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The Boundary Theory between Laminar and Turbulent Flows

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Abstract—The basis of this paper is the assumption, that graviton is a measurable entity of molecular gravitational acceleration and this is not a hypothetical entity. The adoption of this assumption as an axiom is tantamount to fully opening the previously locked door to the boundary theory between laminar and turbulent flows. It leads to the theorem, that the division of flows of Newtonian (viscous) fluids into laminar and turbulent is true only, if the fluid is influenced by a powerful, external force field. The mathematical interpretation of this theorem, presented in this paper shows, that the boundary between laminar and turbulent flow can be determined theoretically. This is a novelty, because thus far the said boundary was determined empirically only and the reasons for its existence were unknown.

Keywords**—**Freed gravitons, free gravitons.

I. Introduction

THE fundamental flows division of Newtonian (viscous) liquids on laminar and turbulent has been known in fluid mechanics since long. Those flows are separated by the so-called boundary Reynolds number Re_{gr}. The said division was discovered empirically approximately in 1883 by Osborne Reynolds (1842-1912), a British physicist and engineer, author of brilliant works on hydraulics and lubrication. He monitored in his experiments, the behavior of a marker (colorant) in water flowing in a tube. When $Re \leq Re_{gr}$, the colored streak moved alongside the tube's axis and continued to be coherent and well visible. As soon as $Re > Re_{gr}$, the streak dissolved and disintegrated quickly, as a result of mixing with the surrounding mass of fluid. Thus far, Reynolds discovery did not have a theoretical interpretation, and the underlying cause and the mechanism of the said phenomenon is still not understood [1].

For explanation of said phenomenon, the recently discovered basis of dualism theory of Newtonian fluids motion [2] will be extended. This will be obtained, inter alia, by introducing the principle of constancy and uniformity of internal opposition forces field to fluid state physics (fluid mechanics). The intensity of opposition forces field is equal to the intensity of gravitational forces field. The said principle provides a basis for the theoretical formulation of a general description of the mechanism of creation of the boundary between laminar and turbulent flows, as presented in this paper. The said mechanism is presented using the example of a steady, axially-symmetric laminar flow of Newtonian fluid through a straight-axis duct of a circular cross-section and the radius R, under the action of natural gravitational forces.

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This paper is the second one in a series of papers describing the possibilities of the theory of dualism in fluid mechanics. The deliberations presented here are a continuation of those contained in paper No. 1 [2]. The dependencies assumed therein are accepted as true here. Therefore, the author wishes to remark that in order to fully understand the content of this paper No. 2 it is necessary to have read paper No. 1.

II. Selected Issues Presented in Paper No. 1 [2]

The previous paper introduced to fluid state physics (fluid mechanics) a new interpretation of physical phenomena taking place in fluid in motion. It introduced the basis for the dualism theory which says, that each flow has its own internal motion structure, which means clearly defined motion organization, not "molecular chaos", known from static conditions. The paper coined the concept of organization of vector fields of forces and momentums. It showed that each Newtonian fluid flow is dual in character and that it consists of active forces C and opposition forces L, which are equal to one another. The model of the theory was presented in Fig. 8/1 (figures number in accordance with paper No 1). Further on, model phenomena were described by means of mathematical formulae.

The previous paper introduced to fluid mechanics the model of cycloidal motion. Its usefulness was exemplified by a description of a steady, axially-symmetric peaceful flow of homogeneous Newtonian fluid through a straight-axis duct of a circular cross-section under the action of constant natural gravitational forces. The paper presented the basic dependencies of the dynamic vector field resulting from the model (equation numbers in accordance with the paper No. 1):

$$V_{max} = 2\,\omega\,\frac{H}{2} = 2\;V_{śr} = \frac{g\,J\,H^2}{4\,\nu} \tag{1-52}$$

$$\omega = \frac{V_{max}}{H} = \frac{2\,V_{śr}}{H} = \frac{g\,J\,H}{4\,\nu} \tag{1-53}$$

$$a_{max} = \omega^2\,\frac{H}{2} = \frac{V_{max}^2}{2\,H} = \frac{2\,V_{śr}^2}{H} = \frac{g^2\,J^2\,H^3}{32\,\nu^2} \tag{1-54}$$

Paper No. 1 describes the influence of natural, external gravitational forces on the formation of internal flow structure. As a result of that action, the fluid is the carrier of natural gravitons. The point of application of each graviton is a single fluid molecule within the range of the gravitational field. Thus, the mass of molecules with gravitons creates within the fluid its own internal gravitational field of constant intensity z = 0,25g ≈ 2,45 m/s^2.

In static conditions, the fluid mass is dominated by "molecular chaos". In dynamic conditions of peaceful flow (0 < Re < 1962) that "chaos" is gradually oriented by opposition forces, defined by the characteristic parameter $a_{max.L}$. However, in the case of peaceful flows, such opposition forces are equal to active forces, and thus $a_{max.L} = a_{max.C}$.

The orientation of "chaos" consists in embedding free gravitons into the structure of opposition forces. The degree of such orientation is measured by the coefficient "U" whose growth is proportional to the growth of flow dynamics. At the threshold flow (Re = 1962) the orientation is completed.

On the pipe wall the structural accelerations (forces) are always directed centripetally.

