To describe the deLaval effect phenomenon, the Euler equations are used to derive the differential equation:

$$\frac{dA}{A} = (M^2 - 1)\frac{du}{u}, \qquad \text{Eq. (1b)}$$

where A is the flow cross-section area, u is the flow velocity corresponding to the cross-section area, and M is the flow M-velocity. As the speed of sound depends on the fluid temperature, so the value M is temperature dependent. Equation 1b says that if the flow is relatively slow (i.e. M <l), then the narrowing of the flow cross-section (i.e. negative dA) corresponds to acceleration of the flow (i.e. positive du); and if the flow is relatively fast (i.e. M> 1), then the widening of the flow cross-section (i.e. positive dA) corresponds to acceleration of the flow (i.e. positive du). Computational fluid dynamics using the classical Euler equations provide numerical solutions for spatial distributions of the fluid velocity, static pressure, and temperature within the deLaval nozzle. Equation 1b says that utilizing a pipe having no a divergent part, the flow cannot be accelerated up to velocities higher than the velocity of sound, i.e. up to M> 1. Equation 1b allows for the acceleration of the fluid flow in a converging nozzle up to the velocity of sound, i.e. M=1.

In practice, firstly, **the deLaval effect occurs on M-velocities substantially lower than M=1**; and secondly, **utilizing a pipe having no divergent part, airflow cannot be accelerated up to velocities higher than approximately only half of the velocity of sound in the air**. Thus, the two mentioned equations 1a and 1b, derived from the mentioned approach, which assumes that the fluid consists of many small volume portions having neither permeable boundaries nor molecular structure, have certain restrictions of applicability.

[0162] To design a shape of a C-D jetnozzle one applies the following equation:

$$\frac{A}{A_*} = \left[\frac{1 + \frac{j-1}{2}M^2}{1 + \frac{j-1}{2}}\right]^{\frac{j+1}{2(j-1)}}, \qquad \text{Eq. (1)}$$

derived basing on equation 1b, where A* is the minimal cross-sectional area at the critical condition point 180, and j is the gas adiabatic compressibility-constant.

C-D Convergent-Divergent Jet-Nozzle

[0645] **FIG. 6a** is a drawing illustration of a C-D jet-nozzle 610, pipe-section applied to accelerate a compressed and hot air stream, or more generally, a laminarly flowing compressed and hot compressible-expandable fluid 611. C-D jet-nozzle 610 has the inner pipe opposite walls shaped, for simplicity, axis-symmetrically around an imaginary axial x-axis 615, as a convergent funnel 612 having open inlet, narrow throat 613 comprising point 618 of the narrowest cross-section, and divergent exhaust tailpipe 614 having open outlet, providing the improved deLaval jet-effect. For simplicity, compressed and hot fluid stream 611 has a uniform front at the inlet.

[0646] The deLaval effect should be understood in a wide sense as comprising both: the deLaval jet-effect, defined as an effect of flow extra-acceleration, and the deLaval retarding-effect, defined as an effect of flow extra-slowing. Thus, the deLaval jet-effect is a particular case of the deLaval effect.

[0647] The specifically shaped pipe, comprising the three major successive constituents: convergent funnel 612 having an open inlet, narrow throat 613, and divergent exhaust tailpipe 614 having an open outlet, has no real separation features between the constituents. Narrow throat 613 is specified as a fragment of the inner pipe located between imaginary inlet 6131 and outlet 6132. The term "principal interval" of the x-axis corresponds to the interval occupied by the specifically shaped pipe, i.e. at least comprising narrow throat 613.

[0648] Fluid stream 611 is subjected to the Coanda-effect, observed as aligning of fluid stream 611 with the curvature of specifically shaped walls of the inner pipe. The Coanda effect is defined by a non-zero partial pressure-"c" $\mathbf{P_c}$ arising when the shape of a fluid portion is varying as the fluid portion moves along the shaped inner pipe of C-D jet-nozzle 610. It is an important point that the specific shape of pipe, prevents disturbances of the fluid motion. This stipulation corresponds to the case when the cumulative-inner-static-pressure P of streaming fluid 611 is varying gradually and the velocity of streaming fluid 611 is varying linearly as the fluid 611 moves within the shaped pipe along imaginary axial x-axis 615.

