Dimensional Analysis, Thermodynamics and Conservation Laws in a Problem of Radiation Processes Simulation

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Abstract

The mathematical modelling of radiation processes, based on experimental data of modern physics and traditional approaches of dimension theory, thermodynamics and gas dynamics is considered. Dimensional analysis allows predicting important characteristics of radiation processes (mass of particles-bosons radiation, the magnitude of the radiation pressure, the characteristic linear dimensions), and also indicate the possibility of superluminal motion (without violating the principle of causality). Methods of thermodynamics lead to the refined modelling of equilibrium radiation, the equation of state of radiation protection, determine the heat capacity and the value of radiation pressure in the source. Gas dynamics approaches to formulate a closed system is thermodynamically consistent conservation laws for radiation heat-conducting gas. In this direction we present one-velocity two-temperature and one-temperature approximation. Demonstrate some practical applications of the methods of modelling.

Keywords: Radiation mathematical physics, Dimensional analysis, Thermodynamically compatible laws, Hidden mass boson, Superluminal motions

1. Introduction

The experimental achievements in physics of the second half of XX century point to the need to revisit the impact of radiation effects on the course of thermal processes in nature and in technical devices. To evaluate these radiation effects we will rely on the numerous experimental data of modern physics, as well as the theoretical basis of dimensional analyses, phenomenological thermodynamics, statistical physics and gas dynamics. The first important experimental result of modern physics for us is the discovery of Cosmic Microwave Background Radiation (CMBR). The results of astrophysics research indicated that the frequency distribution of background radiation intensity corresponds to the frequency distribution of radiation intensity of the black body with the temperature $T_0 = 2.735\ K$ (Penzias & Wilson, 1965; Smoot, 1978). The second significant achievement is the discovery of Dark Matter (DM), which is also called “the hidden mass of the Universe”. About 96% of whole matter in the Universe consists of DM. The baryon substance accounts to only 4%. Recent measurements indicate that the actual average density of the Universe is very close to the critical density value $\rho_0 \approx 10^{-26}\ kg/m^3$ (symposium Dark Matter, 2003; Chernin, 2008). There were a large number attempts to describe the nature of DM, but no of them had been successful yet (Moskowitz, 2006; Mavromatos, 2011).

In connection with these two experimental facts, note the following important fact. Before the discovery of a finite temperature to the CMBR in the physical vacuum of outer space it was assumed that the temperature in space $T = 0$ and particles - photons naturally have zero rest mass. The photons acquires mass and energy only while they were moving with the speed of light (and no other), and the speed of light - the maximum allowable speed of movement. Thus, there was no contradiction between the zero temperature of space and zero rest mass of photons. However, the discovery in outer space of the finite temperature $T_0 = 2.735\ K$ automatically from the dimensional analysis leads to a new dimension characteristic value, namely, the finite rest mass of cosmic space particles-Hidden Mass Boson (HMB)

$$m_0 \sim kT_0/c_0^2\,,$$

where k - the Boltzmann constant, making sense the gas constant per particle.

The non-zero temperature characterizes the hidden kinetic energy of particles with also a non-zero mass. Therefore, the $T_0 = 2.735\ K$ in space points to the need to rethink established views on the photon mass as the carrier of an electromagnetic radiation. In this paper we attempt to get such a rethinking.

In the next part of our paper we fulfils the analysis of the mentioned experimental data with using of physics dimensional theory π-theorem (Buckingham, 1914) and dimensionless π parameters. The main result of this analysis is the presence in free physical space, filled equilibrium radiation at the temperature $T_0 = 2.735\ K$, the material medium with the particle HMB of non-zero mass $m = 5.6 \cdot 10^{-40}\ kg$. This medium might be identified with the classic ether, or the mass "photon" gas, or the DM medium. With our point of view these different media may seeing as the same medium. By that the week perturbation velocity in this medium should be proportional to the square root from its temperature. This fact withdraws the limitation on week propagation perturbations velocity and allows the superluminal motion (without violation of the causality principle). Here relevantly one gives the analogy with the classic gas dynamics, allowing the motion with supercritical (supersonic) velocities. The dimensional theory also allows to estimate the critical pressure value and the critical frequency of the Universe. For the dimensional analysis we use additional the characteristic velocity $c_0 = 2.998 \cdot 10^8\ m/c$ and the values of three constants: the Boltzmann constant $k = 1.38 \cdot 10^{-23}\ kg/(m/s)^2/K$, the gravitational constant $G = 6.67 \cdot 10^{-11}\ N \cdot m^2/kg^2$ and the Planck constant $h = 6.63 \cdot 10^{-34}\ J \cdot s$.

