MAGNETOHYDRODYNAMIC UNSTEADY FREE CONVECTION FLOW PAST A VERTICAL POROUS PLATE

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Unsteady free convection flow of an incompressible electrically conducting viscous liquid past a hot vertical plate in the presence of a transverse magnetic field has been studied in this paper. The flow phenomena have been characterized by the non-dimensional numbers P (Prandtl number), G (Grashoff number), m (magnetic number) and ω (frequency parameter). The effects of these parameters on the velocity and temperature distributions, amplitude and phase of skin-friction and the fluctuating parts of the velocity have been tabulated and represented graphically.

1. INTRODUCTION

Unsteady free convection from an infinite vertical plate has been considered by a number of workers. Illingworth (1950), Rao (1961), Nanda and Sharma (1962), Menold and Yang (1962), Schetz and Eichhorn (1962), Goldstein and Briggs (1964) and some other workers have solved a few unsteady problems by employing different methods. Gupta (1960), Chawla (1967) and Soundalgekar (1972) have solved a few problems on unsteady free convection flow in the presence of a magnetic field.

Our aim in this paper is to study the free convection flow of a viscous liquid past a porous vertical plate whose temperature fluctuates with time harmonically from a constant mean. The suction velocity at the plate also fluctuates with time harmonically from a constant mean velocity. The method of solution is the one suggested by Lighthill (1954), Stuart (1955) and Messiha (1966). The amplitude and the phase of the skin-friction fluctuations, the transient velocity profiles and the fluctuating parts of the velocity profiles are shown by means of several graphs. The effects of the magnetic field, variable suction parameter, Prandtl number and frequency of oscillation on flow characteristics have been studied.

2. FORMULATION OF THE PROBLEM

Here the origin of the coordinate system is taken to be at any point of a flat, vertical, porous, infinite plate. The x'-axis is chosen along the plate vertically upwards and the y'-axis perpendicular to the plate. Then all the physical quantities are independent of x' and hence the unsteady free convection flow of an incompressible viscous liquid in the presence of a magnetic field is governed by the following equations of continuity, motion and energy:

$$\frac{\partial v'}{\partial y'} = 0 \qquad \text{...(1)}$$

$$\rho' \left[\frac{\partial u'}{\partial t'} + v' \frac{\partial u'}{\partial y'}\right] = \rho' f_x \beta (T' - T'_\infty) + \mu \frac{\partial^2 u'}{\partial y'^2} - \sigma B_0^2 u' \qquad \text{..(2)}$$

$$\rho' \left[\frac{\partial v'}{\partial t'} + v' \frac{\partial v'}{\partial y'}\right] = - \frac{\partial p}{\partial y'} + 2\mu \frac{\partial^2 v'}{\partial y'^2} \qquad \text{...(3)}$$

$$\rho' c' \left[\frac{\partial T'}{\partial t'} + v' \frac{\partial T'}{\partial y'}\right] = k' \frac{\partial^2 T'}{\partial y'^2}. \qquad \text{...(4)}$$

In these equations u' is the velocity in the x'-direction, v' the velocity normal to the plate, t' the time variable, μ the coefficient of viscosity, σ the conductivity of the medium, B_0 the applied magnetic field strength, f_x the acceleration due to gravity, β the coefficient of volume expansion, c' the specific heat at constant pressure, k' the thermal conductivity, T' the temperature in the boundary layer and T'_∞ the temperature far away from the plate. In the energy equation (4) terms representing viscous and joule dissipation are assumed to be neglected as they are really very small in free convection flows.

The boundary conditions of the problem are

$$\left.\begin{aligned} & u' = 0,\ T' = T'_m (1 + \epsilon e^{i\omega' t'}) - \epsilon T'_\infty e^{i\omega' t'} \text{ at } y' = 0 \\ & u' \to 0,\ T' \to T'_\infty \text{ as } y' \to \infty \end{aligned}\right\} \qquad \text{...(5)}$$

where T'_m is the mean value about which the temperature fluctuates, $\epsilon \ll 1$ and ω' is the frequency of fluctuation.

From eqn. (1), on integration

$$v' = - v_0 (1 + \epsilon A e^{i\omega' t'}) \qquad \text{...(6)}$$

where v_0 is a mean value of the suction at the plate and A is the variable suction parameter. In view of (6), we get from (2), (3) and (4)

$$\frac{\partial u'}{\partial t'} - v_0(1 + \epsilon A e^{i\omega' t'}) \frac{\partial u'}{\partial y'} = f_x \beta (T' - T'_\infty) + \nu \frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma B_0^2}{\rho'} u' \qquad \text{...(7)}$$

$$- \frac{1}{\rho'} \frac{\partial p'}{\partial y'} = - \epsilon A v_0 i\omega' e^{i\omega' t'} \qquad \text{...(8)}$$

$$\rho'c'\left[\frac{\partial T'}{\partial t'} - v_0(1+\epsilon A e^{i\omega' t'})\frac{\partial T'}{\partial y'}\right] = k'\frac{\partial^2 T'}{\partial y'^2} \qquad ...(9)$$

where $\nu = \dfrac{\mu}{\rho'}$.