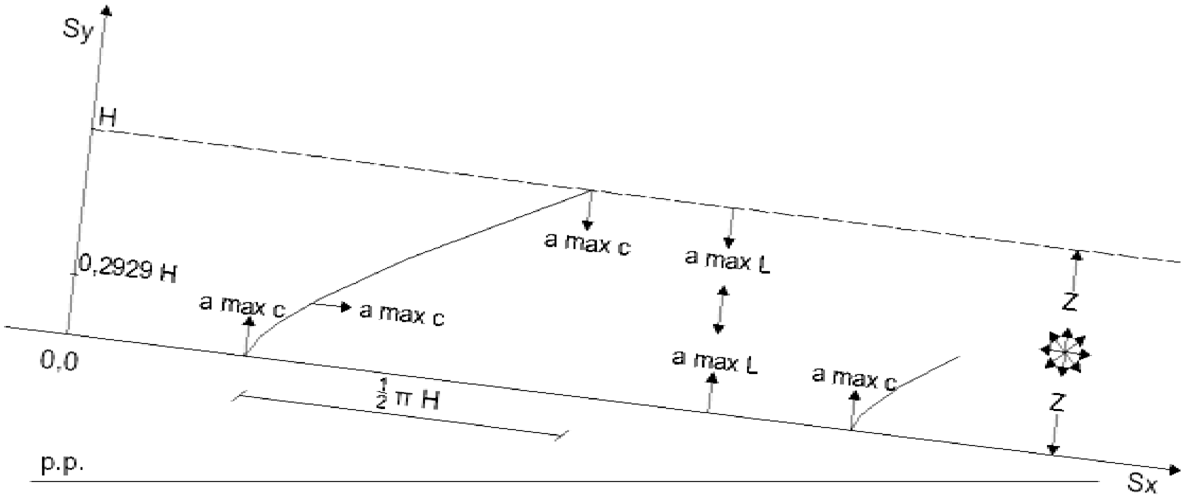

Fig. 8/1. Forces (accelerations) field structure of axially-symmetric peaceful flow.

A. Supplementary Information to Paper No. 1

If one assumes, that internal opposition forces field is created by free gravitons and by gravitons linked to the motion structure (which create laminar motion forces), it is easy to realize, that the principle of constancy and uniformity of the internal field of opposition forces applies to peaceful flows. In the entire mass of fluid in motion the intensity of that field is exactly the same, and its value is z = 0,25g ≈ 2,45 m/s^2, in accordance with the following dependency:

$$a_{max.L} + z(1 - U) = a_{max.pr} = z = 0{,}25g \qquad (2\text{-}1)$$

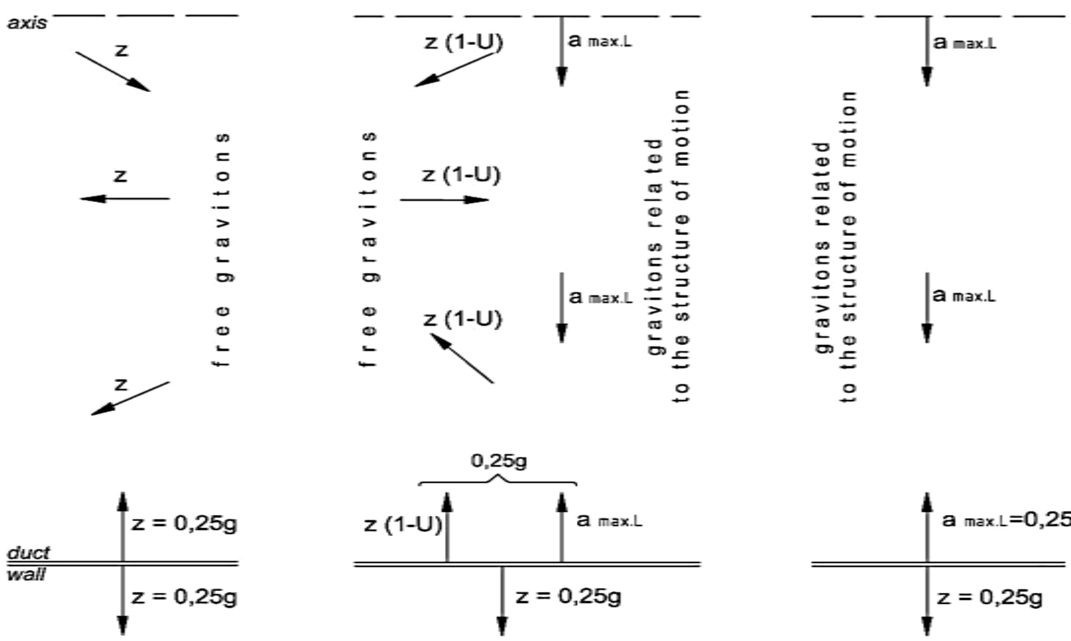

Fig. 1/2. „Molecular chaos", Re = 0 Fig. 2/2. „Partial molecular chaos" 0 < Re < 1962 Fig. 3/2. „Molecular order" Re = 1962

In the whole range of peaceful flows, there is a balance between internal opposition forces and gravitational action forces on the wall of the duct. This leads to the lack of side surface resistance (phase boundary, duct wall) without regard to its "roughness".

B. Classical Definition of Graviton

Graviton – a hypothetical elementary particle, a quantum of energy, which has no rest mass or electric charge, but is able to transmit the gravitational interaction.

C. New Definition of Graviton

Graviton – the unit of gravitational field, measured by the value of gravity acceleration, spatially oriented in homogeneous, chemical composition and mechanical properties monophase systems, outwards and perpendicular directed to the phase boundary in multiphase systems. On Earth conditions, the spatially oriented graviton has a constant value $g \approx 9{,}81\ m/s^2$, the directed outwards graviton has a value z = 0.25 g. Graviton applied to the molecule (together with molecule) is converted to the dynamic impact of molecular unit.

