cosh\alpha\cos\beta-\cosh\alpha\eta\cos\beta\eta\right), \tag{19}$$

where $$\alpha,\beta=\frac{1}{\sqrt{2}}\left[\left(M^4\cos^4\theta+4K^4\right)^{1/2}\pm M^2\cos^2\theta\right]^{1/2}, \tag{20}$$

$$a_1=\frac{2\sinh\alpha\cos\beta}{\left(\cosh 2\alpha-\cos 2\beta\right)};\ \mathrm{b}_1=\frac{2\cosh\alpha\sin\beta}{\left(\cosh 2\alpha-\cos 2\beta\right)}, \tag{21}$$

$$a_2=\frac{\left(a_1\alpha-b_1\beta\right)\cos\theta}{\left(\alpha^2+\beta^2\right)};\ b_2=\frac{\left(a_1\beta+b_1\alpha\right)\cos\theta}{\left(\alpha^2+\beta^2\right)}. \tag{22}$$

3. Non-dimensional Shear Stress at the Plates

The non-dimensional shear stress τ_x and τ_y at the lower and upper plates due to primary and secondary flows respectively, are given by

$$\left.\begin{aligned}\tau_x\big|_{n=0}&=\frac{2\left(\alpha\sinh\alpha\cos\beta+\beta\cosh\alpha\sin\beta\right)}{\left(\cosh 2\alpha-\cos 2\beta\right)},\\ \tau_y\big|_{n=0}&=\frac{2\left(\beta\sinh\alpha\cos\beta-\alpha\cosh\alpha\sin\beta\right)}{\left(\cosh 2\alpha-\cos 2\beta\right)},\end{aligned}\right\} \tag{23}$$

$$\tau_x\big|_{\eta=1}=\frac{\left(\alpha\sinh 2\alpha+\beta\sin 2\beta\right)}{\left(\cosh 2\alpha-\cos 2\beta\right)};\ \tau_y\big|_{\eta=1}=\frac{\left(\beta\sinh 2\alpha-\alpha\sin 2\beta\right)}{\left(\cosh 2\alpha-\cos 2\beta\right)}. \tag{24}$$

4. Non-dimensional Mass Flow Rate

Non-dimensional mass flow rates Q_x and Q_y in primary and secondary flow directions respectively, are given by

$$Q_x = \frac{\left(\alpha \sinh 2\alpha - \beta \sin 2\beta - \alpha\right)}{\left(\alpha^2 + \beta^2\right)\left(\cosh 2\alpha - \cos 2\beta\right)}; \; Q_y = -\frac{\left(\beta \sinh 2\alpha + \alpha \sin 2\beta - \beta\right)}{\left(\alpha^2 + \beta^2\right)\left(\cosh 2\alpha - \cos 2\beta\right)}. \qquad (25)$$

5. Asymptotic Solution

We shall now discuss the asymptotic behavior of the solution (16) to (20) for small and large values of M^2 and K^2 to gain some physical insight into the flow pattern.

Case-I: When $M^2 << 1$ **and** $K^2 << 1$**.**

Since M^2 and K^2 are very small, neglecting squares and higher powers of these parameters in the equations (16) to (20), we obtain velocity and induced magnetic field as

$$u(\eta) = \eta\left[1 - \frac{1}{6}M^2\cos^2\theta\left(1-\eta^2\right) + \ldots\right]; \; v(\eta) = -\frac{1}{3}K^2\eta\left(1-\eta^2\right) + \ldots, \qquad (26)$$

$$\left.\begin{aligned} \frac{B_x(\eta)}{R_m} &= \cos\theta\left[\frac{1}{2}\left(1-\eta^2\right)\left\{1 - \frac{1}{12}M^2\cos^2\theta\left(9-\eta^2\right)\right\} + \ldots\right], \\ \frac{B_y(\eta)}{R_m} &= -\frac{1}{12}K^2\cos\theta\left(1-\eta^2\right)\left(9-\eta^2\right) + \ldots \;. \end{aligned}\right\} \qquad (27)$$

It is evident from the expressions (26) and (27) that in a slowly rotating system when the conductivity of the fluid is low and or the applied magnetic field is weak, the primary velocity u and primary induced magnetic field B_x are independent of rotation whereas secondary velocity v and secondary induced magnetic field B_y are unaffected by the applied magnetic field for every value of angle of inclination θ. Also there is no effect of angle of inclination on secondary flow.

