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The Propagation of Hydromagnetic Cylindrical Shock Waves in Weak Magnetic Field, With A Self-Gravitating Gas

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ABSTRACT

The effects of overtaking disturbances behind the flow on the propagation of diverging cylindrical shock Waves through an ideal gas in presence of a magnetic field having H_{Z_0} =constant= H_{θ_0} and an Initial density distribution $\rho_0 = \rho' r^{-\omega}$ where ω is a constant, ρ' is the density at the plane / exes of symmetry: The analytical formula for flow variables representing both the position form viz; weak and strong cases at shock waves have been obtained. Their numerical estimates at permissible shock front locations have been obtained.

There numerical estimates at permissible shock front location's have been Calculated and compared with earlier result describing in Free Propagation through figures. After inclusion of E.O.D. noted that there is no change at flow variable with parameters r, β^2, ω and ξ. However, the trends of variation with propagation distance r, for shock strength, shock velocity and particle velocity are not change in case of weak shock with work Magnetic field(**wswmf).**

Keywords : E.O.D $\rightarrow$ Effect of overtaking disturbances,
$\rho_0 = \rho' r^{-\omega}$ $\rightarrow$ Density Distributions
H_{Z_0} $\rightarrow$ Azimuthal component of magnetic field
H_{θ_0} $\rightarrow$ Axial comp. of Magnetic field
WSWMF$\rightarrow$Weak shock weak magnetic field.

I. INTRODUCTION

Using CCW method. by including the e.o.d behind the flow of cylindrical weak shock wave in weak magnetic field in a self gravitating gas. CCW method for shock wave dynamics that it's application is useful unless the result obtained are compared with other numerical methods Witham has ruled out this limitation and claimed it's correctness Rosciszewski and oshima formulation of the error involved in using the CCW description by integrating two neighboring overtaking characteristics.

The characteristics method which works for weak and strong condition of shock.

The C.O.D behind the flow on the propagation of diverging cylindrical shock wave through an Ideas and electrically perfectly conducting self gravitating gas in presence of a magnetic field having constant azimuthal $\left(H_{z_0}\right)$ and axial components and magnetic fields for shock weak. The density in the unperturbed state has been $\rho_0 = \rho' r^{-\omega}$ .The case of weak shock explored under weak magnetic field

The expression for flow variables have been computed only at **psfl** with Parameter r, β^2 ,D, β_2^2 ω and ξ also compared with result obtained through Free Propagation in Figures (1-5)

1.2 Fundamental Equation :-

The equation governing the cylindrical flow at the gas under the influence of its own gravitating and magnetic field having constant axial and azimuthal components of Magnetic field are written as

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial r}+\frac{1}{\rho}\frac{\partial \rho}{\partial r}+\frac{\mu}{2\rho}\frac{\partial}{\partial r}(H_0^2+H_z^2)+\frac{\mu}{\rho}\frac{H_0^2}{r}+\frac{Gm}{r^2}-0,$$

$$\frac{\partial u}{\partial t}+u\frac{\partial \rho}{\partial r}+\rho\frac{\partial u}{\partial r}\rho\frac{u}{r}=0,$$

$$\frac{\partial \rho}{\partial t}+u\frac{\partial \rho}{\partial r}+\gamma p\frac{\partial u}{\partial r}+\gamma p\frac{u}{r}=0, \qquad (1)$$

$$\frac{\partial H_\theta}{\partial t}+u\frac{\partial H_\theta}{\partial r}+H_\theta\frac{\partial u}{\partial r}=0,$$

$$\frac{\partial H_z}{\partial t}+u\frac{\partial H_z}{\partial r}+H_z\frac{\partial u}{\partial r}+H_z\frac{u}{r}=0, \qquad \frac{\partial m}{\partial r}-2\pi\rho r=0$$

Where $r \rightarrow$ radial co-ordinate $u, \rho, \rho H_Z, H_\theta, \mu$ and m are. respectively, the particle velocity, thy density. the pressure, azimuthal and axial components at magnetic field permeability at gas, mass inside a cylinder of unit cross-section and unit radius and unit length.

$a_0^2 = \frac{\gamma p_o}{\rho_o}, \gamma \rightarrow$ Adiabatic index of the gas

1.3 Boundary Condition :-

The magnetohydrodynamic conditions can be written in terms of single parameter.

$$\xi = \frac{\rho}{\rho} \quad as \quad \rho = \rho_0 \xi,$$

$$H = H_0\xi, \qquad u = \frac{\xi - 1}{\xi}U \ ,$$

$$U^2 = \frac{2\xi}{(\gamma+1)-(\gamma-1)\xi}\left[a_0^2 + \frac{b_0^2}{2}\{(2-\gamma)\xi+\gamma\}\right]$$

where 'o' stande for the state immediately ahead of the shock front, U is the shock velocity, a_0 is the sound speed $a_0 = \sqrt{\frac{\gamma p_0}{\rho_0}}$ and alfven speed $\left(\frac{\mu H_0^2}{\rho_0}\right)^{\frac{1}{2}}$.