On Earth conditions, the earthly matter (solid, fluid) is the energy carrier of gravitational field. This can be seen in natural oscillatory motion of molecules of matter. Graviton applied to the natural oscillate molecule (together with oscillating molecule) is converted on the unit of carrier or accumulator of gravitational interaction and is converted as a quantum of energy stored in single earthly matter molecule. Physical manifestation of gravitons existence is, among others, the "molecular chaos", observed experimentally in fluids, under static conditions.

The interactions between molecular interaction dynamic forces (and between gravitons) are either spatial or directional and always are directed centrifugally

III. Non-Peaceful Flows and their Components

The notion of non-peaceful flows was partially defined in the previous paper [2]. In general, non-peaceful flows are classified as laminar flows ($0 < Re \leq Re_{gr}$), but due to their specific nature, they constitute a separate group of such flows, that stays within the following range: $Re_{pr} < Re \leq Re_{gr}$. In the analyzed case (steady, axially-symmetric laminar flow of Newtonian fluid through a straight-axis duct of a circular cross-section and radius R, under the action of natural gravitational forces), the value of the threshold Reynolds number is $Re_{pr} = 1962$. The boundary Reynolds number Re_{gr} is different. It defines the laminar flow boundary. This number belongs to the set of terminal numbers, which are the subject of discussion in this paper.

The dualism theory shows, that the structure of motion, created for the purposes of peaceful flows becomes ineffective in the case of non-peaceful flows. This structure must be redeveloped for flows Re > 1962, because there are no sources of new, free gravitons in the fluid. This means, that the opposition forces are not capable of further growth. Further increase in the value of vector $a_{max.L}$ ($a_{max.L} = zU$), coupled with the growth of flow dynamics, becomes impossible. Changes are thus necessary.

And such changes take place. In non-peaceful flows the vector of opposition forces field intensity $a_{max.L}$, is conventionally transformed into the vector of the field of primary above-threshold forces field intensity $a_{max.RPL}$. It turns out, that the said vector is not capable of further growth, despite growing flow dynamics. To the contrary, its value decreases, because the part of gravitons – previously embedded in the motion structure – are spontaneously freed. However, these gravitons do not come from the natural, terrestrial gravitational field. They are freed and require external forces to sustain their existence. They create a new field of forces whose intensity is defined by a characteristic product z(1-U1).

At threshold flow (Re = 1962) all gravitons are embedded in the structure of opposition forces (U = U1), and complete "molecular order" prevails. Opposition forces L constitute a half of all structure's forces. The other half is constituted by active forces C [2].

In the new conditions of non-peaceful flows, the opposition forces become the forces of primary above-threshold motion. Despite the growth in flow dynamics, those forces do not increase, but they generate freed gravitons. The field intensity of those forces is the sum of $a_{max.RPL} + z(1\text{-}U1) = 0{,}25g$. It pervades the entire mass of fluid in motion (in the analyzed case: mass of fluid in a tubular duct of the radius R).

Active forces do not face such limitations. At the same time they increase quickly and become the primary creation motion forces. The structure of such motion is subject to significant changes. It also pervades the entire mass of fluid, but it is divided into two overlapping components, A and B (two partial field forces). The intensity of both fields is diverse and amounts to $a_{max.RA}$ and $a_{max.RB}$, respectively. As a result of such division, the coaxial flow core with the radius R1 is created. Within that core the primary creation motion forces additionally generate the secondary gravitational field and secondary motion, which will be discussed in detail in the forthcoming paper No. 3.

The flow core is surrounded by the flow boundary layer, constituting field B of the primary creation motion. It takes the form of a coaxial ring. The core wall, separating core from boundary layer, creates a fluid-to-fluid monophase boundary, invisible to the naked eye. It has its own specific properties, such as: lack of roughness, flexibility and specific tightness, which allow for clear separation of forces generated within the core from those within the boundary layer.

IV. Primary Above-Threshold Motion

The primary above-threshold motion derives from the laminar motion of threshold flow that creates the field of opposition forces. In the new conditions the said motion transforms from purely laminar to cycloidal and laminar, inheriting the equality of overlapping organizational fields. Therefore, it takes only one vector to describe its active forces and opposition forces, namely the vector of primary above-threshold motion intensity $a_{max.RPL}$. The momentum field takes a characteristic parabolic shape in the longitudinal section.

A. The Share of the Primary Above-Threshold Motion Component in the Entirety of Non-Peaceful Flow

The entirety of the steady primary non-peaceful flow consists of: primary above-threshold motion denoted as L_R and the primary creation motion denoted as C_R. It has been assumed that the mean value of primary flow is the sum of its components, in accordance with the following formula:

$$V_{śr.R} = V_{śr.RPL} + V_{śr.RC} = L_R \cdot V_{śr.R} + C_R \cdot V_{śr.R} = \\ = (L_R + C_R) \cdot V_{śr.R} \quad (2\text{-}2)$$

where:

L_R – share of the primary above-threshold motion in the entirety of primary motion,

C_R – share of the primary creation motion in the entirety of primary motion,

$L_R + C_R = 1$.