Case-II: When $K^2 >> 1$ **and** $M^2 \sim O(1)$**.**

When K^2 is large and M^2 is of small order of magnitude, the flow becomes boundary layer type. For the boundary layer flow near the upper plate $\eta=1$, introducing the boundary layer coordinate $\xi = 1-\eta$, we obtain the velocity and induced magnetic field from (16) to (20) as

$$u(\eta) = e^{-\alpha_1\xi}\cos\beta_1\xi; \; v(\eta) = -e^{-\alpha_1\xi}\sin\beta_1\xi, \qquad (28)$$

$$\left.\begin{aligned} \frac{B_x(\eta)}{R_m} &= \frac{\cos\theta}{2K}\left[1 - e^{-\alpha_1\xi}\left(\cos\beta_1\xi - \sin\beta_1\xi\right)\right], \\ \frac{B_y(\eta)}{R_m} &= -\frac{\cos\theta}{2K}\left[1 - e^{-\alpha_1\xi}\left(\cos\beta_1\xi + \sin\beta_1\xi\right)\right], \end{aligned}\right\} \qquad (29)$$

where $\alpha_1, \beta_1 = K\left(1 \pm \frac{M^2 \cos^2\theta}{4K^2}\right).$ (30)

It is evident from the expressions (28) to (30) that there arises a thin boundary layer of thickness $O\left(\alpha_1^{-1}\right)$ near the moving plate of the channel. This boundary layer may be identified as modified hydromagnetic Ekman boundary layer and can be viewed as classical Ekman boundary layer modified by magnetic field and angle of inclination. The thickness of this boundary layer decreases with the increase in either M^2 or K^2 but it increases with the increase in θ. The exponential terms in the expressions (28) and (29) damp out quickly as ξ increases and when $\xi > 1/\alpha_1$ i.e. outside the boundary layer region, we obtain

$$u(\eta) \approx 0;\ v(\eta) \approx 0, \tag{31}$$

$$\frac{B_x(\eta)}{R_m} \approx \frac{\cos\theta}{2K};\ \frac{B_y(\eta)}{R_m} \approx -\frac{\cos\theta}{2K}. \tag{32}$$

The expressions (31) and (32) show that, in a certain core given by $\xi > 1/\alpha_1$ i.e. outside the boundary layer region, the induced magnetic fields persist in primary as well as secondary flow directions and has considerable affects of rotation and angle of inclination. It may be noted from (31) and (32) that the fluid flow is confined within the boundary layer region only.

Case-III: When $M^2 >> 1$ **and** $K^2 \sim O(1)$**.**

In this case also boundary layer type flow is expected. For the boundary layer flow near the upper plate $\eta=1$, we obtain the velocity and induced magnetic field from (16) to (20) as

$$u(\eta) = e^{-\alpha_2\xi}\cos\beta_2\xi;\ v(\eta) = -e^{-\alpha_2\xi}\sin\beta_2\xi, \tag{33}$$

$$\frac{B_x(\eta)}{R_m} = \frac{1}{M}\left(1 - e^{-\alpha_2\xi}\cos\beta_2\xi\right);\ \frac{B_y(\eta)}{R_m} = \frac{1}{M}e^{-\alpha_2\xi}\sin\beta_2\xi, \tag{34}$$

where $\alpha_2 = M\cos\theta,\ \beta_2 = \frac{K^2}{M\cos\theta},$ (35)