1.4 Weak Shock :-For every weak shock the parameter ξ is written as

$$\frac{\rho}{\rho_0} = 1 + \varepsilon = \xi \qquad (3)$$

Where $\varepsilon(r)$ is another parameter which is negligible in comparison with unity , *i.e.* $\varepsilon(r) << 1$,

Now we consider to weak magnetic field $b_0^2 << a_0^2$, *i.e.*, $\mu H_0^2 / \gamma p_0 << 1$,
by using the boundary condition (2) for every weak chock reduce to

$$\rho = \rho_0(1+\varepsilon), \quad H_\theta = H_{\theta_0}(1+\varepsilon), \; H_z = H_{z_0}(1+\varepsilon)$$

$$U = \left(1 + \frac{\gamma+1}{4}\varepsilon\right) a_0, \quad p = p_0(1+\gamma\varepsilon) \text{ and } u = \varepsilon a_0 \tag{4}$$

1.5 CHARACTERISTIC EQUATION: For diverging shock. the characteristic form of the system of equation (1) is easily obtained by forming a linear combination of (1) and (3) equation of the system of equation (1) in only one direction in (r, t,) plane Equation (1) and (3) of the system can be written as

$$\rho \frac{\partial u}{\partial t} + \rho u \frac{\partial u}{\partial r} + \frac{\partial_t}{\partial r} - \rho \frac{Gm}{r^2} = 0, \tag{5}$$

$$\frac{\partial p_t}{\partial t} + u \frac{\partial p_t}{\partial r} + \rho c^2 \frac{\partial u}{\partial r} + \rho \frac{c^2 u}{r} = 0 \tag{6}$$

$$p_1 = p + \frac{u}{2}\left(H_0^2 + H_z^2\right) + \int \mu H_\theta^2 \frac{dr}{r} \tag{7}$$

is total pressure including magnetic pressure and

$$C^2 = a^2 + b^2 = \frac{\gamma p}{\rho} + \frac{\mu}{\rho}\left(H_\theta^2 + H_z^2\right) \tag{7a}$$

with the help of above equation we get characteristic equation on

$$dp + \mu H_\theta dH_\theta + \mu H_z dH_z + \rho c du + \mu H_\theta^2 \frac{dr}{r} + \rho c^2 \frac{u}{u+c}\frac{dr}{r} + \rho c \frac{Gm}{u+c}\frac{dr}{r^2} = 0 \tag{8}$$

In order to estimate the strength of overtaking disturbances an independents C_+ characteristic is considered the differential relation valid across C_+ disturbances is obtained by replaced c by –c in equation (8) and written as

$$dp + \mu H_\theta dH_\theta + \mu H_z dH_z + \rho c du + \mu H_\theta^2 \frac{dr}{r} + \rho c^2 \frac{u}{u+c}\frac{dr}{r} + \rho c \frac{Gm}{u+c}\frac{dr}{r^2} = 0 \tag{9}$$

equation (9) represent characteristic form of equation (1) for Conversing shock.

1.6 ANALYTICAL RELATIONS FOR FLOW VARIABLES :-

Considered on initial density distribution of the form viz,

$$\rho_0 = \rho^1 r^{-w} \tag{10}$$

For the equilibrium state of the as is assumed

$$\frac{\partial}{\partial t} = 0 = u$$
$$H_{z_0} = H_{\theta_0}, \tag{11}$$

using (ii) and First equation of the system of equation (1), the hydrostatic equilibrium prevailing in front of shock can be written as

$$\frac{1}{p_0}\frac{dp_0}{dr}+\frac{\mu}{2\rho_0}\frac{d}{dr}\left(H_{Z_0}^2+H_{\theta_0}^2\right)+\frac{1}{\rho_0}\frac{\mu H_{\theta_0}^2}{r}+\frac{Gm}{r^2}=0$$
$$\frac{1}{\rho_0}\frac{dp_0}{dr}+\frac{1}{\rho_0}\frac{\mu H_{\theta_0}^2}{r}+\frac{Gm}{r^2}=0 \quad (12)$$

From the sixth equation of (1) can be written as

$$m=2\pi\rho^1\int r^{1-w}$$
$$m=\frac{2\pi\rho^1 r^{2-w}}{2-w} \quad (13)$$

from (10), (12) and (13) we get

$$\frac{p_0}{G\rho^{12}}=K-\beta_2^2 D\log r-K_1 r^{1-2w} \quad (14)$$

why K is constant

$$\frac{a_0}{a^1}=\left(\frac{\gamma r^w}{D}\left(K-\beta_2^2 D\log r-K_1 r^{1-2w}\right)\right)^{\frac{1}{2}}$$

why $K_1=\frac{2\pi}{(1-2w)(2-w)}$, (15)

$$D=\frac{a^2}{G\rho^2}\quad \beta_2^2=\frac{\mu H_{\theta_0}^2}{\gamma p}$$

ρ' it the density at the plane of symmetry in unperturbed state and G is universal Gravitational constant. Variations in the pressure in the unperturbed medium given by equation (14) with the Propagation distance **r.**

1.7 WEAK SHOCK WITH WEAKMANETIC FIELD (WSWMF): Putting the shock condition (4) in to equation (8) and using the equation (12) and neglected the second and higher order term of $\varepsilon(r)$ since $\varepsilon(r)<<1$, we get

$$\frac{d\varepsilon}{\varepsilon}+\frac{1}{2}\left(1-\frac{1}{2}\frac{\mu H_0^2}{\gamma p_0}\right)\left(\frac{dp_0}{p_0}+\frac{da_0}{a_0}+\frac{dr}{r}+\frac{2\mu H_{\theta_0}^2}{\gamma p^0}\frac{dr}{r}\right)=0 \quad (16)$$