Further in the third part of the papers there are presented a few items of statistical physics, phenomenological thermodynamics and gas dynamics for radiation medium properties. The statistical physics methods allows to consider typical properties of mass boson gas (the radiation medium) on the basis of the Bose-Einstein statistics. In particular, for this medium the Bose condensation state is predicted. The thermodynamics methods lead to updated modelling of an equilibrium radiation, the state equation of radiation medium, the specific heat parameters and the radiation pressure value in a source. In the forth part a complete thermodynamically compatible system of conservation laws is written for two-fluid radiation medium, consisting from a original (baryon) gas and radiation component. It is considered one velocity two temperature and one temperature (equilibrium) approximations. In the final fifth part of this article it is described the practice applications for air breathing engine simulation.

2. Dimensional Analysis

Executed dimensional analysis is based on measured values of the following quantities: the light speed $c_0 = 2.998 \cdot 10^8\ m/s$, the CMBR temperature $T_0 = 2.735\ K$ and the assessment of the critical density of the Universe $\rho_0 \sim 10^{-26}\ kg/m^3$. It also uses three well-known constants: the Boltzmann constant $k = 1.38 \cdot 10^{-23}\ kg \cdot (m/s)^2/K$, the gravitational constant $G = 6.67 \cdot 10^{-11}\ Hm^2/kg^2$ and the Planck constant $h = 6.63 \cdot 10^{-34}\ J \cdot s$. Applying π-theorem (Buckingham, 1914), we construct the dimensionless parameters π and physically associated meaningful relationships. The Buckingham theorem is a key theorem in dimensional analysis (see, for examples, Sedov, 1967; Birhoff, 1960). It is a formalization of Rayleigh's method of dimensional analysis,which expresses a functional relationship of same variables in the form of an exponential equation. The simplest dimensionless parameter π_1, linking pressure, density and velocity, is written as

$$\pi_1 = \frac{p}{\rho c^2} \sim 1$$

and allows an assessment of the "critical" pressure value

$$p_0 \sim \rho_0 c_0^2 = 10^{-9}\ Pa.$$

In the case of an ideal "photon" gas with adiabatic constant $\kappa = 4/3$ the perturbations velocity is defined as

$$c_0^2 = \kappa \frac{p_0}{\rho_0}$$

and then we get $p_0 = 1.4 \cdot 10^{-9}\ Pa$. It should be emphasized that this positive value p_0 can be interpreted as "critical" pressure of the Universe, determined by means of dimensional analysis in terms of its critical density ρ_0. We specifically focus on this fact to point out a fundamental difference from the negative pressure of the Universe (Chernin, 2008), which is associated with the phantom dark energy that may influence the effect of "accelerating" expansion of the Universe. A natural explanation for the apparent accelerating expansion of the Universe and a few other important items follow from the consideration of the dimensionless parameter π_2

$$\pi_2 = \frac{kT}{mc^2} \sim 1\ ,$$

leading to the estimation of the particle mass m_0 of the medium with the temperature T_0 and the disturbance propagation velocity c_0

$$m_0 \sim \frac{kT_0}{c_0^2} = 4.25 \cdot 10^{-40}\ kg.$$

An important conclusion of the analysis the parameter π_2 is the directly proportionality of the velocity c_0 to the square root of temperature $c_0 \sim \sqrt{T_0}$. In this connection we would like to get two remarks. The first is the possibility of a superluminal speed for disturbances in physical vacuum by $T > T_0$. In our case the limitation on week propagation perturbations velocity is withdraw and the superluminal motion (without violation of the causality principle) is allowed. Here relevantly one gives the analogy with the classic gas dynamics, which allows the motion with supercritical (supersonic) velocities. The second remark is concerned the apparent accelerating expansion of the Universe. The Universe in the early time periods was hotter, had a higher temperature T_0 and therefore had a higher value c_0. This fact naturally explains the observed luminosity weak effect of distant supernovae, awarded by the Nobel Prize for Physics in 2011 (as the discovery of "accelerating" expansion of the Universe).