[0649] For simplicity, imaginary x-axis 615 is horizontal, i.e. moving fluid 611 does not change its effective height above the Earth's ocean surface level. Thus, equations (5.6) and (5.7) for a stationary laminar flow can be written as (6.1) and (6.2) correspondingly:

$$udu + dQ = 0 \qquad \text{Eq. (6.1)},$$

$$u\rho A = C = \text{Const} \qquad \text{Eq. (6.2)},$$

where **C** is a constant associated with the considered fluid portion, **A** is the flow cross-section area, **u** is the flow velocity, and **ρ** is the fluid density. Introduce value of volume per unit mass **v**, defined as **v=1/ ρ**.

[0650] The fluid characteristic heat portion per unit mass is defined as **Q=P/ρ=Pv**, so **dQ=vdP+Pdv**, where $\mathbf{P=P_{in}P_sP_{drag}+P_{viscous}}$. Therefore, equation (6.1) can be represented as

$$udu + vdP + Pdv = 0 \qquad \text{Eq. (6.3a)}.$$

Dividing (6.3a) by **Pv**, one obtains:

$$\frac{udu}{Pv} + \frac{dP}{P} + \frac{dv}{v} = 0, \qquad \text{Eq. (6.3b)}$$

and so,

$$\frac{dv}{v} = -\frac{udu}{Pv} - \frac{dP}{P}. \qquad \text{Eq. (6.3)}$$

Rewrite equation (6.2) as:

$$uA = Cv \qquad \text{Eq. (6.4a)}.$$

and further in differential form as:

$$Adu + udA = Cdv \qquad \text{Eq. (6.4b)}.$$

Divide the left and right sides of (6.4b) by the left and right sides of (6.4a) correspondingly:

$$\frac{du}{u} + \frac{dA}{A} = \frac{dv}{v}. \qquad \text{Eq. (6.4)}$$

Referring to equation (5.8a) for a real molecular fluid undergoing a reversible adiabatic process, one can write: $P\boldsymbol{v}^{\gamma}$=Const, or in differential form:

$$v^{\gamma}dP + \gamma P v^{\gamma-1}dv = 0 \qquad \text{Eq. (6.5a)}.$$

Dividing (6.5a) by $\boldsymbol{\gamma}P\boldsymbol{v}^{\gamma}$, one obtains:

$$\frac{dv}{v} = -\frac{dP}{\gamma P}. \qquad \text{Eq. (6.5)}$$

Comparing (6.5) and (6.3), one can write:

$$-\frac{udu}{Pv} - \frac{dP}{P} = -\frac{dP}{\gamma P} \qquad \text{Eq. (6.6a)}$$

i.e.

$$-\frac{udu}{Pv}\frac{\gamma u}{\gamma u} = -\frac{dP}{\gamma P} + \frac{\gamma}{\gamma}\frac{dP}{P}. \qquad \text{Eq. (6.6b)}$$

The denominator of the left side of (6.6b) comprises value (**γPv**) that defines velocity of sound via equation $\boldsymbol{u_{sound}}=\sqrt{\boldsymbol{\gamma}\mathbf{Pv}}$, so (6.6b) can be rewritten as:

$$-\frac{\gamma u^2}{u_{sound}^2}\frac{du}{u} = \frac{(\gamma-1)dP}{\gamma P}. \qquad \text{Eq. (6.6c)}$$

Introducing the value **M = $\mathbf{u} / \mathbf{u_{sound}}$** having the meaning of the fluid portion velocity measured in Mach numbers, i.e. M-velocity, (6.6c) can be written as:

$$-\gamma M^2 \frac{du}{u} = \frac{(\gamma-1)dP}{\gamma P}. \qquad \text{Eq. (6.6)}$$