B. Active Forces Creating the Structure of Primary Above-Threshold Motion

In line with the principles of peaceful flow modeling [2] it was assumed, that the value of the forces creating the structure of the primary above-threshold motion field is equal to Newtonian forces, in accordance with the following formula:

$$P_{RPL} = \rho F a_{max.RPL} = \pi R^2 \rho \frac{V^2_{max.RPL}}{2R} = \\ = \rho \cdot \frac{2 L_R^2 V^2_{sr.R} F}{R} \quad (2\text{-}3)$$

where: the value of motion force field intensity $a_{max.RPL}$ decreases proportionally to the increase in the dynamics of the above-threshold flow measured with the Reynolds number of primary flow Re_R, in accordance with the following formula:

$$a_{max.RPL} = \frac{g}{4} \frac{a_{max.RPL}}{a_{max.pr}} = \frac{g}{4} \cdot \frac{2 L_R^2 V^2_{sr.R}}{R} \cdot \frac{2R}{V^2_{sr..pr.R}} = \\ = \frac{g}{4} \cdot \frac{4 L_R^2 Re_R^2}{1962^2} = \frac{g}{4} \cdot \left(\frac{L_R Re_R}{981} \right)^2 \quad (2\text{-}4)$$

C. The Release of Gravitons from the Primary Above-Threshold Motion Structures

As shown in paper No. 1 [2], the threshold flow (Re_{pr} = 1962) is characterized by fact, that all of gravitons in fluid are embedded in the dynamic motion structure (U = U1 = 1).

In primary above-threshold flows (Re > 1962) the process of secondary releasing of gravitons from that motion structure (U1 < 0) takes place. Within the mass of fluid, freed gravitons create areas of “secondary molecular chaos” with a mean intensity of z(1-U1). However, this does not change the intensity of opposition forces field, whose value is z = 0,25g, in accordance with the following formula:

$$a_{max.RPL} = U1 \cdot a_{max.pr} \quad (2\text{-}5)$$

where:

$$a_{max.RPL} + z(1 - U1) = a_{max.pr} = z = 0{,}25g \quad (2\text{-}6)$$

V. Principle of Constancy and Uniformity of the Internal Field of Opposition Forces

As already mentioned, the primary above-threshold motion (non-peaceful flows) derives from the laminar peaceful flow motion. That motion pervaded the entire fluid mass and created – together with free gravitons – a field of opposition forces of constant intensity equal to 0,25g. The deliberations presented above show, that the forces of above-threshold motion also create (in this case – together with freed gravitons) a force field pervading the entire mass of fluid, and such field is uniform and has a constant intensity of 0,25g.

The above is a continuation of the principle of constancy and uniformity of the internal field of opposition forces formulated for peaceful flows (above). But the structures of both flows are different. The structure of internal opposition forces are pervaded by free gravitons (peaceful flows). The structure of internal primary above-threshold forces are now pervaded by freed gravitons (primary non-peaceful flows). In primary non-peaceful flows there is an additional differentiation. The orientation of freed gravitons, pervaded by core is spatial, pervaded by boundary layer is directional. Freed gravitons in core are transformed into free gravitons.

The above means that the principle of constancy and uniformity of the internal field of opposition forces is applicable to the entire range of laminar flows, both peaceful and non-peaceful. This principle becomes the decisive condition in determining the boundary between laminar and turbulent flows, being the subject of this paper. It is the main reason, why exists such boundary.

The existence of the said principle is a logical consequence of the fact, that in Earth conditions fluid in motion is influenced by a strong, external natural and uniform gravitational field of intensity z = 0,25g. The said influence is reflected by the constancy and uniformity of the internal field of accelerations in laminar flows. In homogeneous fluids are also applied the principle of constancy and uniformity of internal opposition forces fields.

The homogeneous fluid is neither delaminated nor broken on pieces under the static conditions, under the influence of the natural gravity forces. In static conditions its mass is uniformity. A uniform is also its internal field acceleration, as well as its internal force field.

VI. Primary Creation Motion

The primary creation motion is, beside primary above-threshold motion, another component of non-peaceful flows. This motion derives from cycloidal (semi-cycloidal) motion of threshold flow, creating a field of active forces within it. In new conditions, this motion pervades the entire mass of flowing fluid in a tubular duct of the radius R. It is divided into two components; A and B (two partial vector fields). Each of those components takes the form of a ring of the thickness H_{RA} and H_{RB} respectively, where $H_{RA} \geq R$ and $H_{RB} \leq R$. The intensity of those both fields is diversified and amounts to $a_{max.RA}$ and $a_{max.RB}$, respectively. As a result of such division the flow core with the radius R1 is created.

As a reminder [2], in the threshold flow ($Re_{pr} = 1962$) both partial fields overlap in space. Their respective intensities were equal ($a_{max.pr.RA} = a_{max.pr.RB} = 0.5\ a_{max.pr.RC}$). The conventional boundary between both fields goes alongside the duct axis, which means, that the thickness of both fields is identical ($H_{RA} = H_{RB} = R$). At the boundary of both fields the maximum velocities are equal to each other ($V_{max.pr.RA} = V_{max.pr.RB}$).

In non-peaceful flows ($Re_{pr} < Re \leq Re_{gr}$) the boundary between the two fields goes beyond the axis of the duct and moves towards its wall, as the Re value grows. It forms an axi-symmetric core of the radius $R1 = (H_{RA} - H_{RB})/2 = H_{RA} - R$, in the axis of the duct. Outside the core a boundary layer of thickness H_{RB} is formed, where $H_{RA} + H_{RB} = 2R$ and $F_{RA} + F_{RB} = 2F$. At the boundary of both fields the maximum velocities continue to be equal ($V_{max.RC} = V_{max.RA} = V_{max.RB}$).