The validity condition of above relation is $\frac{\mu H_0^2}{\gamma\rho_0}<<1$ and this equation can be re-written as

$$\frac{d\varepsilon}{\varepsilon}+\frac{1}{2}\left(1-\frac{\beta^2 p^1}{2p^0}\right)\left(\frac{dp_0}{p_0}+\frac{da_0}{a_0}+\frac{dr}{r}+\frac{\beta_2^2 p^1}{p_0}\frac{dr}{r}\right)=0 \quad (17)$$

Substituting the values of $\frac{dp_0}{p_0}$, and $\frac{dp_0}{p_0}$, into equation (17) and on integration we get

$$\varepsilon(r)=K_{12}r^{K11}\ell.\left(K_{13}\right)$$
$$\boxed{\varepsilon(r)=K_{12}r^{K11}\exp.\left(K_{13}\right)} \quad (18)$$

where $K_{12}\rightarrow$ integration, constant

$$K_{13} = K_6 r + K_7 r^{1-2w} + K_8 \frac{r^{2-2w}}{2-2w} + K_9 \frac{r^{2(1-2w)}}{2(1-2w)} + K_{10} \frac{r^{3-4w}}{3-4w}$$

$$K_3 = -\frac{B_2^2 D}{K^2}, K_4 = -\left\{(1-2w) + \frac{B_2^2 D}{K} + (1-2w)\frac{B_2^2 D}{K}\log r\right\}$$

$$K_5 = -(1-2w)\left(\frac{K_1}{K}\right)^2,$$

$$K_6 = -\frac{3}{4}K_3 + \frac{3B^2 D}{8\gamma K}K_{3,}$$

$$K_7 = -\frac{3}{4}K_4 + \frac{3\beta^2 D}{8\gamma K}K_4 + \frac{3\beta^2 D\beta_2^2}{8\gamma K^2}K_4 \log r + \left(1+\frac{w}{2}\right)\frac{\beta^2 DK_1}{4\gamma K^2} + \frac{2\beta_2^2 DK_1}{\gamma K^2}$$

$$K_8 = -\frac{3}{8}\frac{\beta^2 DK_1}{\gamma K^2}K_3 - \frac{3}{4}K_4 + \frac{3}{8}\frac{\beta^2 D}{\gamma K}K_5 + \frac{3}{4}\frac{\beta^2 D\beta_2^2}{4\gamma K^2}\log rK_5$$

$$K_9 = \frac{3\beta^2 DK_1 K_4}{8\gamma K^2}$$

$$K_{10} = \frac{3}{8}\frac{\beta^2 DK_1 K_5}{8\gamma K^2}$$

$$K_{11} = \left\{\left(1+\frac{w}{2}\right)\left(1+\frac{\beta^2 D}{4\gamma K} + \frac{\beta^2 D^2 \beta_2^2}{2\gamma K^2}\log r\right)\right\}$$

Remember that equation (17) in to (4) describes Free propagation using the equation (17) into (4) we get

$$du\_ = \varepsilon da_0 + a_0\varepsilon\left\{-\frac{1}{2}\left(1-\frac{\mu H_0^2}{\gamma p_0}\right)\left(\frac{dp_0}{p_0} + \frac{da_0}{a_0} + \frac{dr}{r} + \frac{2\mu H_{\theta 0}^2}{\gamma p_0}\frac{dr}{r}\right)\right\} \quad (19)$$

On substituting the shock conditions (4) into (9) and using (12) we get

$$\frac{d\varepsilon}{\varepsilon} + \frac{\gamma p_0}{\mu H_0^2}\left\{\frac{dp_0}{p_0}\left(\frac{1}{2} - \frac{2}{\gamma}\right) - \frac{da_0}{a_0} - \frac{dr}{r}\right\} = 0 \quad (20)$$

using the equation (20) and (4) we get

$$du_+ = \varepsilon da_0 + a_0\left[\left(\frac{\gamma p_0}{\mu H_0^2}\right)\left\{\frac{dp_0}{p_0}\left(\frac{1}{2} - \frac{2}{\gamma}\right) - \frac{da_0}{a_0}\frac{dr}{r}\right\}\varepsilon\right] \quad (21)$$

Now in presence of both and disturbances the fluid velocity behind the shock will be related as

$$du_- + du_+ = \varepsilon da_0 + a_0\varepsilon \quad (22)$$

from equation (19) (21) and (22) we get

$$\frac{d\varepsilon}{\varepsilon} = \frac{dp_0}{p_0}\left[-\frac{1}{4} + \frac{3}{8}\frac{\mu H_0^2}{\gamma p_0} - \frac{\gamma p_0}{\mu H_0^2}\left(\frac{\gamma-4}{2\gamma}\right)\right] + \frac{dr}{r}\left[-\frac{w}{4} - \frac{3}{2} + \frac{\mu H_0^2}{4\gamma p_0}\left(1+\frac{w}{2}\right) - \frac{2\mu H_{\theta 0}^2}{\gamma p_0}\right] \quad (23)$$