A more accurate assessment for m_0 (Ivanov, 1998, 2011) gives

$$m_0 = 5.6 \cdot 10^{-40}\ kg.$$

It should be noted that the combination of dimensionless parameters π_1 and π_2 leads to a state equation of an ideal gas. We write the dimensionless parameter

$$\pi_3 = \frac{\pi_1}{\pi_2} = \frac{p}{nkT} \sim 1,$$

where $n = N_A/m$ - the concentration of particles.

Further the dimensional analysis will be conducted, relying additionally on two parameters. Parameter π_4 is written as

$$\pi_4 = \frac{G\rho}{\omega^2} \sim 1$$

allows us to introduce the characteristic gravitational frequency ω_0, the characteristic time period $t_0 = 1/\omega_0$ and the characteristic linear dimension $L_0 = c_0 t_0$ of our Universe

$$\omega_0 \sim \sqrt{G\rho_0} = 0.82 \cdot 10^{-18}\ 1/s$$

The value of the gravitational frequency is an analog of the plasma frequency, which characterizes the electric displacement of the negative charge from a positively charged layer. The exact value ω_0 is written (by an analogy with the definition of the plasma frequency) with a coefficient of proportionality $\sqrt{4\pi}$, i.e. $\omega_0 = \sqrt{4\pi \cdot G\rho_0}$.

We also consider the dimensionless fifth parameter

$$\pi_5 = \frac{hc}{kTl} \sim 1$$

allowing to produce an assessment of the characteristic length $l_0 \sim \frac{hc_0}{kT_0} = 5.3 \cdot 10^{-3}\ m$. This quantity can be interpreted as estimation of the mean free path of particles for the physical vacuum with temperature T_0.

3. Elements of Thermodynamics and Statistical Mechanics of Radiation Medium

An interesting result of dimensional analysis is the presence of particles with mass m_0 in a free radiating space (the physical vacuum) with the equilibrium temperature T_0 and the disturbance velocity c_0. The zero law of thermodynamics allows to introduce a temperature as the state parameter. The temperature T_0=2.735 characterizes of cosmic background microwave equilibrium radiation state. Using a simple gas kinetic approach we can find more accurate value of the mass of these particles. The averaged kinetic energy of random motion of these particles is

$$E = \frac{m_0 \cdot v_{av}^2}{2} = \frac{3}{2}kT_0 = m_0 \frac{3}{2}\frac{R_g}{m_0}\frac{T_0}{N_A} = \frac{9}{8}m_0 c_0^2 \quad ,$$

where the $k = R_g/N_A$ – Boltzmann constant, R_g – the universal gas constant, N_A – the Avogadro's number. From this relation we obtain

$$m_0 = \frac{4}{3}\frac{kT_0}{c_0^2} = 5.6 \cdot 10^{-40}\ kg \cong 3 \cdot 10^{-4}\ eV.$$

We calculate the gas constant $R_f = R_g/m_0 N_A$ and specific heat capacity c_v and c_p in the assumption of ideal gas with adiabatic index $\kappa = c_p/c_v = 4/3$. This adiabatic index of radiation medium is accurate known value (Pai Shin-I, 1966; Zeldovich & Raizer, 1966). We have:

$$R_f = \frac{k}{m_0} = 0.25 \cdot 10^{17}\ J/K \cdot kg,$$

$$c_v = 0.75 \cdot 10^{17}\ J/kg \cdot K,$$

$$c_p = c_v + R_f = 1 \cdot 10^{17}\ J/K \cdot kg.$$

Further, following the traditional thermodynamics of ideal gas for radiation medium, we can write the classical state equation

$$p = \rho R_f T$$

or

$$p = (\kappa - 1)\rho e,$$

where $e = c_v T$-the specific internal energy.

An important next step is to postulate the structure of radiation particles, which allows to explain the large number of effects and phenomena observed in the physical vacuum. Following (Ivanov, 1998, 2011), we consider a whole electrically neutral particle in the form of a dipole consisting of two parts with positive and negative charge equalled to about $5 \cdot 10^{-29}$ Coulomb. This value follows from the estimation of mass and charge for an electron and a proton (Ivanov, 1998, 2011). Thus, we actually introduce the new mass medium of bosons (HMB) and can apply to its analysis well developed methods of statistical mechanics and thermodynamics.