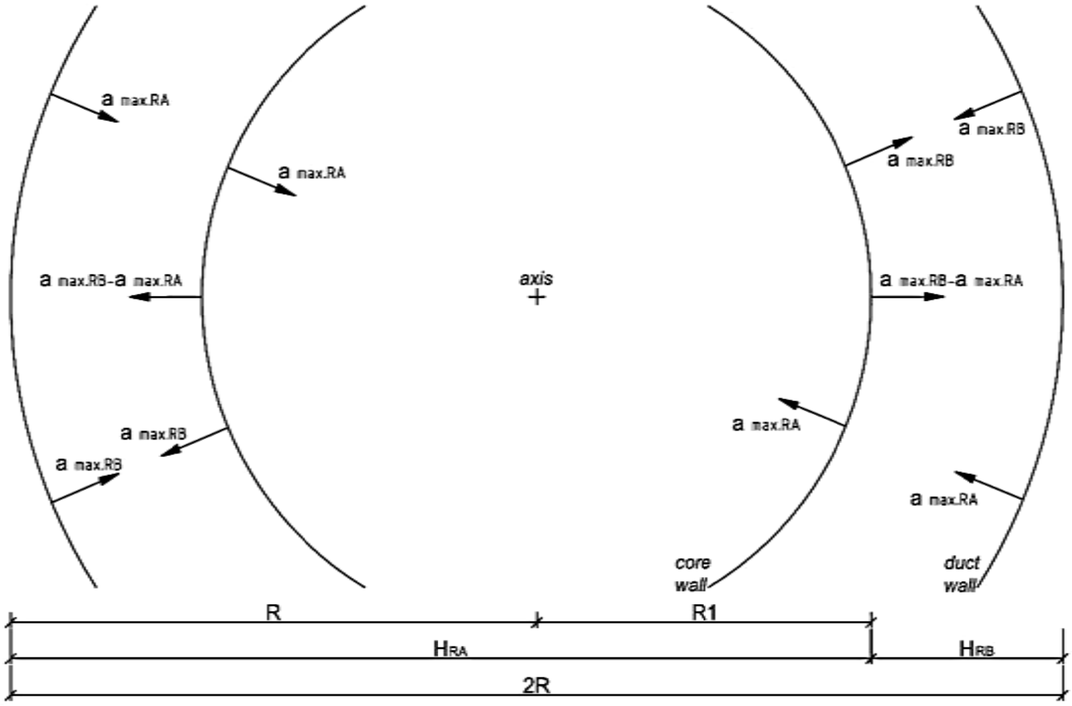

Fig. 4/2. Components of the primary creation motion.

A. Active Forces Forming the Structure of Primary Creation Motion

Bearing in mind the principles of modeling peaceful flows [2] it was assumed that the value of the forces forming the structure of the field of the primary creation motion is equal to Newtonian forces, in accordance with the following formula:

$$\begin{aligned} P_{RC} &= \frac{\rho}{2}\left(F_{RA}a_{max.RA} + F_{RB}a_{max.RB}\right) = \\ &= \pi\left(2R^2 - 2RH_{RA} + H_{RA}^2\right)\rho\frac{V_{max.RC}^2}{4H_{RA}} + \\ &+ \pi\left(2RH_{RB} - H_{RB}^2\right)\rho\frac{V_{max.RC}^2}{4H_{RB}} = \\ &= \rho\cdot\frac{C_R^2\ V_{sr.R}^2\ F}{R}\cdot\left(\frac{F_{RA}}{F}\frac{R}{H_{RA}} + \frac{F_{RB}}{F}\frac{R}{H_{RB}}\right) \end{aligned} \tag{2-7}$$

where: the intensity of the motion's field force a_{maxRC} reflects the dynamics of the above-threshold flow, measured by the

Reynolds number of the primary flow Re_R, in accordance with the following formula:

$$a_{max.RA} = \frac{g}{8} \cdot \frac{a_{max.RA}}{a_{max.pr.RA}} = \frac{g}{8} \cdot \frac{2\,C_R^2\,V_{sr.R}^2}{H_{RA}} \cdot \frac{2\,R}{V_{sr.pr.R}^2} = = \frac{g}{8} \cdot \frac{R}{H_{RA}} \cdot \frac{4\,C_R^2\,Re_R^2}{1962^2} = \frac{g}{8} \cdot \frac{R}{H_{RA}} \cdot \left(\frac{C_R\,Re_R}{981}\right)^2 \qquad (2\text{-}8)$$

$$a_{max.RB} = \frac{g}{8} \cdot \frac{a_{max.RB}}{a_{max.pr.RB}} = \frac{g}{8} \cdot \frac{2\,C_R^2\,V_{sr.R}^2}{H_{RB}} \cdot \frac{2\,R}{V_{sr..pr.R}^2} = = \frac{g}{8} \cdot \frac{R}{H_{RB}} \cdot \frac{4\,C_R^2\,Re_R^2}{1962^2} = \frac{g}{8} \cdot \frac{R}{H_{RB}} \cdot \left(\frac{C_R\,Re_R}{981}\right)^2 \qquad (2\text{-}9)$$