Let us introduce the following non-dimensional variables :

$$\left.\begin{aligned} &\eta = \frac{y' v_0}{\nu},\ t = \frac{v_0^2 t'}{4\nu},\ \omega = \frac{4\nu\omega'}{v_0^2},\ u = \frac{u'}{v_0} \\ &\theta = \frac{T' - T'_\infty}{T'_m - T'_\infty},\ P = \frac{\mu c'}{k'},\ G = \frac{\nu f_x \beta(T'_m - T'_\infty)}{v_0^3} \\ &m = \frac{\sigma B_0^2 \nu}{\rho' v_0^2}. \end{aligned}\right\} \qquad ...(10)$$

In view of transformations (10), eqns. (7) and (9) yield

$$\frac{\partial^2 u}{\partial \eta^2} + (1+\epsilon A e^{i\omega t})\frac{\partial u}{\partial \eta} - \tfrac{1}{4}\frac{\partial u}{\partial t} - mu = -G\theta \qquad ...(11)$$

$$\frac{\partial^2 \theta}{\partial \eta^2} + P(1+\epsilon A e^{i\omega t})\frac{\partial \theta}{\partial \eta} - \tfrac{1}{4}P\frac{\partial \theta}{\partial t} = 0 \qquad ...(12)$$

Boundary conditions (5) now reduce to

$$\left.\begin{aligned} &u = 0,\quad \theta = 1 + \epsilon e^{i\omega t} \text{ when } \eta = 0 \\ &u \to 0,\quad \theta \to 0 \quad \text{as } \eta \to \infty. \end{aligned}\right\} \qquad ...(13)$$

3. Solution of Equations

To solve eqns. (11) and (12) subject to boundary conditions (13) in the neighbourhood of the plate, we take

$$u(\eta, t) = u_1(\eta) + \epsilon e^{i\omega t} u_2(\eta) \qquad ...(14)$$

$$\theta(\eta, t) = 1 + \epsilon e^{i\omega t} - \theta_1(\eta) - \epsilon e^{i\omega t}\theta_2(\eta). \qquad ...(15)$$

Substituting (14) and (15) into (11) and (12), and comparing the harmonic terms, we get

$$u_1'' + u_1' - mu_1 = -G + G\theta_1 \qquad ...(16)$$

$$u_2'' + u_2' - (m + \tfrac{1}{4}i\omega)u_2 + Au_1' = G\theta_2 - G \qquad ...(17)$$

$$\theta_1'' + P\theta_1' = 0 \qquad ...(18)$$

$$\theta_2'' + P\theta_2' - \frac{i\omega}{4}P\theta_2 + PA\theta_1' + \frac{i\omega}{4}P = 0 \qquad ...(19)$$

where primes now denote differentiation with respect to η. The boundary conditions on u_1, u_2, θ_1 and θ_2 are

$$\left.\begin{aligned} & u_1 = u_2 = 0,\ \theta_1 = \theta_2 = 0 \text{ at } \eta = 0 \\ & u_1 \to 0,\ u_2 \to 0,\ \theta_1 \to 1,\ \theta_2 \to 1 \text{ as } \eta \to \infty \end{aligned}\right\} \quad \ldots(20)$$

Solving (18) and (19) with the conditions in (20), we get

$$\theta_1 = 1 - e^{-P\eta} \quad \ldots(21)$$

$$\theta_2 = 1 + \frac{4PA}{i\omega} e^{-P\eta} - \left(1 + \frac{4PA}{i\omega}\right) e^{-Ph\eta} \quad \ldots(22)$$

where

$$h = \tfrac{1}{2}\left[1 + \left(1 + \frac{i\omega}{P}\right)^{\frac{1}{2}}\right].$$

Solving (16) and (17) with the conditions in (20) and expressions for θ_1 and θ_2 from (21) and (22), we get

$$u_1 = \frac{G}{P^2 - P - m}\left[e^{-g\eta} - e^{-P\eta}\right] \quad \ldots(23)$$

where

$$g = \tfrac{1}{2}\left[1 + (1 + 4m)^{1/2}\right]$$

and

$$\begin{aligned} u_2 = & \frac{4APG}{i\omega(P^2 - P - m)}\left[e^{-P\eta} - e^{-L\eta}\right] \\ & - \frac{G\left(1 + \frac{4PA}{i\omega}\right)}{(P^2h^2 - Ph - m - \frac{1}{4}i\omega)}\left[e^{-Ph\eta} - e^{-L\eta}\right] \\ & + \frac{AGg}{(P^2 - P - m)\left(g^2 - g - m - \frac{i\omega}{4}\right)}\left[e^{-g\eta} - e^{-L\eta}\right] \end{aligned} \quad \ldots(24)$$

where

$$L = \tfrac{1}{2}\left[1 + (1 + 4m + i\omega)^{1/2}\right].$$

Now from (24) the real and imaginary parts of $u_2(\eta) = M_r + iM_i$ are given by