Let us explain in more detail, why the mass particle radiation of the physical vacuum is taken in our analysis in the form of the dipole, called hereafter by the hidden mass boson. First, in this case the issue of physical vacuum polarization is extremely clear. In external electric field orientation of the HMBs takes on power lines of the electric field, partly compensating for the external field. Thus, we obtain a clear physical interpretation of the Maxwell's displacement current in free space. Further, the energy flux vector of electromagnetic field - the Umov – Pointing vector indicates the direction of the HMB polarization under an influence of external electromagnetic field. In particular, when charging of the capacitor without insulator between the plates HMBs are moving from outer space in between the capacitor plate space, providing in this case, the displacement current. Another important process of electron-positron pair birth in the physical vacuum in the collision of two sufficiently intense electromagnetic pulse (Burke, 1997) should be interpreted as a break in a certain (sufficiently large) number of dipoles - HMB followed by concentration of their parts of the same sign of charge at the center of the electron and positron under the influence of forces including non-electromagnetic nature (e.g., gas dynamics, gravity, etc.). When implementing this scenario, the HMBs will determine the mass of the birth of baryon matter in the physical vacuum.

Substantiated to some extent the chosen postulated HMB structure, we proceed the methods of statistical mechanics. We consider the important question of the consistency of our work to well-known basics and conclusions of statistical physics and thermodynamics of a boson gas and its special case – a photon gas with zero rest mass of photons. Below we will demonstrate the absence of such contradictions.

First of all, we write the state equation for gases obeying Bose statistics and Fermi statistics. Here, the dimensionless parameter can be written

$$\pi_3 = \frac{p}{nkT} = 1 \mp \frac{1}{2^{5/2}}\lambda_0 + \cdots,$$

where the signs $\mp$, respectively, for the Bose and Fermi gases, as well as $\lambda_0^{-1} = (2\pi mkT)^{3/2}/h^3 n$ - the statistical sum per particle. The second and higher terms in the right side of the above formula are quantum statistical origin. This series expansion is valid for values $\lambda_0 < 1$ or to values $n < (2\pi mkT)^{3/2}/h^3$. The magnitude $h/(2\pi mkT)^{1/2}$ is the length of the thermal de Broglie wavelength, and the value $h/(3mkT)^{1/2}$ corresponds to the thermal energy of the particle $\frac{3}{2}kT$. Thus the Bose statistics in the usual manner is applied to the entered us with dimensional analysis and thermodynamics of the HMB gas. For future study the Bose condensation state of the HMB gas on the lowest temperature and high pressure is also very important item.

As for the well-known theory of blackbody radiation, in our approximation it requires some revision, which consists of transition from the linearized formulation of the problem to a fully nonlinear formulation. The essence of this transition can be clearly illustrated with the linearized theory of acoustics and the original theory of the nonlinear gas dynamics. It seems to be very clear that in a limited gas volume it is possible to describe the it's state in the acoustic approximation using the equation for the acoustic pressure perturbation

$$\nabla^2 p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0.$$

Based on this description, we can then determine an acoustic sound radiation from a closed cavity and the radiation field in the outer vicinity of the limit volume. In this description one can calculate the acoustic field in a gas without going into details of what the gas medium consists of a mass of individual particles. However, to calculate the real total pressure in the limited volume the initial nonlinear laws of gas dynamics are required (of them will be discussed in next section).

A similar situation occurs with the thermal radiation of a blackbody. Currently, in the approximation of massless photon equilibrium radiation field is described by linear wave equation (Isihara, 1973)

$$\nabla^2 E - \frac{1}{c^2}\frac{\partial^2 E}{\partial t^2} = 0.$$

The radiation field is represented by a set of simple harmonic oscillators with discrete spectrum of energy. As a result of the energy spectrum of equilibrium radiation gives the Planck formula

$$U_\nu = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{kT}} - 1}.$$

Calculations using this formula are in full agreement with the experimental in the far field of radiation, where the linearized theory actually works (as in acoustics case). However, in the case of massive bosons radiation the study of the thermal process in limited volume should use a of nonlinear formulation, which we consider in detail below.