B. Primary Creation Motion as a Builder of Core Wall

The structure of the primary creation motion is characterized by the wall separating its components A and B. The said wall also divides the flow core from the boundary layer. For the following arguments it is important that maximum velocity vectors of both fields (A and B) of the primary creation motion are equal to each other:

$$V_{max.RC} = V_{max.RA} = V_{max.RB} \qquad (2\text{-}10)$$

This makes for Re > 1962, that the intensities of accelerations in both fields (A and B) are different. On the duct wall, the perimeter dynamic pressure of centripetal action is formed. Its unitary intensity is equal to the sum of intensities of both fields of the primary creation motion ($a_{max.RB}$ + $a_{max.RA}$). On the core wall, perimeter dynamic pressure of centrifugal action is formed. Its unitary intensity is equal to the difference of intensities of both fields of the primary creation ($a_{max.RB}$ - $a_{max.RA}$). Its value depends on the Reynolds number of the primary flow Re_R and is equal to:

$$a_{max\,RB} - a_{max.RA} = \frac{g}{8} \cdot \frac{R \cdot (H_{RA} - H_{RB})}{H_{RA} \cdot H_{RB}} \cdot \left(\frac{C_R\,Re_R}{981}\right)^2 \qquad (2\text{-}11)$$

VII. Secondary Gravitational Field

It follows from the arguments presented above, that within the range of non-peaceful flows, the primary creation motion forces form the motion structure of two different fields: the core field and the boundary layer. The intensity of both those fields grows together with the flow dynamics, but that growth is uneven (it is faster in the boundary layer and slower in the core). Thus, a difference in the intensity of both fields is created and it grows together with the flow dynamics.

Such difference in intensities on both sides of core wall should theoretically affect the structure of internal field of opposition forces. The “dynamic vacuum”, that is the lower intensity of force field in the core in relation to the intensity of boundary layer, on the value of ($a_{max.RA}$ - $a_{max.RB}$), should theoretically cause centripetal transverse motion of the fluid’s molecules and thus turbulence of the flow. In practice such phenomenon occurs, but only in unsteady flows. We observe them experimentally, for example, each time during draining the water from the bathtub. However, at the same time, this phenomenon does not appear in steady flows, which is confirmed experimentally as well. So, what is the key to solving this theoretical contradiction in unsteady motion?

The said key, in steady flows, is the mentioned principle of constancy and uniformity of the internal field of opposition forces which stipulates, that in whole mass of fluid in motion the intensity of that field must be exactly the same, and must amount to 0,25g. It should be added, that the core field of active forces is built in an area, previously occupied by internal field of opposition forces of constant intensity ($a_{max.RPL}$ + z(1- U1) = 0,25g). If the “dynamic vacuum” zone will be pervaded with gravitons, then reformed core will take the form modeled on natural terrestrial gravitational field, which means that the following is true:

$$z_1 = (a_{maxRB} - a_{maxRA}) + a_{maxRPL} = 0{,}25g \qquad (2\text{-}12)$$

Leaving the primary creation motion forces aside, a new situation arises in core, where the gravitational field intensity of the secondary flow is equal to the intensity of natural, terrestrial gravitational field. In this case the opposition forces are transformed into ampholytes which, depending on situation, are converted either on vectors $a_{max.RPL}$ or into spatially oriented freed gravitons, formed on the model of free gravitons.

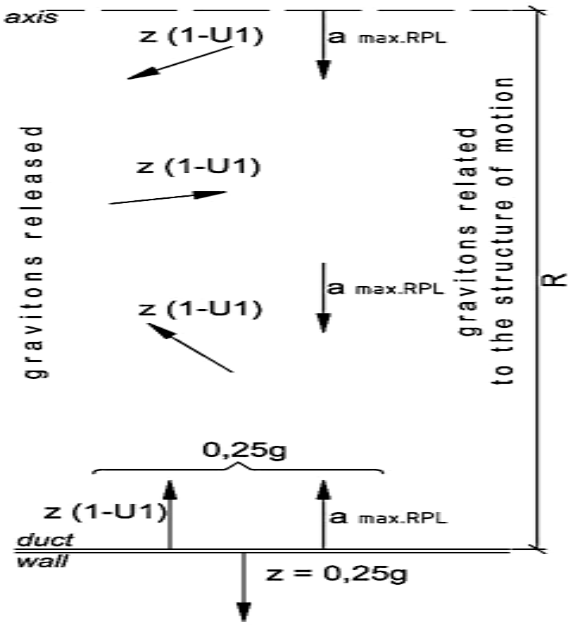

Fig. 5/2. Components of the primary field of opposition forces (U1 < 1)

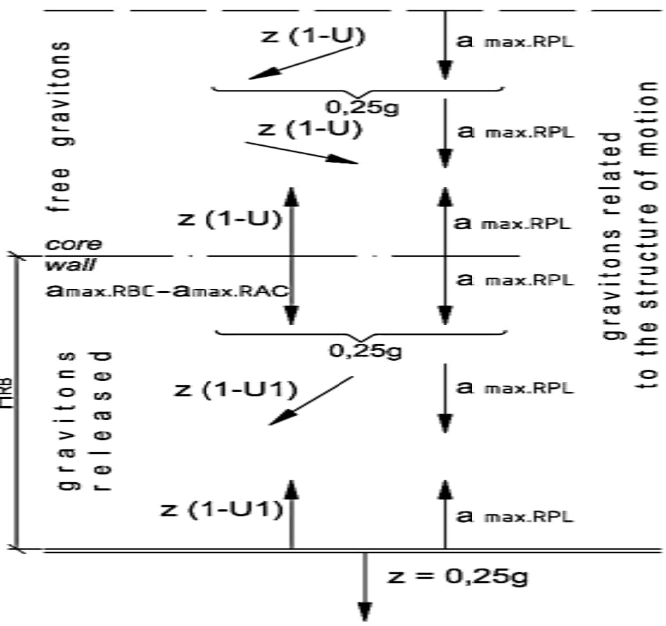

Fig. 6/2. Components of the primary field of opposition forces and the secondary gravitational field (U = 0, U1 < 1)

In non-peaceful flows a new situation is created, where the boundary layer is pervaded partially by freed gravitons and partially by gravitons linked to the motion structure ($a_{max.RPL}$, U1 < 1). The core field (secondary gravitational field) is now pervaded partially by freed gravitons and partially filled by ampholytic vectors $a_{max.RPL}$. The sum of freed and ampholytic gravitons inside the core creates free gravitons (U = 0).