The expressions (33) to (35) reveal that there appears a thin boundary layer of thickness $O\left(\alpha_2^{-1}\right)$ adjacent to the moving plate of the channel. This boundary layer may be recognized as modified Hartmann boundary layer and can be viewed as Hartmann boundary layer modified by angle of inclination. The thickness of this boundary layer decreases with the increase in M^2 and increases with the increase in angle of inclination θ. When $\xi > 1/\alpha_2$ i.e. outside the boundary layer region, we obtain from (33) and (34) as

$$u(\eta) \approx 0;\ v(\eta) \approx 0, \tag{36}$$

$$\frac{B_x(\eta)}{R_m} \approx \frac{1}{M};\ \frac{B_y(\eta)}{R_m} \approx 0. \tag{37}$$

The expressions (36) and (37) show that, in a certain core given by $\xi > 1/\alpha_2$ i.e. outside the boundary layer region, induced magnetic field in secondary flow direction vanishes away while it persists in primary flow direction and it is independent of angle of inclination and rotation. In this case also there is no fluid flow outside the boundary layer region.

5. Results and Discussion

To study the effects of angle of inclination, rotation and magnetic field on flow-field and induced magnetic field, the numerical solution for the velocity and induced magnetic field, computed from analytical solution with the help MATLAB 7.5, is depicted graphically versus η in figures 1 to 6 for various values of θ, K^2 and M^2 while the numerical values of shear stress at the moving plate due to primary and secondary flows and mass flow rate in primary and secondary flow directions are presented in tabular form in tables 1 to 4 for various values of θ, K^2 and M^2. It is evident from figures 1 to 3 that the primary velocity u increases with the increase in θ whereas it decreases with the increase in either K^2 or M^2. The secondary velocity v increases with the increase in θ whereas it decreases with the increase in M^2. Also v increases with the increase in K^2 near the moving plate $\eta=1$ while its characteristics is changed near the stationary plate. It is noticed from figure 2 that there exists incipient reverse flow in primary flow direction near the stationary plate $\eta=0$ on increasing K^2. Figures 4 to 6 reveal that, the primary induced magnetic field B_x decreases with the increase in either θ or K^2 or M^2 whereas the secondary induced magnetic field B_y decreases with the increase in either θ or M^2 and it increases with the increase in K^2.

It is found from tables 1 and 2 that the shear stress at the moving plate due to primary flow $\tau_x\big|_{\eta=1}$ decreases with the increase in θ whereas it increases with the increase in either K^2 or M^2. Shear stress due to secondary flow $\tau_y\big|_{\eta=1}$ increases with the increase in either θ or K^2 while it decreases with the increase in M^2. It is observed from tables 3 and 4 that the primary mass flow rate Q_x decreases with the increase in either θ or K^2 while it increases with the increase in M^2. Mass flow rate in secondary flow direction Q_y increases with the increase in θ while it decreases with the increase in either K^2 or M^2.

6. Conclusion

Angle of inclination accelerates primary and secondary flows whereas magnetic field retards it. Rotation retards primary flow throughout the channel whereas it accelerates secondary flow near the moving plate. Rotation induces incipient reverse flow, near the stationary plate, in primary flow direction. The angle of inclination and magnetic field reduce primary and secondary induced magnetic fields whereas rotation reduces primary induced magnetic field and it increases secondary induced magnetic field.