$$\begin{aligned} M_r = & \frac{4APG}{\omega(P^2 - P - m)} e^{-\gamma\eta} \sin \delta\eta - \frac{G}{Y_r^2 + Y_i^2}\left[\left(Y_r - \frac{4AP}{\omega} Y_i\right)\right. \\ & \times \left(e^{-\alpha P\eta} \cos(\beta P\eta) - e^{-\gamma\eta} \cos \delta\eta\right) - \left(Y_i + \frac{4AP}{\omega} Y_r\right) \left(e^{-\alpha P\eta} \sin(\beta P\eta)\right. \\ & \left.\left. - e^{-\gamma\eta} \sin \delta\eta\right)\right] + \frac{AGg}{(P^2 - P - m)\left(Z_r^2 + Z_i^2\right)}\left[Z_r(e^{-g\eta}\right. \\ & \left. - e^{-\gamma\eta} \cos \delta\eta) + Z_i e^{-\gamma\eta} \sin \delta\eta\right] \end{aligned} \quad \ldots(25)$$

and

$$M_i = \frac{4APG}{\omega(P^2 - P - m)} \left\{e^{-\gamma\eta} \cos \delta\eta - e^{-P\eta}\right\} + \left\{\left(Y_r - \frac{4AP}{\omega} Y_i\right) \times (e^{-\alpha P\eta} \sin(\beta P\eta) - e^{-\gamma\eta} \sin \delta\eta) + \left(Y_i + \frac{4AP}{\omega} Y_r\right) \times (e^{-\alpha P\eta} \cos(\beta P\eta) - e^{-\gamma\eta} \cos \delta\eta)\right\} \times \frac{G}{Y_r^2 + Y_i^2}$$
$$+ \frac{AGg}{(P^2 - P - m)\left(Z_r^2 + Z_i^2\right)} \left\{Z_r e^{-\gamma\eta} \sin \delta\eta - Z_i(e^{-g\eta} - e^{-\gamma\eta} \cos \delta\eta)\right\} \qquad \ldots(26)$$

where

$$\left.\begin{aligned}
\alpha &= \tfrac{1}{2}\left[1 + \left\{\tfrac{1}{2}\left(1 + \sqrt{1 + \frac{\omega^2}{P^2}}\right)\right\}^{1/2}\right] \\
\beta &= \tfrac{1}{2}\left\{\tfrac{1}{2}\left(\sqrt{1 + \frac{\omega^2}{P^2}} - 1\right)\right\}^{1/2} \\
\gamma &= \tfrac{1}{2}[1 + \{\tfrac{1}{2}(\sqrt{(1 + 4m)^2 + \omega^2} + 1 + 4m)\}^{1/2}] \\
\delta &= \tfrac{1}{2}\{\tfrac{1}{2}(\sqrt{(1 + 4m)^2 + \omega^2} - 1 - 4m)\}^{1/2} \\
Y_r &= P^2(\alpha^2 - \beta^2) - P\alpha - m \\
Y_i &= 2\alpha\beta P^2 - P\beta - \frac{\omega}{4} \\
Z_r &= g^2 - g - m \\
Z_i &= -\frac{\omega}{4} \\
h &= \alpha + i\beta \text{ and } L = \gamma + i\delta.
\end{aligned}\right\} \qquad \ldots(27)$$

Hence from (14) the real part of $u(\eta, t)$ is given by

$$u(\eta, t) = u_1(\eta) + \epsilon(M_r \cos \omega t - M_i \sin \omega t). \qquad \ldots(28)$$

Again from (22) the real and imaginary parts of $\theta_2 = N_r + iN_i$ are given by

$$\left.\begin{aligned}
N_r &= 1 - e^{-\alpha P\eta} \cos(\beta P\eta) + \frac{4AP}{\omega} e^{-\alpha P\eta} \sin(\beta P\eta) \\
&\text{and} \\
N_i &= -\frac{4AP}{\omega} e^{-P\eta} + e^{-\alpha P\eta} \sin(\beta P\eta) + \frac{4AP}{\omega} e^{-\alpha P\eta} \cos(\beta P\eta).
\end{aligned}\right\} \qquad \ldots(29)$$

Hence, from (15) the real part of $\theta(\eta, t)$ is given by

$$\theta(\eta, t) = e^{-P\eta} + \epsilon\,[\cos\omega t - N_r \cos\omega t + N_i \sin\omega t]. \qquad \ldots(30)$$

Using the transformations (10), the shearing stress at the wall is

$$\mu\left(\frac{\partial u'}{\partial y'}\right)_{y'=0} = \rho' v_0^2 \left(\frac{\partial u}{\partial \eta}\right)_{\eta=0}.$$

Hence, the skin-friction

$$\tau = \left(\frac{\partial u}{\partial \eta}\right)_{\eta=0}. \qquad \ldots(31)$$

