# MHD Effects on Blood Flow in a Stenosis

Mr.M.V.Surseh[1], Dr.P.Sekar[2]
[1]*Research Scholar, SPIHER, Avadi, Chennai – 600 054.*
[2]*Dean, Faculty of Science and Humanities, SRM University, Ramapuram, Chennai.*

***Abstract***

*The crucial issue of blood stream in a channel with stenosis affected by a consistent uniform attractive field is considered. The scientific model utilized for the detailing of the issue is reliable with the standards of Magneto hydro dynamics (MHD). Blood is considered as a homogeneous Newtonian liquid and is dealt with as an electrically directing attractive liquid. The limited volume (LV) discretization conspire in curvilinear directions is utilized for the discretization of the arrangement of conditions administering the MHD blood stream. For the numerical arrangement of the issue, which is depicted by a coupled, nonlinear arrangement of PDEs, with suitable limit conditions, the SIMPLE strategy is received. Results concerning the speed, weight, and skin grinding demonstrate that the nearness of the attractive field impacts significantly the stream field.*

**Keywords:** *Magnetic fluid, MHD, channel flow, stenosis, blood flow.*

## I. INTRODUCTION

As per ongoing evaluations, coronary conduit sickness is in charge of one of six passing's in the India and the created nations, causing around one million heart assaults every year just in the India. Among these, the crack of coronary defenseless plaques (DPs) trailed by luminal blockage is perceived as a noteworthy reason for sudden heart assaults. In these neurotic conditions coronary supply routes can be impeded by greasy stores framing the defenseless plaque (DP) that may trigger quick thrombosis upon break and cause a heart assault [10]. The fundamental goal of this investigation is to investigate entryway methods for decreasing extreme hemodynamic impacts that could prompt DP break by building up a scientific model in light of standards of biomagnetic liquid elements (BLE). Since blood contains press, one essential inquiry is whether an attractive field could impact the stream at the stenotic area.

As of late, a broadened biofluid elements (BFE) numerical model, which includes the underlying BFE model of Haik et al, was produced by Tzirtzilakis [14]. Air conditioning cording to this BFE display, a biofluid is considered as a Newtonian, homogeneous, incompressible, and electrically directing liquid and the stream is considered as laminar. A standout amongst the most trademark biofluids, which shows electrical conductivity, is blood [14]. As per the BFE model of [14] the biofluid stream affected by a connected attractive field is steady with the standards of Magneto hydro dynamics (MHD), [1, 2, 12] and Ferro hydro dynamics (FHD) [11].

The central issues of biomagnetic liquid stream in a direct with stenosis and in a top driven hole have been examined in [15] and [16], individually. The scientific model utilized for the plan of these issues is the one created in [14]. The outcomes concerning the speed field, for the two issues, demonstrated that the nearness of the attractive field impacted extensively the stream field. The standards of MHD can't be overlooked when a uniform unfaltering attractive field is connected, either all around or locally, and assume an essential part in the arrangement of the stream field. By and large, the developed numerical model has been demonstrated valuable for understanding the impact of the attractive field in the investigation of MHD physical issues [14– 16].

The MHD stream in a channel with symmetric stenosis is numerically researched. The stream is thought to be two dimensional (2D), laminar, in-compressible and the attractive field is consistently connected universally at the stream field. The two impermeable plates of the channel and the biofluid entering the channel are kept at steady temperatures. The two plates of the channel frame a half stenosis at the focal point of the space. To the extent the scientific model is concerned, the numerical model depicted in [14, 16] is considered and is substantial for the stream like the one in vast veins, where the blood can be considered as a homogeneous and Newtonian liquid [9, 14].

The geometry of the stenotic 2D channel requires the advancement of a summed up non-orthogonal curvilinear organize approach. This approach is a neighborhood procedure that permits the depiction of complex geometries such the one utilized in this examination [13]. The biofluid is blood and is considered as a homogeneous, Newtonian and electrically directing liquid. The physical issue is depicted by a coupled, nonlinear arrangement of PDEs which is discretized utilizing the limited volume system and numerically settled applying the semi-certain technique for weight connected conditions (SIMPLE).