Substituting the values of $\frac{dp_0}{p_0}, \frac{p_0}{p_1}$ and $\frac{da_0}{a_0}$ into equation (23) and on integration

$$\boxed{\varepsilon(r) = K_{20} r^{K_{15}} \exp.(K_{21})} \quad (24)$$

$K_{20} \rightarrow$ Integration constant

$$K_{21} = K_{14} + K_{16}\frac{r^{1-2w}}{1-2w} + K_{17}\frac{r^{2-2w}}{2-2w} + K_{18}\frac{r^{2-4w}}{2-4w} + K_{19}\frac{r^{3-4w}}{3-4w}$$

$$K_{14} = -\frac{K_3}{4} + \frac{3\beta^2 DK_3}{8\gamma K} + \frac{3}{8}\frac{D^2\beta_2^2 K_3}{\gamma K_2}\beta^2 \log r - K_3\frac{\gamma K}{D\beta^2}\left(\frac{\gamma-4}{2\gamma}\right) + \frac{\gamma-4}{2\gamma}\frac{K\gamma\beta_2^2}{\beta^2}\log r$$

$$K_{15} = -\frac{w}{4} + \frac{3}{2} + \frac{\beta^2 D}{4\gamma K} + \left(1+\frac{w}{2}\right)$$

$$K_{16} = -\frac{K_4}{4} + K_4\frac{3\beta^2 D}{8\gamma K} + \frac{3\beta^2 D}{8\gamma K}\left(D\beta_2^2 \log r\right) - \left(\frac{\gamma-4}{2}\right)\frac{K}{\beta^2 D}\left(1-\frac{D\beta_2^2}{K}\log r\right)$$

$$K_{17} = \left\{\frac{3}{8}\frac{\beta^2 D}{\gamma K} + \left(\frac{\gamma-4}{2}\right)\frac{1}{\beta^2 D}\right\}K_1 K_3 - \frac{\gamma-4}{2}\frac{K}{\beta^2 D}\left(1-\frac{\beta_2^2 D}{K}\log r\right)$$

$$K_{18} = K_4\left(-\frac{1}{4} + \frac{3\beta^2 D}{8\gamma K}K_1\right)$$

$$K_{19} = K_5\left(\frac{3\beta^2 D}{8\gamma K^2} + \frac{\gamma-4}{2\beta^2 D}K_1\right)$$

Equation (24) is the propagation parameter which includes the e.o.d behind the flow on the motion of shock.

1.8 ANALYTICAL EXPRESSIONS FOR FLOW VARIABLES FOR WSWMF :-

Substitution the equation (18) and (24) in to shock condition (4), we get respectively for FP and flow variable h and included the e.o.d.

Free propagation

$$\frac{U}{a_0} = \left[1 + \frac{1+\gamma}{4}\left\{K_{12} r^{K11} \exp.(K_{13})\right\}\right] \tag{25}$$

$$\frac{U}{\sqrt{G\rho^1}} = \left[\left\{\gamma r^w\left(K - \beta_2^2 D\log r - K_1 r^{1-2w}\right)\right\}^{\frac{1}{2}}\left\{1+\frac{1+\gamma}{4}\left(K_{12} r^{K11}\exp.K_{13}\right)\right\}\right] \tag{26}$$

$$\frac{\rho}{G\rho'^2} = \left[\left(K - \beta_2^2 D\log r - K_1 r^{1-2w}\right) + \left\{1+\gamma\left(K_{12} r^{K11}\exp(K_{13})\right)\right\}\right] \tag{27}$$

$$\frac{u}{\sqrt{G\rho^1}} = \left[\left\{\gamma r^w\left(K - \beta_2^2 D\log r - K_1 r^{1-2w}\right)\right\}^{\frac{1}{2}}\left\{K_{12} r^{K11}\exp(K_{13})\right\}\right] \tag{28}$$

$$\frac{\rho}{\rho} = r^{-w}\left[\left\{1 + K_{12} r^{K11}\exp(K_{13})\right\}\right]$$

EOD:-

$$\frac{U}{a_0} = \left[1 + \frac{1+\gamma}{4}\left\{K_{20} r^{K15}\exp.(K_{21})\right\}\right] \tag{29}$$

$$\frac{U}{\sqrt{G\rho^1}} = \left[\left\{\gamma r^w\left(K - \beta_2^2 D\log r - K_1 r^{1-2w}\right)\right\}^{\frac{1}{2}}\left\{1+\frac{1+\gamma}{4}\left(K_{20} r^{K12}\exp.K_{21}\right)\right\}\right] \tag{30}$$

$$\frac{\rho}{G\rho^{12}} = \left[\left(K - \beta_2^2 D\log r - K_1 r^{1-2w}\right) + \left\{1+\gamma\left(K_{20} r^{K15}\exp(K_{21})\right)\right\}\right] \tag{31}$$

$$\frac{u}{\sqrt{G\rho^1}} = \left[\left\{ \gamma r^w \left(K - \beta_2^2 D \log r - K_1 r^{1-2w} \right) \right\}^{\frac{1}{2}} \left\{ K_{20} r^{K15} \exp(K_{21}) \right\} \right] \quad (32)$$

$$\frac{\rho}{\rho^1} = r^{-w} \left[\left\{ 1 + K_{20} r^{K15} \exp.(K_{21}) \right\} \right] \quad (33)$$

II. Result and Discussion

The present analysis gives a description of shock wave propagation with better degree of accuracy by including the e.o.d. behind the flow in CCW Method.