From (14) and (31), $\tau = [u_1' + \epsilon e^{i\omega t} u_2']_{\eta=0}$

where dashes denote differentiation with respect to η. Hence, from (23) and (24)

$$\tau = \frac{G}{P^2 - P - m}(P - g) + \epsilon e^{i\omega t}\left[\frac{i\,4APG}{\omega(P^2 - P - m)}(P - L) - G\left(1 - i\,\frac{4AP}{\omega}\right)\frac{L - Ph}{Y_r + i\,Y_i} + \frac{AGg(L - g)}{(P^2 - P - m)(Z_r + i Z_i)}\right]$$

$$= \frac{G}{P^2 - P - m}(P - g) + \epsilon e^{i\omega t}[F_r + iF_i]$$

$$= \frac{G}{P^2 - P - m}(P - g) + \epsilon\,|F|\,e^{i(\omega t + \phi)}$$

where

$$|F| = \sqrt{F_r^2 + F_i^2}$$

$$\tan\phi = \frac{F_i}{F_r}$$

$$F_r = \frac{4APG\delta}{\omega(P^2 - P - m)} - \frac{G}{Y_r^2 + Y_i^2}\left[\left\{(\gamma - P\alpha) + \frac{4AP}{\omega}(\delta - P\beta)\right\}Y_r + \left\{\delta - P\beta - \frac{4AP}{\omega}(\gamma - P\alpha)\right\}Y_i\right] + \frac{AGg}{P^2 - P - m}\cdot\frac{(\gamma - g)Z_r + \delta Z_i}{Z_r^2 + Z_i^2}$$

and

$$F_i = \frac{4APG(P-\gamma)}{\omega(P^2-P-m)} - \frac{G}{Y_r^2+Y_i^2}\left[\left\{\delta - P\beta - \frac{4AP}{\omega}(\gamma - P\alpha)\right\} Y_r \right.$$

$$\left. - \left\{\gamma - P\alpha + \frac{4AP}{\omega}(\delta - P\beta)\right\} Y_i\right]$$

$$+ \frac{AGg}{P^2-P-m} \cdot \frac{\delta Z_r - (\gamma - g) Z_i}{Z_r^2 + Z_i^2}.$$

CONCLUSIONS

In this paper we have studied the free-convection flow of a viscous liquid past a porous vertical plate, whose temperature fluctuates harmonically with time from a constant mean. The effects of the magnetic field, the variable suction parameter, Prandtl number, the frequency of oscillation and the Grashoff number on flow characteristics have been studied and are tabulated and illustrated graphically.

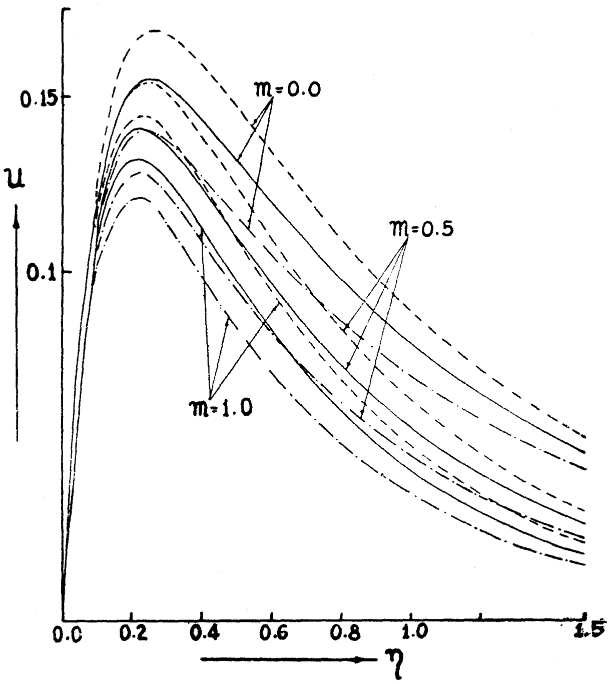

FIG. 1. Velocity distribution for different values of magnetic field strength m and variable suction parameter A. $\omega = 10$, $P = 10$, $G = 20$. $A = 0$ - - - -, $A = 0.5$ ——, $A = 1.0$ - · - · -

Figure 1 shows that the velocity at any point of the fluid decreases as m, the magnetic field strength increases. A similar effect is observed as the variable suction parameter, A increases. The effects of these parameters are more prominent at a point far away from the plate.

Figure 2 illustrates the velocity for different values of P (Prandtl number) and G (Grashoff number). The velocity at any point of the fluid decreases as P increases. And the velocity at a point increases with G.

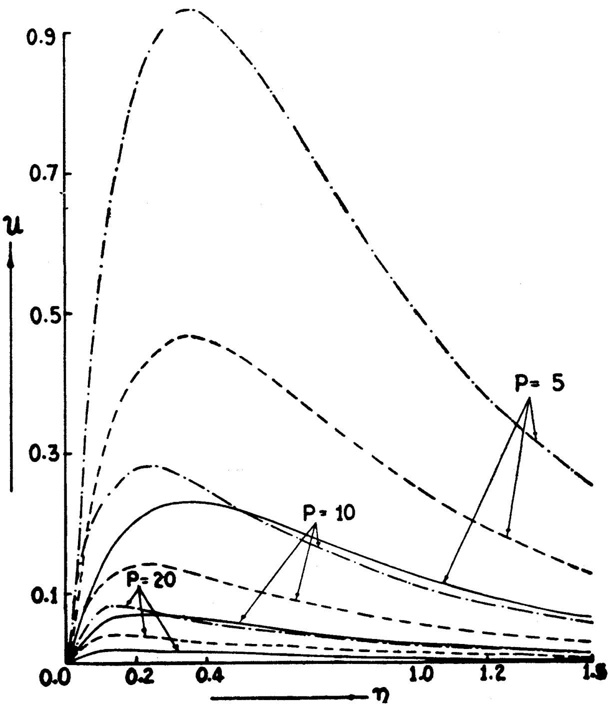

FIG. 2. Velocity distribution for different values of Prandtl number P and Grashof number G. $A = 0.5$, $m = 0.5$, $\omega = 10$. $G = 10$ ——, $G = 20$ - - - -, $G = 40$ - · - - · -

Table I shows that the velocity at any point in the liquid increases with the frequency of oscillation ω. It is seen from Fig. 3 that the temperature at any point decreases as A increases. A similar effect is observed as P increases.