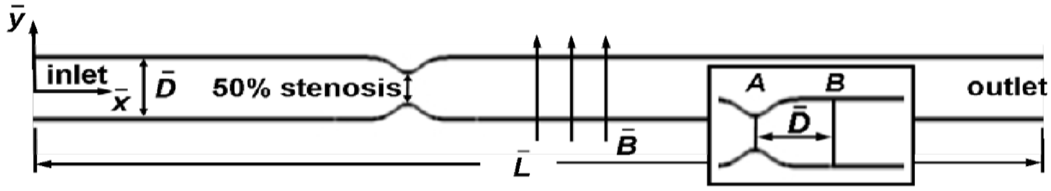


**Figure 1: Schematic portrayal of the geometry, physical issue design and areas where the speed is exhibited in the outcomes.**

## II. MATHEMATICAL FORMULATION

The thick, relentless, 2-dimensional, incompressible, laminar, biomagnetic liquid (blood) stream is viewed as occurring between two impermeable plates framing a narrowing. The length of the plates is $\bar{L}$ and the separation between them at the passage is $\bar{D}$ , as delineated in Figure.1. The places of the upper and the lower plate, are figured scientifically by the utilization of a capacity as for the $\bar{x}$ heading and more points of interest can be discovered somewhere else [3].

The stream is liable to a uniform attractive field with heading opposite to the $\bar{x}$ bearing. A schematic portrayal of the geometry and the stream field is given in Figure.1. The stream at the passageway is thought to be illustrative while for the outlet a completely created stream limit condition was forced. The cause of the Cartesian facilitate framework is situated at the bay of the geometry, Figure.1.

For the liquid (blood) stream the accompanying suppositions are made. Blood is considered to be an electrically leading biomagnetic Newtonian liquid [14]. The stream is thought to be laminar and the augmentation of the consistency because of the attractive field is thought to be insignificant. The dividers of the channel are accepted electrically noncon-ducting and the electric field is viewed as unimportant.

Under the above presumptions the conditions administering the stream under thought are [14, 16]:

$$\frac{\partial \bar{u}}{\partial \bar{x}} + \frac{\partial \bar{v}}{\partial \bar{y}} = 0 \qquad (1)$$

$$\bar{\rho}\left(\bar{u}\frac{\partial \bar{u}}{\partial \bar{x}} + \bar{v}\frac{\partial \bar{u}}{\partial \bar{y}}\right) = -\frac{\partial \bar{p}}{\partial \bar{x}} - \bar{\sigma}\bar{B}^2\bar{u} + \bar{\mu}\left(\frac{\partial^2 \bar{u}}{\partial \bar{x}^2} + \frac{\partial^2 \bar{u}}{\partial \bar{y}^2}\right) \qquad (2)$$

$$\bar{\rho}\left(\bar{u}\frac{\partial \bar{v}}{\partial \bar{x}} + \bar{v}\frac{\partial \bar{v}}{\partial \bar{y}}\right) = -\frac{\partial \bar{p}}{\partial \bar{x}} + \bar{\mu}\left(\frac{\partial^2 \bar{v}}{\partial \bar{x}^2} + \frac{\partial^2 \bar{v}}{\partial \bar{y}^2}\right) \qquad (3)$$

The boundary conditions of the problem are:

$$\left.\begin{array}{ll} \text{Inflow} & \left(\bar{x} = 0,\ -\bar{D}/2 \le \bar{y} \le \bar{D}/2\right):\ \bar{u} = \bar{u}(\bar{y}),\ \bar{v} = 0, \\ \text{Outflow} & \left(\bar{x} = \bar{L},\ -\bar{D}/2 \le \bar{y} \le \bar{D}/2\right):\ \partial\left(\bar{R}\right)/\partial\bar{x} = 0, \\ \text{Upper plate} & \left(\bar{y} = \bar{D}/2,\ 0 \le \bar{x} \le \bar{L}\right):\ \bar{u} = 0,\ \bar{v} = 0, \\ \text{Lower plate} & \left(\bar{y} = -\bar{D}/2,\ 0 \le \bar{x} \le \bar{L}\right):\ \bar{u} = 0,\ \bar{v} = 0, \end{array}\right\} \qquad (4)$$