WSWMF. the flow variable are dependent on $r, \beta_2^2,\ D$ and w

Taking $\varepsilon(r) = 0.24\ at\ r = 0.5\ \ for = 1.4,$

$\beta_2^2 = 0.10,\ 0.15, 0.20\ and\ \beta^2 = 0.25, 0.30\ D = 0.10,\ 0 + 80$

$\omega = 0.75,\ 1.0, 1.25$

The Numerical estimates of flow variables for both F.P and have including e.o.d.

given by expression 25-33 have been calculated only at **psfl**, the flow variables together with correction percentage due to e.o.d. variation in the flow variable with propagation distance r, have been shown in Figures (1-5)

"The shock strength increase where as the shock velocity, The pressure and density decrease with propagation distance r. Increase in β_2^2 and D leads to increase the shock strength and density whereas the shock velocity. The correction percentage lie between -0.0479% to 1.4122%

1.9 GRAPH AND TABLE FOR FLOW VARIABLE

Table 1 :- Flow variable for cylindrical WSWMF. in S.G.G. with Magnetic Field

$$H_{Z_0} = const = H_{\theta_0},\ \rho_0 = \rho^1 r^{-w}$$

S.No.	Variation of flow Variable	FD	E.O.D.
1	shock strength (u/a₀) versus $r, \beta_2^2, \beta^2.wD$	Increase Decrease	Increase Increase
2	shock velocity versus $\left(\frac{U}{\sqrt{G\rho^1}}\right) r, \beta_2^2, D, w\beta^2$	Decrease Increase	Decrease Increase
3	Pressure versus $\left(\frac{\rho}{\sqrt{G\rho^{12}}}\right) r, \beta_2^2, D, \beta^2, w.$	Decrease Increase	Decrease Increase

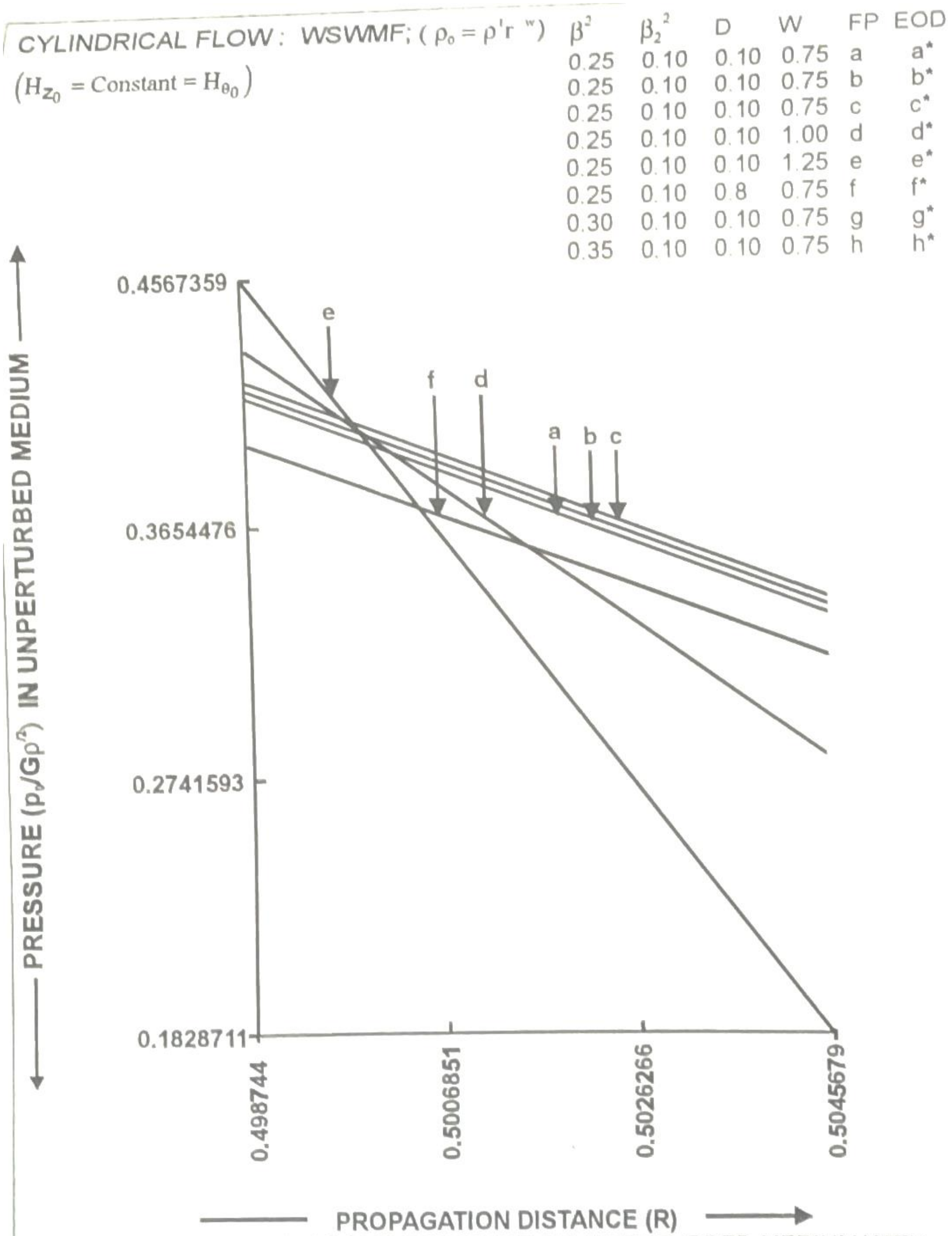

FIG .1 VARIATION OF THE PRESSURE IN UNPERTURBED MEDIUM WITH PROPAGATION DISTANCE (r) FOR CYLINDRICAL WSWMF IN A SGG.