Table II illustrates that the effect of ω, is to increase the temperature at a point. Fig. 4 plots the amplitude of skin-friction $| F |$ against ω, for different values of m. It shows that m increases the values of $| F |$ for very small non-zero values of ω. But an opposite nature is observed for large values of ω.

We observe from Fig. 5 that the effect of A is to decrease the value of $| F |$ whereas G increases it. Table III shows that $| F |$ decreases, with an increase in P, for all values of ω.

TABLE I

Values of the velocity for different values of the frequency parameter ω.
$A = 0.5,\ m = 0.5,\ P = 10,\ G = 20$

η \ ω	10.0	30.0	50.0
0.0	0.0	0.0	0.0
0.1	0.11322	0.11565	0.11637
0.2	0.13972	0.14252	0.14296
0.3	0.13631	0.13881	0.13897
0.4	0.12380	0.12598	0.12603
0.5	0.10953	0.11146	0.11148
0.6	0.09593	0.09765	0.09765
0.7	0.08367	0.08521	0.08521
0.8	0.07287	0.07424	0.07426
0.9	0.06342	0.06464	0.06470
1.0	0.05518	0.05627	0.05637

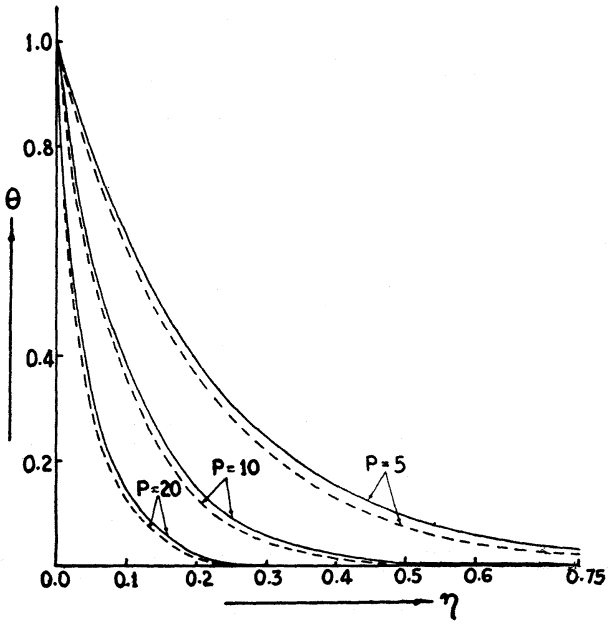

FIG. 3. Temperature distribution for different values of P and A ($\omega = 10$). $A = 0$ ——, $A = 1$ - - -

TABLE II

Values of the temperature for different values of the frequency parameter ω.
$A = 0.5,\ m = 0.5,\ P = 10,\ G = 20$

η \ ω	10.0	30.0	50.0
0.0	1.0	1.0	1.0
0.1	0.37298	0.38224	0.38698
0.2	0.13603	0.13815	0.13892
0.3	0.04861	0.04871	0.04882
0.4	0.01605	0.01670	0.01675
0.5	0.00588	0.00589	0.00603
0.6	0.00199	0.00206	0.00222
0.7	0.00067	0.00074	0.00082
0.8	0.00022	0.00027	0.00030
0.9	0.00007	0.00010	0.00011
1.0	0.00002	0.00003	0.00004

Figure 6 exhibits the effect of m on the skin friction phase $\tan \phi$, for different values of ω. For small non-zero values of ω, $\tan \phi$ decreases as m increases. At about $\omega = 14$, the curves for different values of m intersect and for larger values of ω, $\tan \phi$ increases with m. Table IV illustrates that $\tan \phi$ increases with P and also with A.

Figure 7 shows that the fluctuating part M_r decreases, near the plate as the suction parameter A increases, and almost at the edge of the boundary layer an opposite effect takes place.

It is seen from Fig. 8 that M_r decreases with an increase in m. And a similar effect is observed with an increase in ω in the neighbourhood of the plate. But an opposite effect is noticed after a certain distance from the plate.

Figure 9 shows that M_r decreases with an increase in P, near the plate, but an opposite effect is observed away from the plate. This figure also exhibits that on M_r G plays just an opposite role to that of P.

Figure 10 shows that M_i increases as A increases. When $A = 0$, M_i is negative and tends to zero asymptotically as η increases. When $A = 0.5$, M_i is negative near the plate and after $\eta = 0.2$ it becomes positive and when $A = 1.0$, M_i is positive; but for both these values of A, M_i falls to zero asymptotically as η increases.