In the conditions above $\bar{p} = \left(\bar{u}, \bar{v}\right)$ is the dimensional speed, $\bar{p}$ is the weight, $\bar{u}(\bar{y})$ is an illustrative speed profile relating to the completely created stream, $\bar{R}$ remains for $\bar{u}$ or $\bar{v}$ , $\bar{\rho}$ is the biomagnetic liquid thickness, $\bar{\sigma}$ is the electrical conductivity, $\bar{\mu}$ is the dynamic consistency, $\bar{B}$ is the attractive enlistment, and the bar over the amounts indicates that they are dimensional. The term $\bar{\sigma}\bar{B}^2\bar{u}$ showing up in (2), speaks to the Lorentz constrain per unit volume and emerges because of the electrical conductivity of the liquid [1, 2, 12].

## III. TRANSFORMATION OF EQUATIONS

In order to proceed to the numerical solution of the system equation (1) to (3) with the boundary conditions (4), the following non-dimensional variables are introduced

$$x = \frac{\bar{x}}{\bar{D}}, \quad y = \frac{\bar{y}}{\bar{D}}, \qquad u = \frac{\bar{u}}{\bar{u}_o}, \qquad v = \frac{\bar{v}}{\bar{u}_o}, \qquad p = \frac{\bar{p}}{\bar{\rho}\bar{u}_o^2} \tag{5}$$

where $\overline{u_0}$ is the most extreme speed of the blood at the passageway of the channel and $\bar{D}$ is the separation between the two plates at the passageway.

By substitution of (5) to conditions (1) to (3), the accompanying arrangement of conditions is inferred

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{6}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} - Mu + \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \tag{7}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) \tag{8}$$

The non-dimensional parameters going into the issue under thought are $\mathrm{Re} = \frac{\overline{D\rho u_0}}{\bar{\mu}}$ (Reynolds number), $M = \frac{\bar{\sigma}\bar{B}^2\bar{D}}{\bar{u}_0\bar{\rho}} = \frac{Ha^2}{\mathrm{Re}}$ (Attractive parameter), where $Ha = \frac{\bar{\sigma}\bar{B}^2\bar{D}^2}{\bar{\mu}}$ is the Hartman number. The limit conditions are presently trans- shaped to:

$$\left.\begin{array}{ll} \text{Inflow} & (x = 0,\ -0.5 \le y \le 0.5):\ u = u(y),\ v = 0, \\ \text{Outflow} & \left(x = \bar{L}/\bar{D}\ \ -0.5 \le \bar{y} \le 0.5\right):\ \partial(R)/\partial x = 0, \\ \text{Upper plate} & (y = 0.5\ \ 0 \le x \le \bar{L}/\bar{D}):\ u = 0,\ v = 0, \\ \text{Lower plate} & (y = -0.5\ \ 0 \le x \le \bar{L}/\bar{D}):\ u = 0,\ v = 0, \end{array}\right\} \tag{9}$$

The parameter M , is the attractive parameter which is the proportion of the square of the Hartman number to the Reynolds Number [1, 2, 12]. It merits specifying here that when M is zero, the issue is decreased to the issue of a typical hydrodynamic stream in a channel with a stenosis.

## IV. GENERALIZED CURVILINEAR COORDINATE METHOD AND NUMERICAL APPROACH

A summed up non-orthogonal curvilinear organize approach with ξ and η as independent factors were utilized to define the arrangement of conditions for depicting complex geometries as the stenosis zone in this physical issue [13]. The non-dimensional equations can be composed as:

$$\frac{\partial U}{\partial \xi} + \frac{\partial V}{\partial \eta} = 0 \tag{10}$$

$$\frac{\partial(Uu)}{\partial \xi} + \frac{\partial(Vu)}{\partial \eta} = -\left(y_\eta\frac{\partial p}{\partial \xi} - y_\xi\frac{\partial p}{\partial \eta}\right) - JMu + \frac{1}{\mathrm{Re}}\frac{\partial}{\partial \xi}\left(q_1 u_\xi - q_2 u_\eta\right) + \frac{1}{\mathrm{Re}}\frac{\partial}{\partial \eta}\left(q_3 u_\eta - q_2 u_\xi\right) \tag{11}$$

$$\frac{\partial(Uu)}{\partial \xi} + \frac{\partial(Vu)}{\partial \eta} = -\left(x_\xi\frac{\partial p}{\partial \eta} - x_\eta\frac{\partial p}{\partial \xi}\right) + \frac{1}{\mathrm{Re}}\frac{\partial}{\partial \xi}\left(q_1 v_\xi - q_2 v_\eta\right) + \frac{1}{\mathrm{Re}}\frac{\partial}{\partial \eta}\left(q_3 v_\eta - q_2 v_\xi\right) \tag{12}$$