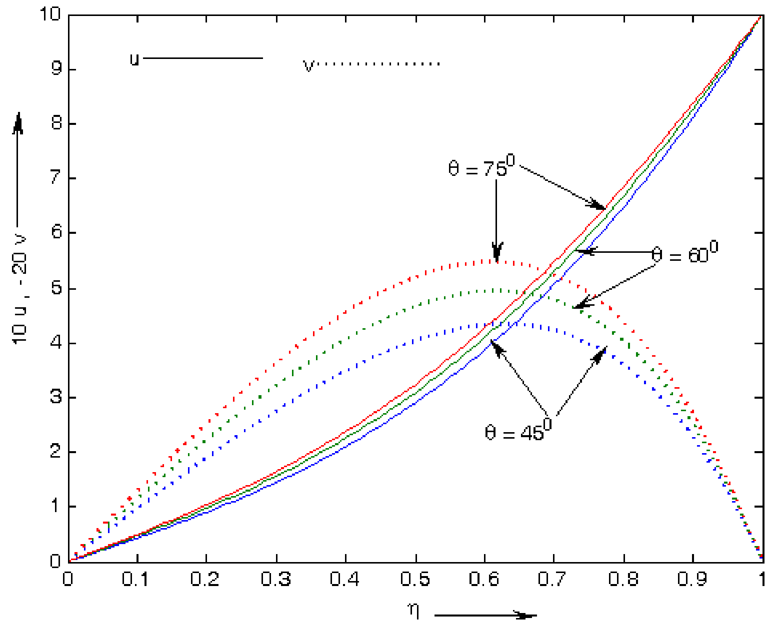

Figure 1: Velocity Profiles for $M^2 = 4$ and $K^2 = 3$

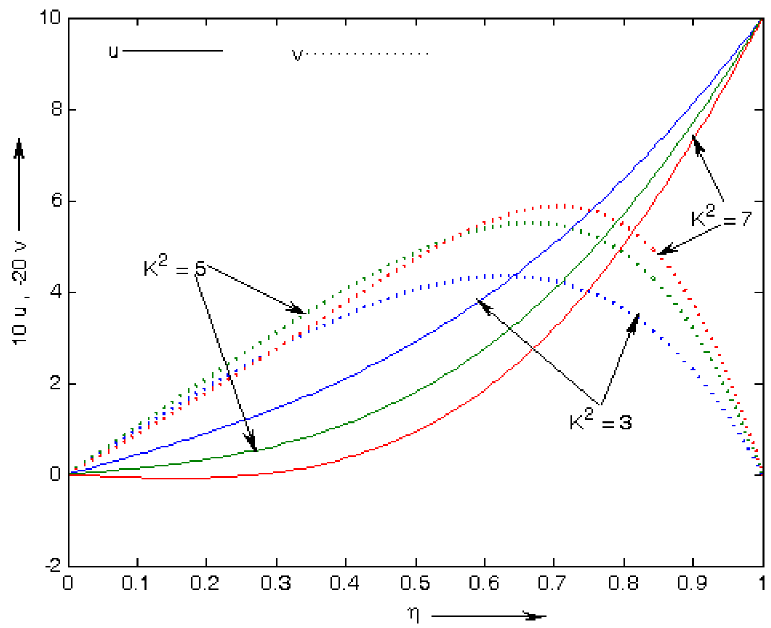

Figure 2: Velocity Profiles for $M^2 = 4$ and $\theta = 45^0$

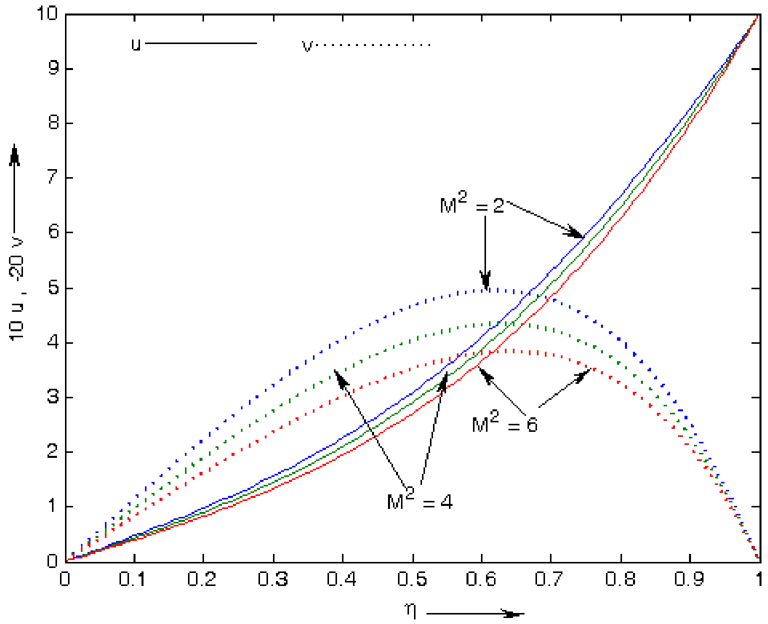

Figure 3: Velocity Profiles for $K^2 = 3$ and $\theta = 45^0$

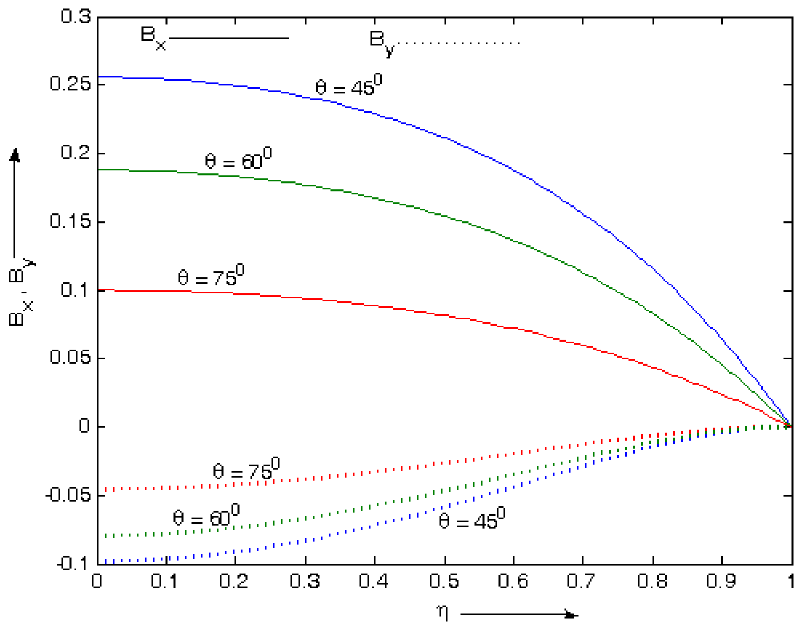

Figure 4: Induced Magnetic Field Profiles for $M^2 = 4$ and $K^2 = 3$

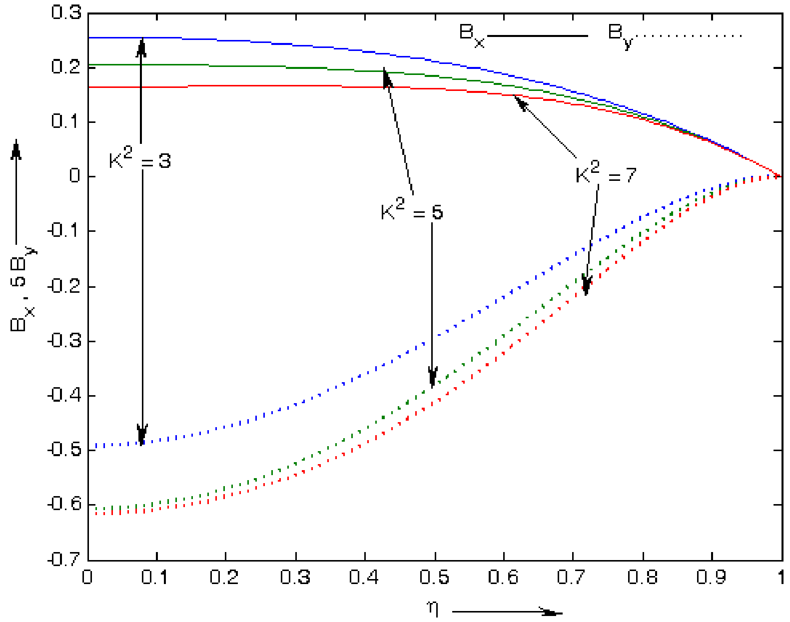

Figure 5: Induced Magnetic Field Profiles for $M^2 = 4$ and $\theta = 45^0$

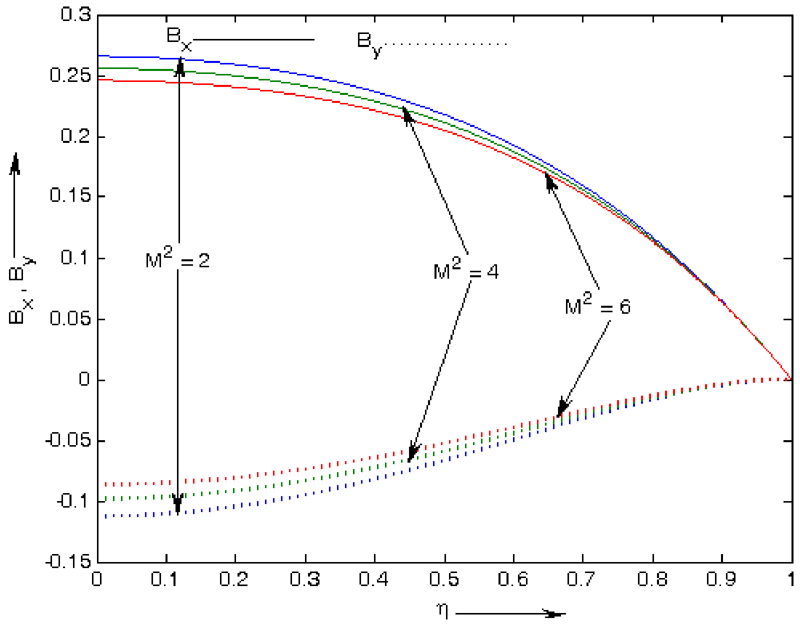

Figure 6: Induced Magnetic Field Profiles for $K^2 = 3$ and $\theta = 45^0$

Table 1: Shear Stress components τ_x and τ_y at the moving plate when M^2=4.