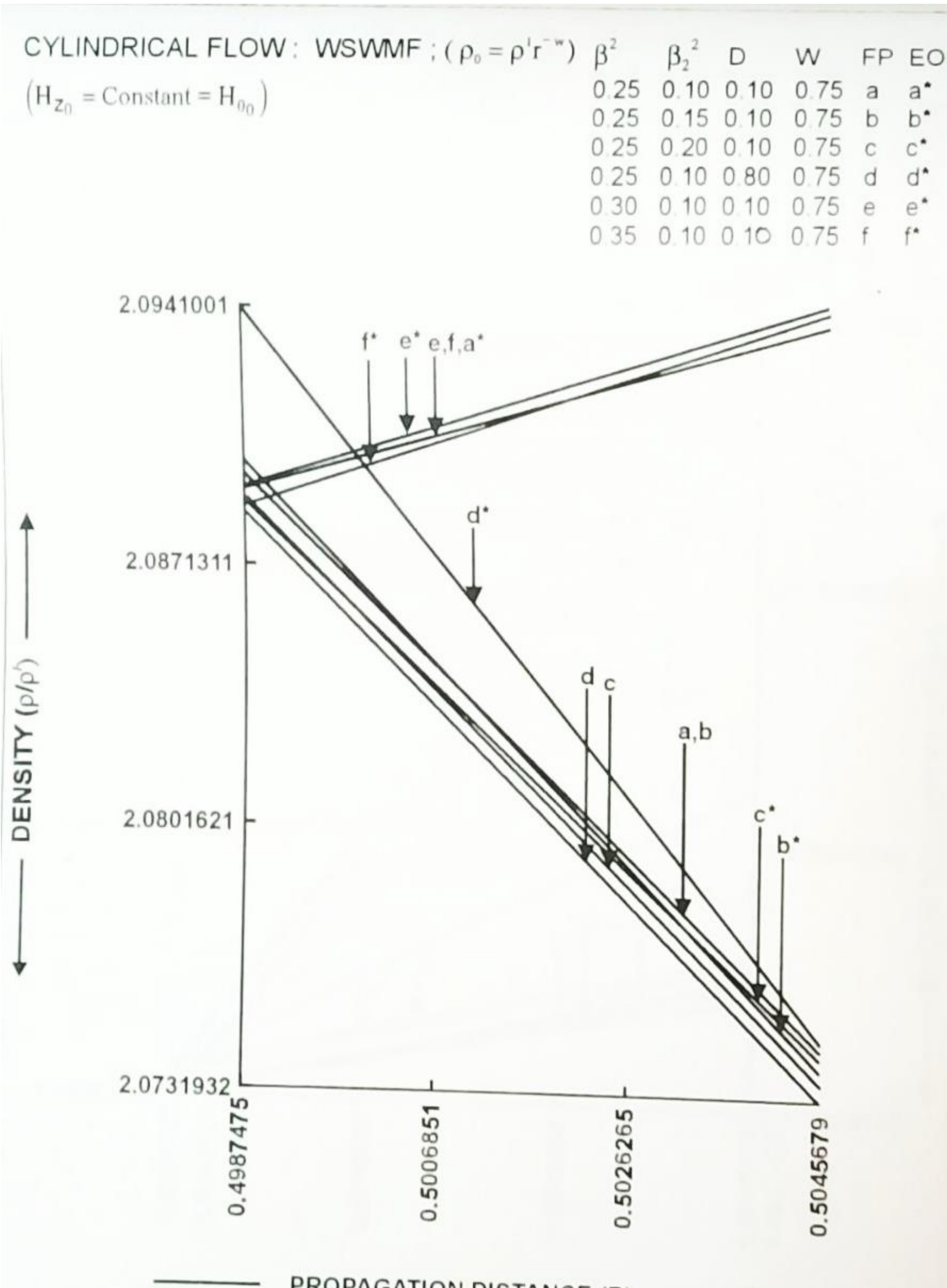

FIG 2. VARIATION OF DENSITY IMMEDIATELY BEHIND THE SHOCK WITH PROPAGATION DISTANCE (r) FOR CYLINDRICAL WSWMF IN A ...