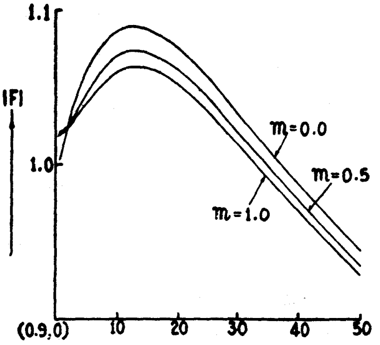

FIG. 4. Amplitude of skin-friction $|F|$ for different values of m. $A = 0.5$, $P = 10$, $G = 20$.

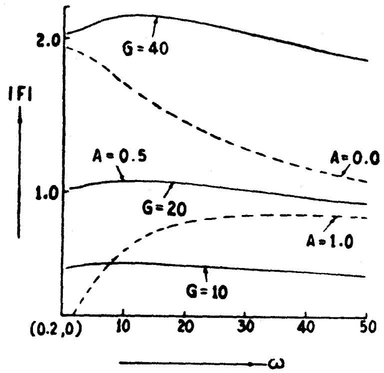

FIG. 5. Effect of A and G on amplitude of skin-friction $|F|$. $m = 0.5$, $P = 10$, $G = 20$.

TABLE III

Values of $|F|$ the *amplitude of the skin-friction for different values of P.*
$A = 0.5$, $m = 0.5$, $G = 20$

ω \ P	5.0	10.0	20.0
2.0	2.09765	1.02542	0.50633
4.0	2.14778	1.03958	0.50927
6.0	2.17096	1.05337	0.51253
8.0	2.16719	1.06395	0.51574
10.0	2.14623	1.07065	0.51876
12 0	2.11579	1.07368	0.52152
14.0	2.08065	1.07360	0.52393
16.0	2.04361	1.07104	0.52597
18.0	2.00624	1.06658	0.52760
20.0	1.96943	1.06069	0.52884
22.0	1.93367	1.05375	0.52969
24.0	1.89919	1.04605	0.53017
26.0	1.86611	1.03784	0.53032
28.0	1.83446	1.02928	0.53016
30.0	1.80420	1.02051	0.52972
32.0	1.77531	1.01162	0.52904
34.0	1.74770	1.00269	0.52813
36.0	1.72133	0.99379	0.52704
38.0	1.69611	0.98495	0.52578
40.0	1.67198	0.97620	0.52438
42.0	1.64887	0.96757	0.52285
44.0	1.62673	0.95908	0.52121
46.0	1.60548	0.95074	0.51948
48.0	1.58508	0.94255	0.51768
50.0	1.56547	0.93453	0.51581

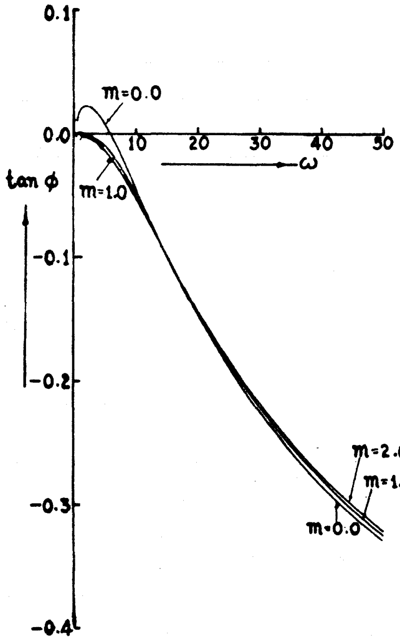

FIG. 6. Effect of m on skin-friction phase $\tan \phi$. $A = 0.5$; $P = 10$; $G = 20$.

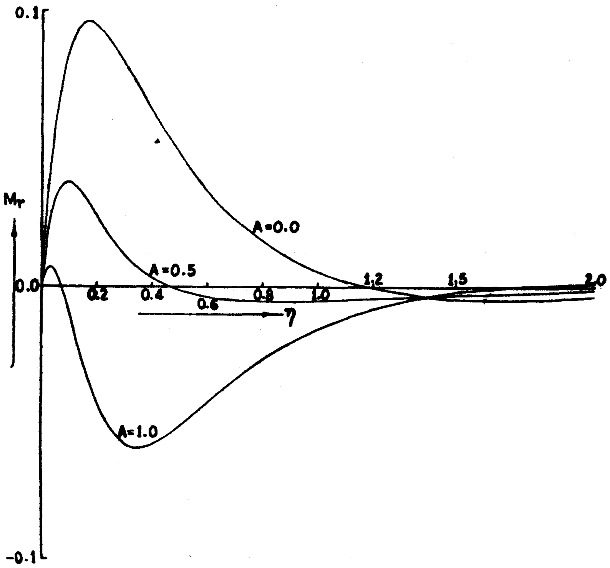

FIG. 7. Effect of A on fluctuating part M_r of velocity. $m = 0.5$, $\omega = 10$, $P = 10$, $G = 20$.