Where U, V are the velocity components at $\xi$ and $\eta$ directions and the coefficients $q_1$, $q_2$ and $q_3$ are given as:

$$U = y_\eta u - x_\eta v, \quad V = x_\xi v - y_\xi u \tag{13}$$

$$q_1 = \frac{1}{J}\left(x_\eta^2 + y_\eta^2\right),\ q_2 = \frac{1}{J}\left(x_\xi y_\eta + y_\xi x_\eta\right)\ q_3 = \frac{1}{J}\left(x_\xi^2 + y_\xi^2\right) \tag{14}$$

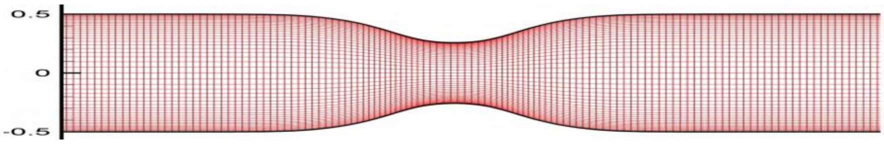

Figure 2: Computational matrix at the stenotic district, suitable extending of the framework was connected. Near the dividers the matrix was better and ended up coarser at the focal point of the area.

A stunned lattice course of action was additionally utilized in our approach, offering advantages over the gathered plan particularly in convective ruled streams [7]. A fitting extending of the matrix was connected where the computational lattice was better near the dividers and wound up coarser near the focal point of the space, Figure 2. The upwind plan is acquainted with the discretized conditions to conquer issues concerning high convection terms in the energy. The upwind plan gives a first request precision rather than second request that the dispersion terms hold, prompting inaccurate arrangement when the neighborhood speed inclinations are huge. To beat this issue the "conceded redress" approach was used. In this plan, higher-arrange transition approximations (focal contrast conspires) are processed unequivocally and this estimation is joined with verifiable low-arrange approximations (upwind distinction plot) [4].

The semi-understood technique for weight connected conditions (SIMPLE) was utilized to illuminate the arrangement of the energy and weight redress conditions. Picking the under-unwinding factors in SIMPLE strategy could be trying, since these elements are issue particular. In the present examination, the unwinding factor utilized for the energy conditions was equivalent to 0.7 while for the weight amendment conditions it was equivalent to 0.3. More insights about the SIMPLE calculation can be discovered somewhere else [4, 8].

## V. RESULTS AND DISCUSSION

The above depicted numerical method in summed up curvilinear directions was ap-utilized to illuminate the arrangement of conditions (6) to (8), under the fitting limit conditions (9). To continue to the deduction of the numerical outcomes, it is important to dole out qualities to the dimensionless parameters going into the issue under consideration, such as the Reynolds number, Re, and the attractive parameter, M . Re was thought to be equivalent to 400, which relates to the pinnacle systolic Re in a coronary course. The electrical conductivity $\bar{\sigma}$ of stationary blood was estimated to be 0.7 Sm−1 [6].