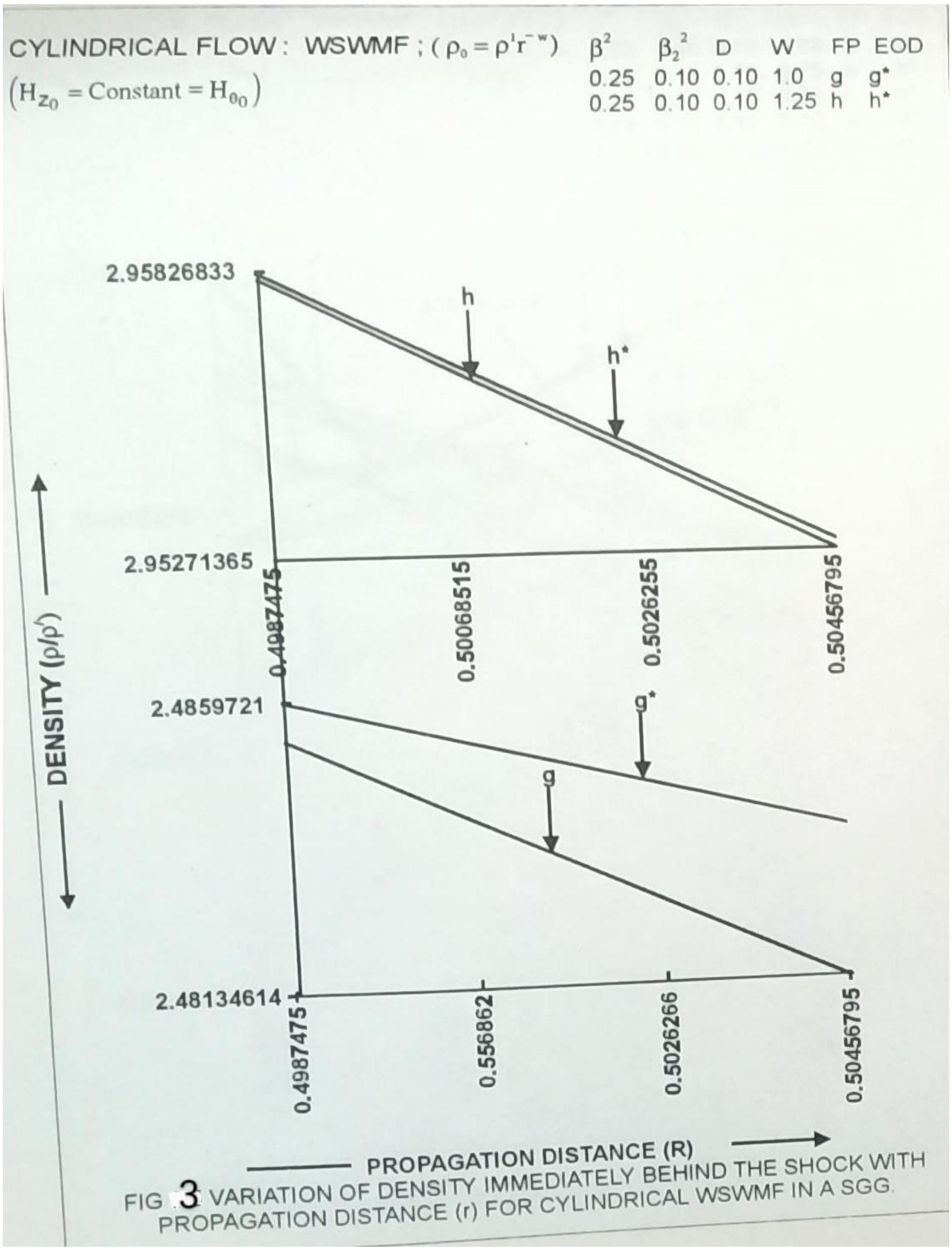

FIG 3 VARIATION OF DENSITY IMMEDIATELY BEHIND THE SHOCK WITH PROPAGATION DISTANCE (r) FOR CYLINDRICAL WSWMF IN A SGG.