Now comparing (6.5) and (6.4), one gets:

$$\frac{dP}{\gamma P} = -\frac{dA}{A} - \frac{du}{u}. \qquad \text{Eq. (6.7)}$$

Substituting the expression for **dP/γP** from (6.7) into (6.6), one obtains:

$$-\gamma M^2 \frac{du}{u} = (\gamma-1)\left(-\frac{dA}{A} - \frac{du}{u}\right)$$

and after simple algebraic transformations one formulates:

$$\frac{dA}{A} = \left(\frac{\gamma}{\gamma-1}M^2 - 1\right)\frac{du}{u}. \qquad \text{Eq. (6.8)}$$

Equation (6.8) comprises the term $\boldsymbol{M^2\gamma/(\gamma\text{-l})}$ characterizing the effect of the gas compressibility and expandability. Equation (6.8) differs from classical equation (1b) derived from the Euler equations applied to an ideal fluid defined in frames of the continuum mechanics. In particular, equation (6.8) says that: if the horizontally moving flow is relatively slow (i.e. M<$\sqrt{(\boldsymbol{\gamma}-\mathbf{l})/\boldsymbol{\gamma}}$), then the narrowing of the flow cross-section (i.e. negative dA) corresponds to acceleration of the flow (i.e. positive du); and if the flow is relatively fast (i.e. M> $\sqrt{(\boldsymbol{\gamma}-\mathbf{l})/\boldsymbol{\gamma}}$), then just the widening of the flow cross-section (i.e. positive dA) corresponds to acceleration of the flow (i.e. positive du). This means, in particular, that at so-called "critical condition" point 680 defined for the narrowest throat of the deLaval nozzle, the flow specific M-velocity equals

$$M^* = \sqrt{(\gamma-1)/\gamma} \qquad \text{Eq. (6.9).}$$

[0651] For the purposes of the present patent application, the index "*" is applied to an M-velocity, geometrical and thermodynamic parameters in a critical condition point.

[0652] **<u>For air as a diatomic molecular gas</u>**, the generalized adiabatic compressibility parameter **γ** equals $\boldsymbol{\gamma}$=7/5=1.4, and M*= $\sqrt{(\boldsymbol{\gamma}-\mathbf{l})/\boldsymbol{\gamma}}$ ≈**<u>0.5345 Mach, but not 1 Mach as follows from classic equation</u>** (1b). For a gas composed of multi-atomic molecules, the generalized adiabatic compressibility parameter **γ** is closer to 1, and so the de Laval jet-effect is expected at lower M-velocities. In a case of an almost incompressible liquid, the generalized adiabatic compressibility parameter **γ** is extremely great and equation (6.8) comes close to classic equation (1b), for which M*= 1 Mach..

[0653] In many actual and imaginary applications the phenomenon of shock sound-wave emission, that arises at M-velocities near 1 Mach, is undesirable or unacceptable. **<u>Therefore, the conclusion of resulting equation (6.8), that the deLaval jet-effect begins from the velocity being substantially lower than the speed of sound, becomes important to provide for a utilization of this useful effect avoiding the phenomenon of shock sound-wave emission</u>**.

[0654] Now consider the case where a compressed and/or heated gas, defined by the stagnation parameters: pressure $\mathbf{P_0}$, density $\boldsymbol{\rho_0}$, and temperature $\mathbf{T_0}$, is launching into a convergent-divergent jet-nozzle. Let the stagnation pressure $\mathbf{P_0}$, temperature $\mathbf{T_0}$, and density $\boldsymbol{\rho_0}$ be much high to provide the specific M-velocity M*= $\sqrt{(\boldsymbol{\gamma}-\mathbf{l})/\boldsymbol{\gamma}}$ at the narrowest cross-section of the throat. The gas characteristic heat portion per unit mass, expressed in terms of the gas temperature, is: **Q=RT**. Substitution of this expression into (6.1) gives:

$$T_0 = T + \frac{u^2}{2R} = T\left(1 + M^2\frac{\gamma}{2}\right) \qquad \text{Eq. (6.10)}$$

where $\mathbf{T_0}$ is the stagnation temperature; T is the gas portion current temperature; $\mathbf{u_{sound}}=\sqrt{\boldsymbol{\gamma}\mathbf{Pv}}=\sqrt{\boldsymbol{\gamma}\mathbf{RT}}$, and M= $\mathbf{u}$ /$\mathbf{u_{sound}}$= $\mathbf{u}$ /$\sqrt{\boldsymbol{\gamma}\mathbf{RT}}$. Though the normalized value M depends on temperature, one retains the form of equation (6.10) expressed via M, because the value of M=1 Mach has the physical sense of the shock sound-wave emission condition. Taking into account relations between thermodynamic parameters in an adiabatic process, equation (6.10) can be rewritten as:

$$\frac{T_0}{T} = \left(\frac{P_0}{P}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{\rho_0}{\rho}\right)^{\gamma-1} = 1 + M^2\frac{\gamma}{2} \qquad \text{Eq. (6.11)}$$

where P and $\boldsymbol{\rho}$ are the current static pressure and density correspondingly.

[0642] It is important to introduce the ratio A/A*, where A* is the narrowest cross-sectional area of the nozzle throat, i.e. is the critical condition area corresponding to the critical condition point, and A is the current cross-sectional area. It follows from (6.2) that

$$\frac{A}{A_*} = \frac{\rho_*}{\rho}\frac{u_*}{u} \qquad \text{Eq. (6.12)}$$

Taking into account (6.11) and that the specific M-velocity equals M*= $\sqrt{(\boldsymbol{\gamma}-\mathbf{1})/\boldsymbol{\gamma}}$, the ratio **A/A*** can be expressed via M-velocity:

$$\frac{A}{A_*} = \frac{1}{M}\left(\frac{\gamma-1}{\gamma}\right)^{\frac{1}{2}}\left(\frac{2+\gamma M^2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \qquad \text{Eq. (6.13)}$$

Equation (6.13) is the equation of principle, bonding the generalized adiabatic compressibility parameter $\boldsymbol{\gamma}$, M-velocity M, and ratio A/A* of the molecular fluid, fast and laminarly flowing through the deLaval nozzle, oriented horizontally. Equation (6.13) differs from classical equation (1) derived basing on the Euler equations applied to an ideal fluid defined in frames of the continuum mechanics. Equation (6.13), as one of the primary teachings of the present invention, says that to accelerate a warmed and compressed air portion up to 1 Mach, one must apply a C-D jet-nozzle and provide the nozzle inner pipe divergent part expansion up to the ratio of A/A*≈1.5197.

[0674] Moreover, as soon as the deLaval effect occurs in an adiabatic process, the condition of fluid stream 611 motion through the narrowest cross-section of throat 613 at critical condition point 618 with the specific M-velocity M*, accompanied by thermodynamic parameters: static pressure P*, temperature T*, and fluid density $\boldsymbol{\rho}$ *, interrelates with a condition of fluid stream 611 motion with an M-velocity and accompanied thermodynamic parameters static pressure P, temperature T, and fluid density $\boldsymbol{\rho}$ at any cross-section of C-D jet-nozzle 610's inner pipe, wherein the conditions interrelation depends on the pipe geometry only. **In other words, if a hypothetic propeller pushing a hypothetic inviscid fluid provides the inviscid fluid laminar flow with the specific M-velocity M* at the critical condition point of a deLaval nozzle, then the deLaval effect becomes triggered in the deLaval nozzle**, wherein the thermodynamic parameters of the moving inviscid fluid portions are interrelated as in an adiabatic process. In this case, **the hypothetic propeller triggering the deLaval effect expends power for the launching of accompanying shock and/or Mach waves only.**