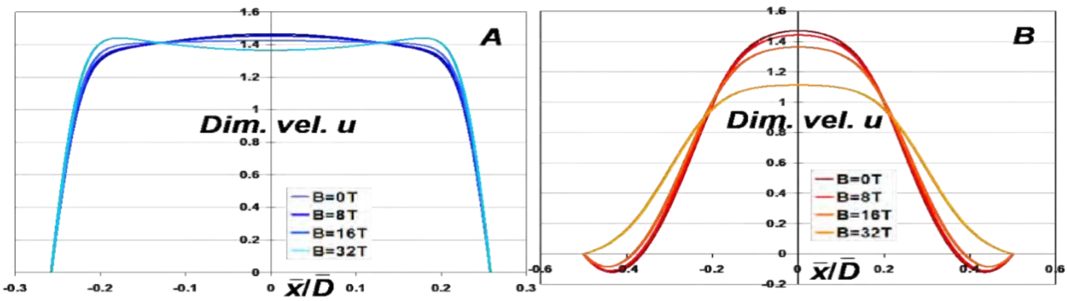


Figure: 3: Effect of magnetic field on the dimensionless velocity at two different locations for various magnetic field intensities: (A) At the center of the stenosis. (B) Downstream the stenosis by one diameter $\bar{D}$ from the center of the stenosis.

The electrical conductivity of streaming blood is constantly more noteworthy than that of the stationary. The augmentation for medium shear rates is around 10% and increments with the addition of the hematocrit [5]. In the present investigation the electrical conductivity of blood was expected, for effortlessness, temperature–autonomous and equivalent to 0.8 Sm−1 as in [14]. Four distinct estimations of the attractive acceptance, $\bar{B}$ , were considered, ( $\bar{B}$ = 0, 8, 16 and 32 T ), where for $\bar{B}$ = 0 we have the hydrodynamic case. These estimations of attractive enlistment compare to attractive parameter M = 0 for the hydrodynamic case and M = 36.6, 146.3, 585.1 for the situations where $\bar{B}$ = 8, 16, 32 T, separately and for $\bar{\mu}$ = 0.0035 kg/ms. Figure. 3 demonstrates the impact of the attractive field and the attractive parameter on the dimensionless speed at two unique areas in the computational space, at the focal point of the half stenosis, area A, and downstream of the stenosis by one measurement $\bar{D}$ from the focal point of the stenosis, area B (Figure 1). The outcomes demonstrated that the dimensionless speed extent does not change generously at location A with the expansion of the attractive field. Notwithstanding, downstream of the stenosis, area B, use of the attractive field results in a considerable decrease of the dimensionless speed extent and a decrease of the stream inversion. These discoveries are critical and propose a huge stream decrease reducing the hydrodynamic anxieties downstream of the supply route stenosis.

These outcomes are featured in Figure 4. The figure portrays the impact of the attractive field on the distribution zone downstream of the stenosis. It is evident that the expansion of the attractive field generously decreases the distribution zone prompting a decrease of the hydrodynamic worries at this district. A standout amongst the most critical stream attributes is the neighborhood skin contact coefficient, $c_f$ . This amount can be characterized by

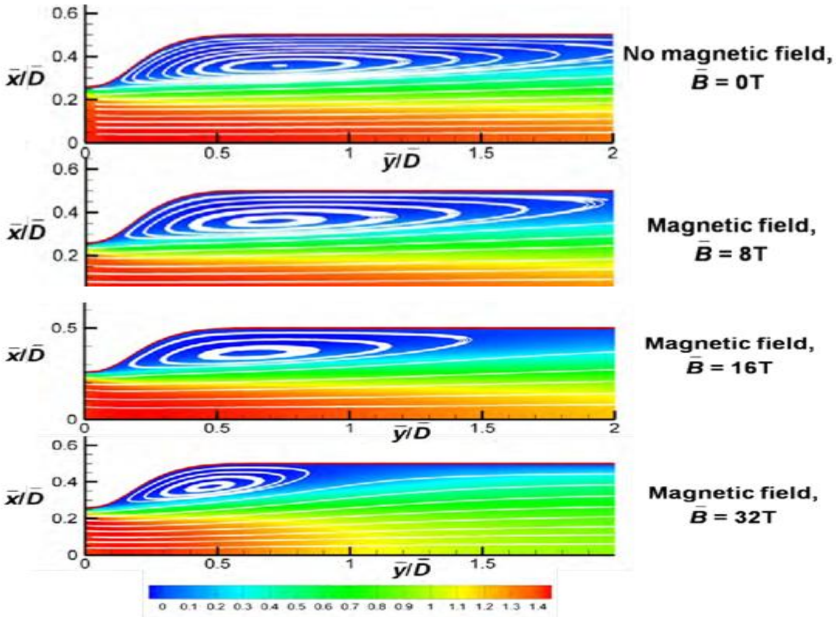


**Figure 4: Effect of magnetic field on the dimensionless velocity and recirculation blood zones downstream of the stenosis.**