In the conclusion of this part we emphasize that known values p_0 and ρ_0 characterize the state of the photon gas in the physical vacuum of space (in the vicinity of the Earth and Solar system) with the measured temperature CMBR $T_0 = 2.735\ K$. The pressure p_0 is the direct pressure of the HMBs medium in the region (source) at T_0. This value differs on a factor $c_0 = 3 \cdot 10^8\ m/s$ from the linearized values in a far field, which is calculated by methods of classical electrodynamics. Here should specify the full analogy with the usual gaseous medium in which acoustic pressure away from the noise source is different from the pressure at the source (this difference is also characterized by a factor containing the magnitude of the velocity of disturbance propagation, in this case - the sound speed c).

Further consideration of the influence of thermal radiation effects environment will be carried out within the framework of two-component model of the emitting gas with the mass of the radiation component (Ivanov, 2011).

4. Conservation Laws for Two-Component Model with the Gas and Radiation Components

Here we consider a complete system of conservation laws for two-component model of gas-like environment, taking into account the radiation component. All used parameters will be denoted in the traditional way. Attributing them to the corresponding indices: g - for the gas component, f - for the radiation component (e.g. density ρ_g andρ_f). The total value of the density, pressure and internal energy will be denoted without an index.

The laws of conservation of mass, momentum and energy in the divergence form for each of two components have the form (Ivanov, 2011)

$$\begin{cases} \dfrac{\partial \rho_g}{\partial t} + div(\rho_g \bar{V}_g) = q_g, \\ \dfrac{\partial \rho_f}{\partial t} + div(\rho_f \bar{V}_f) = q_f, \\ \dfrac{\partial \rho_g \bar{V}_g}{\partial t} + div(\rho_g \bar{V}_g(\bar{V}_g \cdot \bar{n})) + grad\ p_g = r_g, \\ \dfrac{\partial \rho_f \bar{V}_f}{\partial t} + div(\rho_f \bar{V}_f(\bar{V}_f \cdot \bar{n})) + grad\ p_f = r_f, \\ \dfrac{\partial \rho_g e_g}{\partial t} + div(\rho_g e_g \bar{V}_g) + p_g div \bar{V}_g = div(K_g grad T_g) + c_{fg}(T_f - T_g) + Q_g, \\ \dfrac{\partial \rho_f e_f}{\partial t} + div(\rho_f e_f \bar{V}_f) + p_f div \bar{V}_f = div(K_f grad T_f) + c_{fg}(T_g - T_f) + Q_f. \end{cases} \tag{1}$$

This system of equations is written for the thermal conductivity of the gas and radiation components (the first terms on the right hand side, K_g and K_f - the thermal diffusivity of the gas and radiation components, respectively). The second terms on the right sides of two last equations characterize the energy exchange between the gas and radiation components. The last terms, Q_g and Q_f are supplementary sources of energy, taking into account the availability of additional channels of energy exchange (e.g., in the case of registration of chemical reactions, etc.). The system (1) is closed by equations of state for the gas and radiation components.

Of course, a solution of this system in general form involves considerable difficulties, because it is necessary to specify the value of the exchange heat coefficient c_{fg} between the phases. Substantial simplification can be achieved having considered the approximation of one velocity and one temperature movement phase in the presence of a thermodynamically equilibrium $V_g = V_f = V; T_g = T_f = T$.

We also assume that there are no external sources of mass and momentum in this region of flow and mass transfer between phases: $q_g = q_f = 0; r_g = r_f = 0$.

Then, following (Marble, 1970; Loytcansky, 1973), we represent the continuity equation of each phase in the form

$$\frac{1}{\rho_g}\frac{d\rho_g}{dt} + div\bar{V} = 0,$$

$$\frac{1}{\rho_f}\frac{d\rho_f}{dt} + div\bar{V} = 0$$

or

$$\frac{d}{dt}\left(\ln\frac{\rho_f}{\rho_g}\right) = 0.$$

The last equality is shown the preservation of values

$$\alpha = \rho_f/\rho_g \tag{2}$$

along the stream lines, and if we assume that the initial time the density ratio is constant and independent of the coordinates, the equation (2) is valid at any point of considered medium.