It should be remembered, that the secondary gravitational field in non-peaceful flows ($a_{max.RPL}$, U < 1) is formed by the forces of the primary motion, while the gravitational field in peaceful flows ($a_{max.L}$, U < 1) was formed by the forces of the natural terrestrial gravitational field. This means, that if the natural terrestrial gravitational field has thus far provided the basis for creating the primary motion, then the secondary gravitational field forms an ample basis for creating the secondary motion. The issue of the shape and structure of the secondary motion is not discussed here. It will be analyzed in detail in the next paper in the series.

VIII. Primary Boundary of Laminar Flows

The above mechanism of creation of the secondary gravitational field simultaneously describes the formation of limitations for such creation, which are identical to the limitations for the existence of laminar flows. It is obvious that the said limitations must grow together with the flow dynamics. The theoretical boundary of laminar flows is formed by rearranging the equation (2-12):

$$(a_{maxRB} - a_{maxRA}) + a_{maxRPL} = 0{,}25g \qquad (2\text{-}12)$$

The above rearrangement shows that:

$$\left[\frac{1}{8}\left(\frac{R}{H_{RB}} - \frac{R}{H_{RA}}\right)\left(\frac{C_R\,Re_R}{981}\right)^2\right] + \frac{1}{4}\left(\frac{L_R\,Re_R}{981}\right)^2 = \frac{1}{4} \qquad (2\text{-}13)$$

$$\left(\frac{R}{H_{RB}} - \frac{R}{H_{RA}}\right)C_R^2 + 2L_R^2 = 2\left(\frac{981}{Re_R}\right)^2 \qquad (2\text{-}14)$$

$$\left(2 + \frac{R}{H_{RB}} - \frac{R}{H_{RA}}\right)C_R^2 - 4C_R + 2\left[1 - \left(\frac{981}{Re_R}\right)^2\right] = 0 \qquad (2\text{-}15)$$

The plot of the function $C_R = f(H_{RA}/R, Re_R)$ defines the plot of the share of the primary creation motion in the entirety of the primary flow which grows together with the flow dynamics until:

$$C_R = \frac{2 - \sqrt{4 - 2\left(2 + \frac{R}{H_{RB}} - \frac{R}{H_{RA}}\right)\left[1 - \left(\frac{981}{Re_R}\right)^2\right]}}{2 + \frac{R}{H_{RB}} - \frac{R}{H_{RA}}} \qquad (2\text{-}16)$$

The equation makes numerical sense, which is true only if:

$$4 - 2\left(2 + \frac{R}{H_{RB}} - \frac{R}{H_{RA}}\right)\left[1 - \left(\frac{981}{Re_R}\right)^2\right] \geq 0 \qquad (2\text{-}17)$$

$$Re_R \le 981 \sqrt{1 + \frac{2\,H_{RA}\,H_{RB}}{R\left(H_{RA} - H_{RB}\right)}} \qquad (2\text{-}18)$$

The equation (2-18) allows one to define the set of primary, terminal Reynolds numbers $Re_{gr.RR1}$, arising from the existence of the primary motion, above which non-peaceful flows do not exist because of mathematical limitations stipulating, that the radicand of the square root must be non-negative. For such values of $H_{gr.RA}/R$, the value $Re_{gr.RR1}$ is as follows:

$H_{gr.RA}/R$	1,0	1,0700	1,1886	1,2441	1,2518	2,0
R1/R	0,0	0,0700	0,1886	0,2441	0,2518	1,0
$Re_{gr.RR1}$	∞	3827	2426	2174	2131	981

The above allows one to formulate the following theorem:

„If flowing fluid is affected by natural terrestrial gravitational forces, then it has its theoretical determinable initial phase, known as laminar flow”.

This theorem is not a discovery. It was similarly formulated by Osborne Reynolds nearly a century and a half ago. Yet the phrase “similarly” makes a significant difference in this particular case, as the above theorem introduces the theoretical boundaries of laminar flow. Thus, it introduces to the empirical division the previously unknown theoretical counterpart.

A. The Difference between Re_{gr} and $Re_{gr.RR1}$

Until now, for the analyzed example (steady, axially-symmetric laminar flow of Newtonian fluid through a straight-axis duct of a circular cross-section and radius R, under the action of natural gravitational forces), the boundary Reynolds number Re_{gr} was determined only experimentally and here always was only one number, eg. $Re_{gr} \approx 2320$ [3].

This paper creates the theorem, that the primary boundary between laminar and turbulent flows creates a collection of primary, terminal Reynolds numbers Regr.RR1 in range 981 ≤ Regr.RR1 ≤ +∞, where Regr.RR1 = f(R1/R) is a descending function.

The above analysis has also other theorem that increase of primary Reynolds numbers ReR in non-peaceful flows is possible only in this case, when the core diameter increases, which means that in range 1962 < ReR ≤ Regr.RR1, where ReR = f(R1/R) is an ascending function.

The intersection point of these two functions (descending and ascending) sets the limit of the primary flow terminal Reynolds number (Regr.R, R1gr/R), where Regr.R   Regr.RR1 and Regr.R   ReR.