$K^2\downarrow/\theta\rightarrow$	$\tau_x\|_{\eta=1}$				$\tau_y\|_{\eta=1}$			
	30^0	45^0	60^0	75^0	30^0	45^0	60^0	75^0
3	2.1677	1.9832	1.7933	1.6517	1.3102	1.4092	1.5259	1.6248
5	2.5564	2.4251	2.2970	2.2064	1.9314	2.0343	2.1479	2.2382
7	2.9301	2.8286	2.7309	2.6623	2.3958	2.4864	2.5822	2.6553
9	3.2608	3.1745	3.0908	3.0314	2.7737	2.8528	2.29345	2.9958

Table 2: Shear Stress components τ_x and τ_y at the moving plate for θ=45^0.

$M^2\downarrow/K^2\rightarrow$	$\tau_x\|_{\eta=1}$				$\tau_y\|_{\eta=1}$			
	3	5	7	9	3	5	7	9
2	1.7933	2.2970	2.7309	3.0908	1.5259	2.1479	2.5822	2.9345
4	1.9832	2.4251	2.8286	3.1745	1.4092	2.0343	2.4864	2.8528
6	2.1677	2.5564	2.9301	3.2608	1.3102	1.9314	2.3958	2.7737
8	2.3461	2.6891	3.0344	3.3494	1.2255	1.8382	2.3103	2.6975