TABLE IV

Values of tan ϕ for different values of A and P.
$G = 20$, $m = 0.5$

ω \ A	0.0	0.5	1.0	P
2.0	− 0.14034	− 0.00043	0.83686	5.0
	− 0.07405	0.00546	1.05577	10.0
	− 0.03792	0.00624	1.19310	20.0
6.0	− 0.33823	− 0.06800	0.55805	5.0
	− 0.19639	− 0.01043	1.01117	10.0
	− 0.10451	0.00327	1.47771	20.0
10.0	− 0.45238	− 0.14923	0.31283	5.0
	− 0.28697	− 0.04715	0.73448	10.0
	− 0.16093	− 0.00613	1.26025	20.0
14.0	− 0.52503	− 0.21521	0.16490	5.0
	− 0.35503	− 0.08846	0.54422	10.0
	− 0.20973	− 0.02051	1.05322	20.0
18.0	− 0.57574	− 0.26745	0.06421	5.0
	− 0.40761	− 0.12786	0.41097	10.0
	− 0.25211	− 0.03790	0.88812	20.0
22.0	− 0.61351	− 0.30969	− 0.01034	5.0
	− 0.44944	− 0.16350	0.31204	10.0
	− 0.28904	− 0.05684	0.75780	20.0
26.0	− 0.64297	− 0.34467	− 0.06871	5.0
	− 0.48360	− 0.19528	0.23494	10.0
	− 0.32138	− 0.07628	0.65329	20.0
30.0	− 0.66675	− 0.37427	− 0.11622	5.0
	− 0.51212	− 0.22357	0.17257	10.0
	− 0.34986	− 0.09555	0.56773	20.0
34.0	− 0.68645	− 0.39975	− 0.15600	5.0
	− 0.53633	− 0.24885	0.12067	10.0
	− 0.37513	− 0.11425	0.49629	20.0
38.0	− 0.70311	− 0.42202	− 0.19002	5.0
	− 0.55733	− 0.27158	0.07650	10.0
	− 0.39769	− 0.13218	0.43557	20.0
42.0	− 0.71743	− 0.44170	− 0.21962	5.0
	− 0.57565	− 0.29213	0.03825	10.0
	− 0.41797	− 0.14925	0.38317	20.0
46.0	− 0.72990	− 0.45929	− 0.24572	5.0
	− 0.59185	− 0.31082	0.00464	10.0
	− 0.43631	− 0.16544	0.33735	20.0
50.0	− 0.74089	− 0.47513	− 0.26899	5.0
	− 0.60630	− 0.32791	− 0.02523	10.0
	− 0.45299	− 0.18077	0.29682	20.0

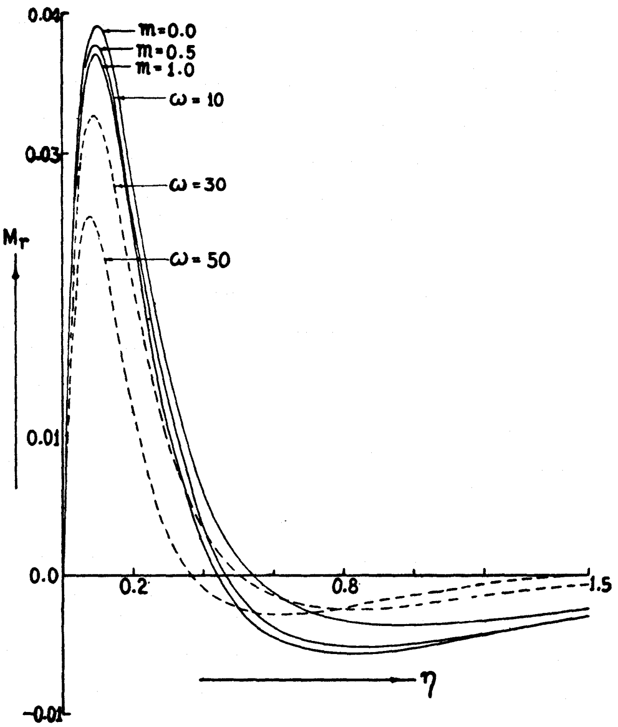

FIG. 8. Effect of m and ω on M_r. $A = 0.5$, $P = 10$, $G = 20$. $\omega = 10$ ——: $m = 0.5$ - - - -

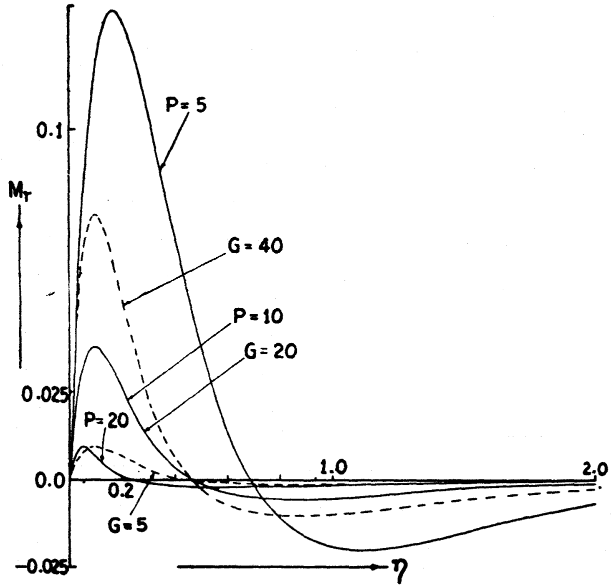

FIG. 9. Effect of P and G on M_r. $A = 0.5$, $m = 0.5$, $\omega = 10$. $G = 20$ ——; $P = 10$ - - - -