We write total conservation laws for both components of the medium. Adding first two and second two equations in the system (1) we obtain, taking into account our assumptions, usual equations of a continuity and a motion for one-component medium

$$\frac{\partial\rho}{\partial t} + div(\rho\bar{V}) = 0,$$

$$\frac{\partial\rho\bar{V}}{\partial t} + div(\rho\bar{V}(\bar{V}\cdot\bar{n})) + grad\ p = 0.$$

Slightly change the total energy equation. Adding the last two equations in (1) we obtain

$$\frac{\partial}{\partial t}\left[\left(c_{vg}\rho_g + c_{vf}\rho_f\right)T\right] + div\left[\left(c_{vg}\rho_g + c_{vf}\rho_f\right)T\right] + pdiv\bar{V} = -divW + Q,$$

$$-W = K_g grad\ T_g + K_f grad\ T_f, Q = Q_g + Q_f.$$

In order to give the energy equation the usual form, we transform the expression

$$N = c_{vg}\rho_g + c_{vf}\rho_f,$$

as

$$N = c_{vg}\rho_g(1 + (c_{vf}\rho_f)/(c_{vg}\rho_g)) = c_{vg}\rho/(1+\alpha)(1 + (k_g - 1)/(k_f - 1)p_f/p_g)) = \bar{c}_v\rho,$$

$$\bar{c}_v = c_{vg}(1 + (k_g - 1)/(k_f - 1)p_f/p_g))/(1+\alpha), \quad k = c_p/c_v.$$

Recall that, according to (2) $\alpha = \rho_f/\rho_g$ is constant along streamlines. Consequently, when $T_f = T_g$ the ratio p_f/p_g is constant along streamlines.

Similarly, we transform the equation of state for the total system

$$p = \bar{R}\rho T, \quad \bar{R} = R_g(1 + p_f/p_g)/(1+\alpha).$$

The energy equation with right term $-divS$, where the radiation flux $S = \sigma T^4$, is often used to the simulation of the radiate flows. For further analysis with using of this approximation we obtain the following system, describing the equilibrium one velocity flow in the presence of radiation effects:

$$\begin{cases} \dfrac{\partial \rho}{\partial t} + div\,(\rho \bar{V}) = 0, \\ \dfrac{\partial \rho \bar{V}}{\partial t} + div\,(\rho \bar{V}(\bar{V} \cdot \bar{n})) + grad\ p = 0, \\ \dfrac{\partial}{\partial t} \bar{c}_v T + div\ \bar{c}_v T + p\ div \bar{V} = -div\ \sigma T^4, \\ p = \bar{R} \rho T. \end{cases} \tag{3}$$

Obviously, when $\rho_f = 0$ we obtain the ordinary system of gas dynamics equations for one component radiation medium. Further we present two examples of our model applications.

5. Determination of Nozzle Capacity and Model High Enthalpy Channel Flow

As the first example we consider one-dimensional steady flow of radiating gas in a Laval nozzle in a problem of modern air breathing engine simulation. Estimation of the energy ratio of the radiation flux to the thermal flux is

$$M = \frac{\sigma T^4}{\rho V c_{pg} T.}$$

For the flow parameters of the modern engines: pressure $p = 3 \cdot 10^6\ Pa$, temperature $T = 2000\ K$ and velocity coefficient $\lambda = 0.2$ at the value $R_g = 287\ J/(kg \cdot K)$, we obtain: the parameter $M = 5 \cdot 10^{-4}$, the density $\rho = 5.2\ kg/m^3$ and the velocity $V = 170\ m/s$. It is evident that the direct contribution of radiation component (the source term on the energy equation right side of the system (3)) in under these conditions is negligibly, and the source term for this temperature can be discarded. Than the solution of the reduced system (3) is well known and can be expressed in terms of known gas dynamic functions, where instead of the adiabatic index and the usual universal gas constant there are used their reduced values k and R for the two-component medium

$$k = k_g\{1 + k_f/k_g(k_g - 1)/(k_f - 1)p_f/p_g\}/\{1 + (k_g - 1)/(k_f - 1)p_f/p_g\},$$

$$R = R_g(1 + p_f/p_g)/(1 + \alpha).$$

At temperatures $T = 1000-2000\ K$ the adiabatic index gas and radiate components are near the same $k_g = 9/7, k_f = 4/3$. Therefore, with good accuracy we can assume k= k_g. For adiabatic processes we can use the relations (Loytcansky, 1973):

$$\frac{p_f}{p_o} = \left(\frac{T}{T_o}\right)^4, \quad \frac{\rho_f}{\rho_o} = \left(\frac{T}{T_o}\right)^3.$$