$$M_e = \sqrt{\left(\frac{2}{\gamma}\right)} \sqrt{\left(\frac{P_o}{P_e}\right)^{\frac{(\gamma-1)}{\gamma}} - 1} \qquad \text{Eq. (7.1a)}$$

$$\frac{P_o}{P_e} = \left(\frac{2+\gamma M_e^2}{2}\right)^{\frac{\gamma}{\gamma-1}} \qquad \text{Eq. (7.1b)}$$

$$\frac{T_o}{T_e} = \left(\frac{2+\gamma M_e^2}{2}\right) \qquad \text{Eq. (7.1c)}$$

$$\frac{\rho_o}{\rho_e} = \left(\frac{2+\gamma M_e^2}{2}\right)^{\frac{1}{\gamma-1}} \qquad \text{Eq. (7.1d)}$$

The classical theory says that both the deLaval jet-effect and the velocity of sound are reachable when the ratio $\mathbf{P_0/P_e}$ is of 1.893. Equation (7.1 b) shows that, on the one hand, to obtain the deLaval jet-effect [i.e. condition $\mathbf{M_e} > \mathbf{M^*}$] for air using a nozzle having an optimal C-D shape, one must provide the ratio $\mathbf{P_0/P^*}$ at least of 1.893, and, on the other hand, to accelerate an air portion up to the velocity of sound [i.e. Me=1], one must provide the ratio $\mathbf{P_0/P_e}$ at least of 6.406. Equation (7.1c) says that, on the one hand, to obtain the deLaval jet-effect for air utilizing a pipe having optimal C-D shape, one must provide the ratio $\mathbf{T_0/T^*}$ at least of 1.2; and, on the other hand, to accelerate an air portion up to the velocity of sound, one must provide the ratio $\mathbf{T_0/T_e}$ at least of 1.7. So, the principle condition either $1.893<\mathbf{P_0/P_e}<6.406$ or/and $1.2<\mathbf{T_0/T_e}<1.7$ **may provide the deLaval jet-effect occurring without the phenomenon of shock sound-wave emission** that is one of the primary principles of the present invention.

[0699] Thus, a C-D jet-nozzle, constructed according to this invention, allows an optimal implementation and efficient use of an enhanced jet-effect at deLaval M-velocities.

(x) a generalized adiabatic compressibility parameter, indicated by γ, is defined for said molecular fluid as

$$\begin{cases} \gamma = j & \text{for hypothetical ideal gases} \\ \gamma = 1 + r(j-1) & \text{for real gases} \\ \gamma \gg 1 & \text{for real liquids and plasma} \\ \gamma \to \infty & \text{for hypothetical incompressible liquids} \end{cases} \qquad \text{Eq. (5.8d)}$$

where j is an adiabatic compressibility-constant defined for said molecular fluid imagined as said hypothetical ideal gas, wherein the adiabatic compressibility-constant j is quantified as j=1+2/f, where f is the number of degrees of freedom per said molecule of said molecular fluid; and

(y) said cumulative impact effect, characterized by the inner-static-pressure $\mathbf{P_{in}}$ is further specified as comprising: said stationary-effect, said drag-effect, said effect of viscosity, and the inner-static-pressure $\mathbf{P_{in}}$ is further defined as expressed by $\mathbf{P_{in}} = \mathbf{P_s} + \mathbf{P_{drag}} + \mathbf{P_{viscous}}$

and wherein the inner-static-pressure $\mathbf{P_{in}}$ interrelates with thermodynamic characteristics of said molecular fluid moving-small-portion by the equation $\mathbf{P_{in}=\rho Q=\rho RT}$, where **Q** is the characteristic heat portion per unit mass stored in said molecular fluid's molecular Brownian random motion related to degrees of freedom causing said fluid matter molecules cumulative impact effect acting on said imaginary boundaries of said moving-small-portion;