| Mag.intensity B | $c_f$ at loc. A | $c_f$ at loc. B | $u_{max}$ | $\Delta p$ |
|---|---|---|---|---|
| 0 T | 0.273 | 0.15 | 1.536 | 0.8 |
| 8 T | 0.277 (1.5%) | 0.145 (-3.3%) | 1.524 (-0.8%) | 0.9 |
| 16 T | 0.288 (5.5%) | 0.13 (-13.3%) | 1.494 (-2.7%) | 1.6 |
| 32 T | 0.313 (14.7%) | 0.025(-83.3%) | 1.457(-5.1%) | 4.6 |

Table 1: Local skin friction coefficient, $c_f$ , maximum dimensionless velocity, $u_{max}$ and dimensionless pressure drop, $\Delta p$ , for hydrodynamic and MHD cases. The following relation:

$$C_f = \frac{2\bar{\tau}_w}{\bar{\rho}\bar{u}_0^2} \tag{15}$$

Where $\bar{\tau}_w = \bar{\mu}.(\partial\bar{u}/\partial\bar{y})\,|_{\bar{y}=-\bar{D}/2,\bar{D}/2}$ is the divider shear worry between the liquid and the plates. Table.1 condenses the neighborhood skin grinding coefficient, $c_f$ , variety at the two unique areas of Figure 3. It is seen that the nearby skin contact coefficient, $c_f$ , increments at area A (focal point of the stenosis) yet generously diminishes downstream of the stenosis at area B because of the attractive field connected consistently all through the stenosed channel. Table. 1 likewise reports the decrease of the most extreme speed extent because of the attractive field impact.

The outcomes concerning the speed and skin erosion coefficient demonstrate that the stream is obviously impacted by the attractive field. A considerable decrease of the vortices shaped downstream of the stenosis was watched, fundamentally influencing the stream qualities. Be that as it may, the weight drop in the space essentially expanded as the attractive parameter expanded. This weight augmentation is because of the magneto-hydro dynamic weight incited to the stream field from the attractive field as delineated in Table 1. This weight drop increment requires promote examination and it would be a subsequent stage of this investigation. The presentation of the vitality condition would be additionally a future advance of this examination. The vitality condition could give essential data about the temperature increment of the biofluid (blood) because of the attractive parameter increment.

Defenseless plaque burst typically happens towards the luminal side of the plaque and is reliant on the sinewy top thickness and nearness of microcalcifications [10]. Since crest speeds, and in this way focuses, are seen in the stenotic area as delineated in Table.1A, decrease in downstream anxieties (Table.1B) may not moderate the danger of break of the sinewy top. Then again the decrease in the measure of the distribution zones under an attractive field may help diminish the frequency of thrombosis in the stenosis area. The potential MHD consequences for blood moving through the area of intrigue could be a little change in consistency or even platelet testimony and cell harm. Be that as it may, these impacts require facilitate trial examination past the extent of this investigation.

The above outcomes show that utilization of an attractive field on the stream of a biomagnetic liquid could be helpful for therapeutic and building applications prompting another road of stream control in stenotic areas.

## VI. CONCLUSIONS

The biomagnetic liquid (blood) stream in a channel with symmetric stenosis is contemplated. The numerical arrangement of the issue is gotten by the improvement of a numerical strategy in view of the limited volumes discretization plot in curvilinear directions for the discretization of the nonlinear arrangement of PDEs administering the MHD blood stream. This approach depends on the improvement of a semi-understood numerical system, changes, extending of the lattice, and legitimate development of the limit conditions on the strong dividers. The proposed model can foresee the decrease of blood's speed field and the difference in the distribution zones downstream of the stenosis. The skin rubbing coefficient, $c_f$ , was privately expanded at the stenosis territory and fundamentally lessened at the distribution zones as the attractive field power was expanded. The proposed model could anticipate neurotic conditions, for example, the stenotic coronary arteries and give the open door for new roads of stream control at these stenotic locales without the need of in vivo testing of the patient.

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