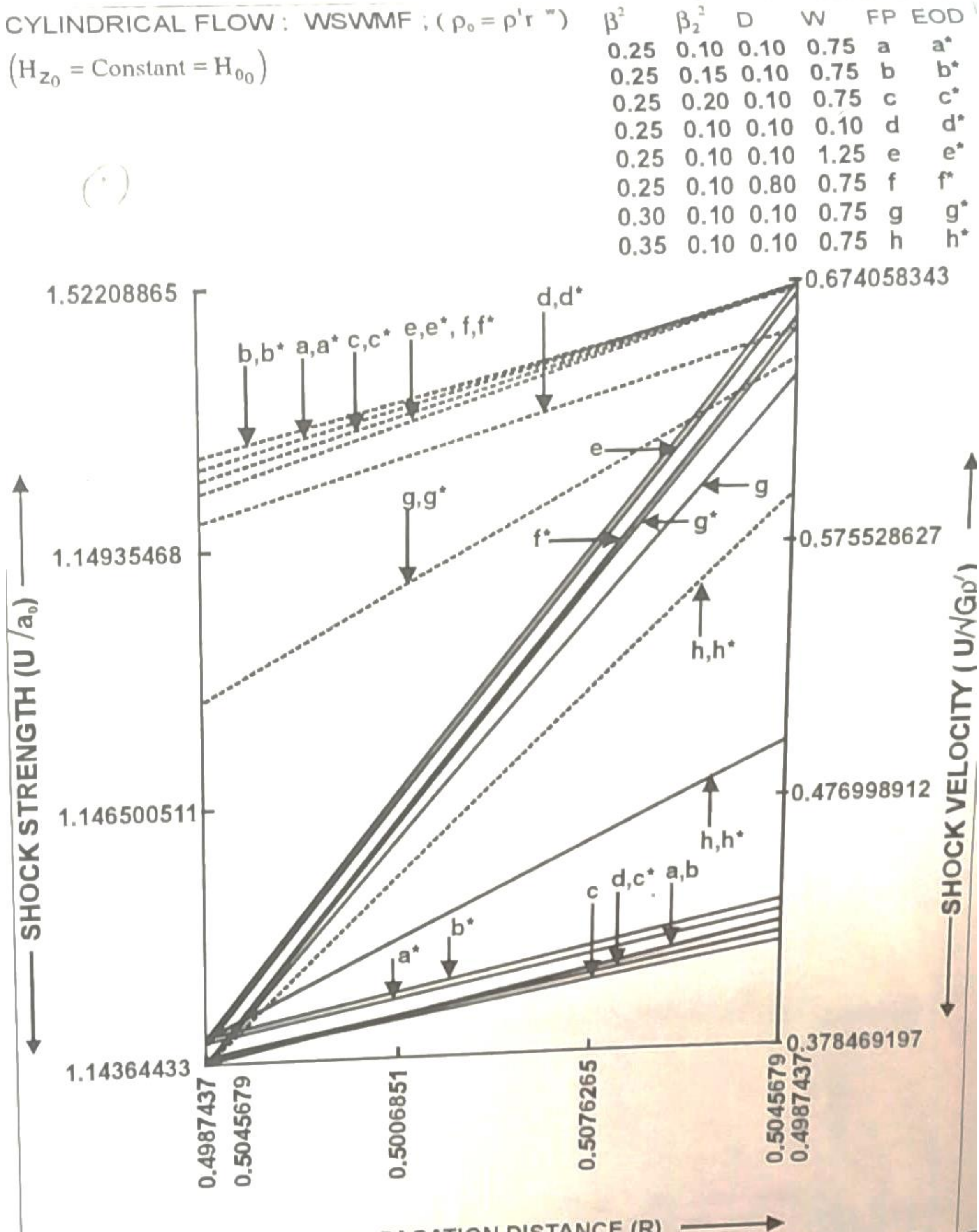

FIG :4 VARIATION OF SHOCK STRENGTH (—) AND SHOCK VELOCITY (---) WITH PROPAGATION DISTANCE (r) FOR CYLINDRICAL WSWMF IN A SGG.

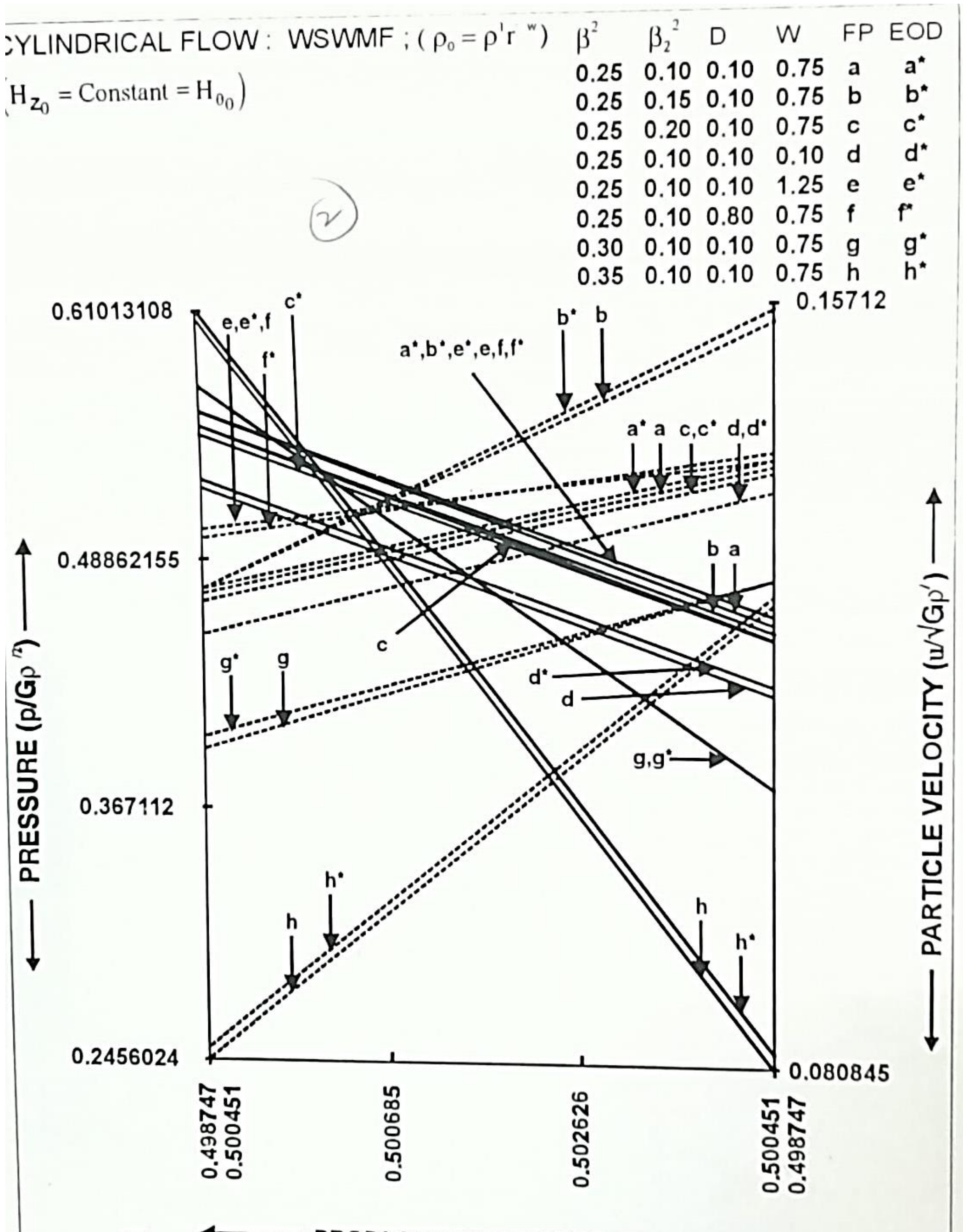

FIG. 5 VARIATION OF PRESSURE (—) AND PARTICLE VELOCITY (---) WITH PROPAGATION DISTANCE (r) FOR CYLINDRICAL WSWMF IN A SGG.

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