The above analysis describes the existence of the primary creation motion. The existence of a secondary motion is omitted, which will be analyzed in the next paper in the series. Therefore, in this analysis, we use the conventional value U = 0, when in fact 0 < U < 1.

The creation of secondary motion in core, with its own structure, causes the mixing of the primary motion (with dynamic range specified by the ReR) with secondary motion (with dynamic range specified by the ReR1). This causes, that there is only one boundary Reynolds number Regr for the analysed example, where Regr = Regr.R + Regr.R1.

TABLE I
SYMBOLS USED IN PAPER

Symbol	Quantity [Unit]
a	dynamic field intensity, directional acceleration, [m/s^2]
f	function denotation
g	gravitational, steric acceleration, [g ≈ 9,81 m/s^2]
z	intensity of the natural, terrestrial gravitational field, [m/s^2]
z1	intensity of the secondary gravitational field, [m/s^2]
A	partial force field, subdomain of the thickness H_{RAC}
B	partial force field, subdomain of the thickness H_{RBC}
C	active forces, the share of primary creation motion in whole primary motion
F	cross section area, [m^2]
H	height (thickness) of the analyzed layer of fluid, measured transverse direction to the flow direction, where H ≥ 0, [m]
J	resistance to motion
L	opposing forces, the share of primary above-threshold motion in whole primary motion
P	force, [N][kG]
R	radius of the straight-axis duct of a circular cross-section, [m]
R1	radius of the straight-axis core of a circular cross-section, [m]
Re	Reynolds number
S	displacement, [m]
U	coefficient of free gravitons incorporation into motion fluid structure
U1	coefficient of freed gravitons incorporation into motion fluid structure
V	velocity, [m/s]
ν	kinematic viscosity coefficient, [m^2/s]
ρ	mass density, [kg/m^3]
ω	angular velocity of a rolling wheel (or drop), [1/s]
Subscripts	
gr	boundary, terminal
max	maximal
pr	threshold
śr	average
x	on parallel direction to the fluid flow direction
y	transverse to the fluid flow direction
A	subdomain
B	subdomain
C	cycloidal, creation
G	free gravitons
L	laminar, above-threshold
P	above-threshold
R	primary
R1	secondary

IX. SUMMARY AND CONCLUSIONS

1) This paper discusses the theory of boundary between steady laminar flows and turbulent flows. The underlying causes and the mechanism of the said boundary, known empirically since the times of Osborne Reynolds, but have not been previously described theoretically. This paper contains such theoretical description.
2) Two decisive conditions for the creation of the said boundary are assumed and described here. These are:

- Fluid flow must be affected by external terrestrial gravitational forces of the intensity $g \approx 9{,}81\ m/s^2$, $z = 0{,}25g \approx 2{,}45\ m/s^2$.
- The field of opposition forces, formed within the flowing mass of fluid, must be constant and uniform, and its intensity must be equal to gravitational intensity, i.e. must be equal to 0,25g.

3) The said conditions provide a basis for a description of the formation mechanism of the boundary. The boundary theory is universal in character, but due to the limited space in this paper the method of its determination was exemplified exclusively by the analysis of the structure of a steady axially-symmetric laminar flow of homogeneous Newtonian fluid through a straight-axis duct of a circular cross-section under the action of natural gravitational forces. Previously it was determined that laminar flows include peaceful and non-peaceful flows.
4) In the case discussed here, the boundary between laminar and turbulent flows is determined by the set of primary, terminal Reynolds numbers of the primary motion $Re_{gr.R}$, being in a functional dependency with the set of terminal values of the core radius $R1_{gr.}$, formed in the tubular duct of the radius R by the fluid flowing in the duct. The said dependency is a property of the relation scheme $Re_{gr.RR1} = f(R1_{gr.}/R)$ determined by one of the fundamental mathematical rules saying that the radicand of a square root must be non-negative.
5) The boundary theory describes differences, inter alia, between the structure of primary core motion and the structure of primary boundary layer motion. This difference is necessary, because only primary core motion structure creates a base for the construction of secondary flow structure, this means, it creates the secondary gravitational field. The structure of secondary flow and its part in creation of whole non-peaceful flow structure will be discussed in the next paper in the series.
6) While this paper No. 2 explains the causes and describes the mechanism of the formation of the boundary, yet it does not specify the value of the boundary number Re_{gr} for the case analyzed here. To specify that number it will be necessary to define the third decisive condition, which will be discussed in the next paper in the series.

X. Issues to Address in Paper No. 3

Paper No. 3 will present further possibilities of the dualism theory of cycloidal-laminar dualism of Newtonian fluid flows. It will contain further detailed deliberations over the structure of non-peaceful flows, featuring such elements as:

- Share of the secondary motion in the creation of non-peaceful flow structure,
- Internal friction forces
- Origin of turbulence, discrete undulation of core, etc.

The selected example of steady axially-symmetric laminar flow of homogeneous Newtonian fluid through a straight-axis duct of a circular cross-section under the action of natural gravitational forces, will still be used as reference. As a result, it will be possible to complete the deliberations over laminar flows in this particular example. The effect of paper No. 3 will be a precise, theoretical calculation of the boundary Reynolds number, amounting to $Re_{gr} = 2302$.

At this point, the author wishes to remark that the value $Re_{gr} = 2302$ is the sum of the terminal value of the primary motion $Re_{gr.R} = 2131$ and the terminal value of the secondary motion $Re_{gr.R1} = 171$, when $H_{gr.RA}/R = 1{,}2518497$, $U1 = 0{,}2124$, $U = 0{,}087$.

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