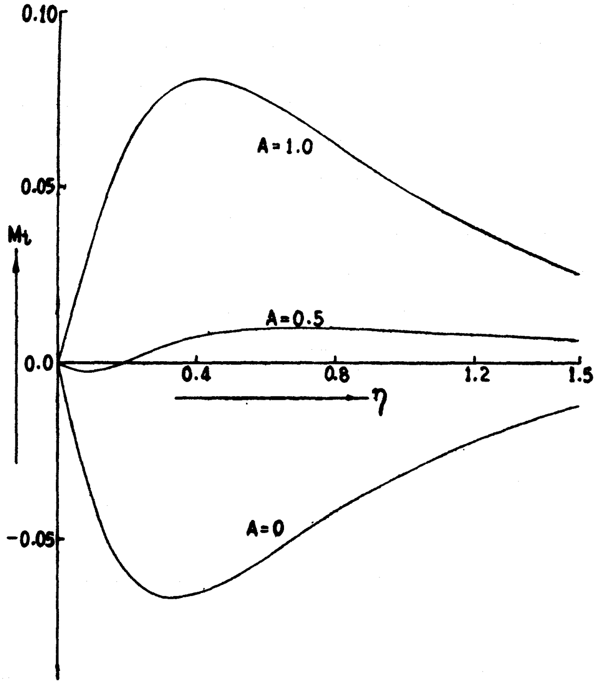

FIG. 10. Effect of A on fluctuating part M_i of velocity. $m = 0.5$, $\omega = 10$, $P = 10$, $G = 20$.

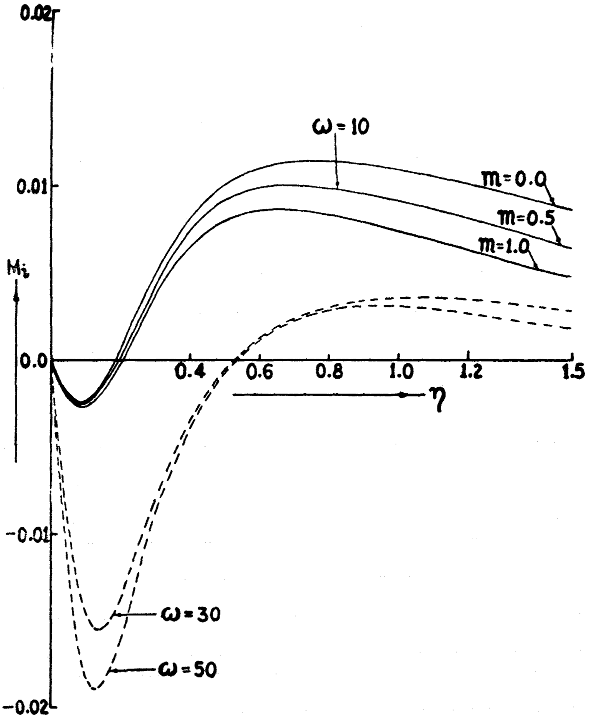

FIG. 11. Fluctuating part M_i for different values of m and $A = 0.5$, $P = 10$, $G = 20$. $\omega = 10$ ——, $m = 0.5$ - - - -

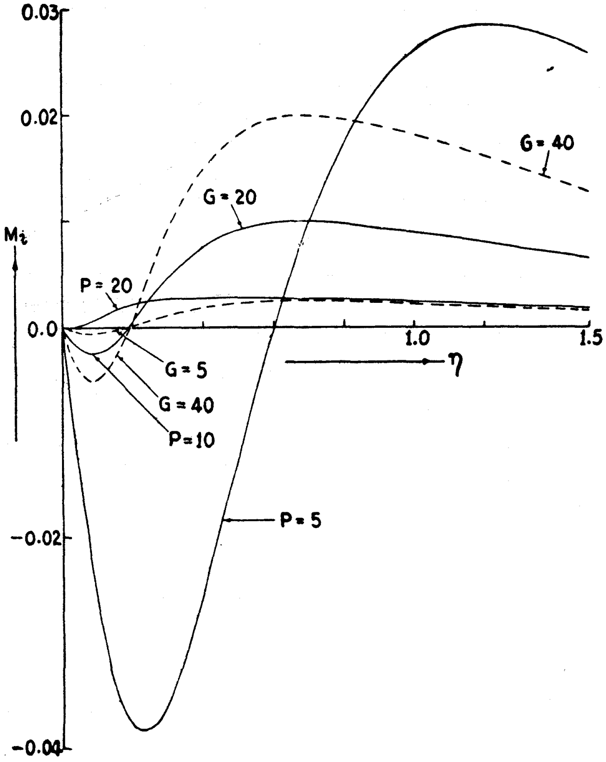

FIG. 12. Fluctuating part M_i for different values of P and G. $A = 0.5$, $m = 0.5$, $\omega = 10$. $G = 20$ ——; $P = 10$ - - - -

Figure 11 shows that M_i decreases with an increase in m. Moreover, the values of M_i are negative near the plate and are positive away from the plate. A similar effect is observed with an increase in ω. Figure 12 exhibits that M_i increases with an increase in P, near the plate but after a certain distance an opposite effect is discerned. The effect of G on M_i is seen to be just opposite to that of P.

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