Table 3: Mass Flow Rates Q_x and Q_y for M^2=4.

$K^2\downarrow/\theta\rightarrow$	Q_x				$-Q_y$			
	30^0	45^0	60^0	75^0	30^0	45^0	60^0	75^0
3	0.3114	0.3000	0.2822	0.2664	0.1968	0.2194	0.2380	0.2472
5	0.2448	0.2388	0.2312	0.2247	0.1793	0.1912	0.2023	0.2098
7	0.2053	0.2010	0.1957	0.1914	0.1641	0.1720	0.1794	0.1847
9	0.1788	0.1753	0.1713	0.1681	0.1508	0.1563	0.1615	0.1651

Table 4: Mass Flow Rates Q_x and Q_y for θ=45^0.

	Q_x				$-Q_y$			
$M^2\downarrow/K^2\rightarrow$	3	5	7	9	3	5	7	9
2	0.2822	0.2312	0.1957	0.1713	0.2380	0.2023	0.1794	0.1615
4	0.3000	0.2388	0.2010	0.1753	0.2194	0.1912	0.1720	0.1563
6	0.3114	0.2448	0.2053	0.1788	0.1968	0.1793	0.1641	0.1508
8	0.3162	0.2490	0.2089	0.1818	0.1734	0.1670	0.1561	0.1452

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