At $T = 2000\ K$ the density of the radiation is negligibly small compared with the density of ordinary gas component (Ivanov, 2011). Using the equality $p = p_g + p_f$ we obtain

$$R = R_g \frac{p}{p - p_f}. \tag{4}$$

For a one-dimensional adiabatic flow of ideal gas in the Laval nozzle gas flow rate is determined by the form (Loytcansky, 1973)

$$G = m\frac{p^o F q(\lambda)}{\sqrt{R_g T^o}}, \quad m = \sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}, \quad q(\lambda) = \left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \lambda \left(1 - \frac{k-1}{k+1}\lambda^2\right)^{\frac{1}{k-1}} \quad ,$$

where p^o and T^o – the stagnation pressure and the stagnation temperature, F – cross-sectional area of the nozzle. We consider here an ideal gas flow. For the two-component mixture we should use the reduced gas constant (6) and have the ratio of gas flow

$$\mu = \frac{G}{G_{ideal}} = \sqrt{1 - p_f/p} \quad ,$$

where G_{ideal} – the ideal mass nozzle flow. Coefficient μ characterizes similarity of flows. For conservation of mass flow the channel throat cross section should be increased in $1/\mu$ times.

To estimate the maximum irreversible pressure losses in the non-equilibrium flow of the radiate gas we can calculate mass flow coefficient as

$$\mu_n = 1 - \frac{p_f}{p}.$$

Figure (1) shows the μ (upper curves) and μ_H for different gas temperature at the inlet of the nozzle with three initial pressures p^0 (20, 30 and 40 atm.). It is seen that the influence of the radiation component should be included into account at the flow temperatures $1500K$. With further increasing of temperature influence the radiation component increases markedly.

The second example considers a two dimensional scramjet channel flow for the inlet Mach number $M_\infty = 4$ with heat addition and radiation effect simulations. The cross section of the channel is presented on the top of the figure (2). Here we apply the computational fluid dynamics modeling, which describes in detail in (Ivanov & Nigmatullin, 2008, 2009). We can see temperature and pressure distributions inside channel on the top and the hub walls. The calculation results show that an intensive heat addition and radiation effect get the shock waves location near the channel throat section.

6. Conclusion

The discovery of the finite temperature $T_0 = 2.735\ K$ in outer space automatically leads to the finite rest mass of cosmic space particles $m_0 = 5.6 \cdot 10^{-40}\ kg$. The space medium of these particles named here Hidden Mass Bosons can be considered as the classic ether, or massive photon gas, or Dark Matter (Hidden Mass). The dimensional analysis allows to predict the main performances of the medium and to indicate on the possibility of superluminal motion (without the causality principle infringement). Thermodynamics and gas dynamics of the medium give the closed system of thermodynamically compatible conservation laws for medium motion. We have demonstrated some practice applications of these models for air breathing engine simulation.

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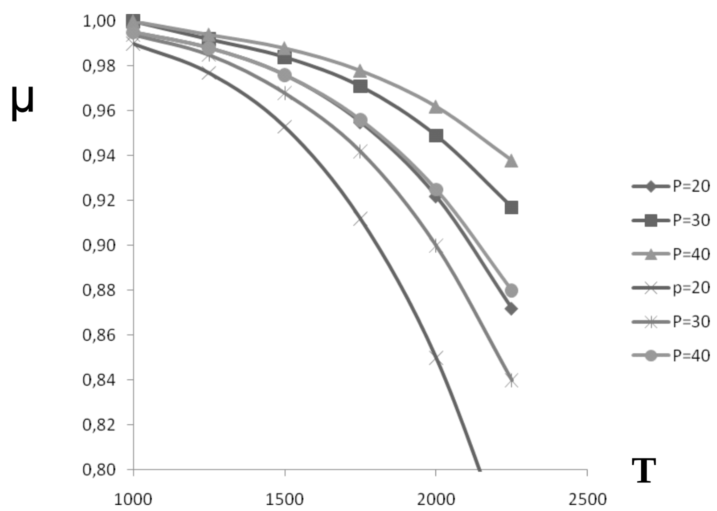

Figure 1. The nozzle mass flow coefficient for different gas temperature

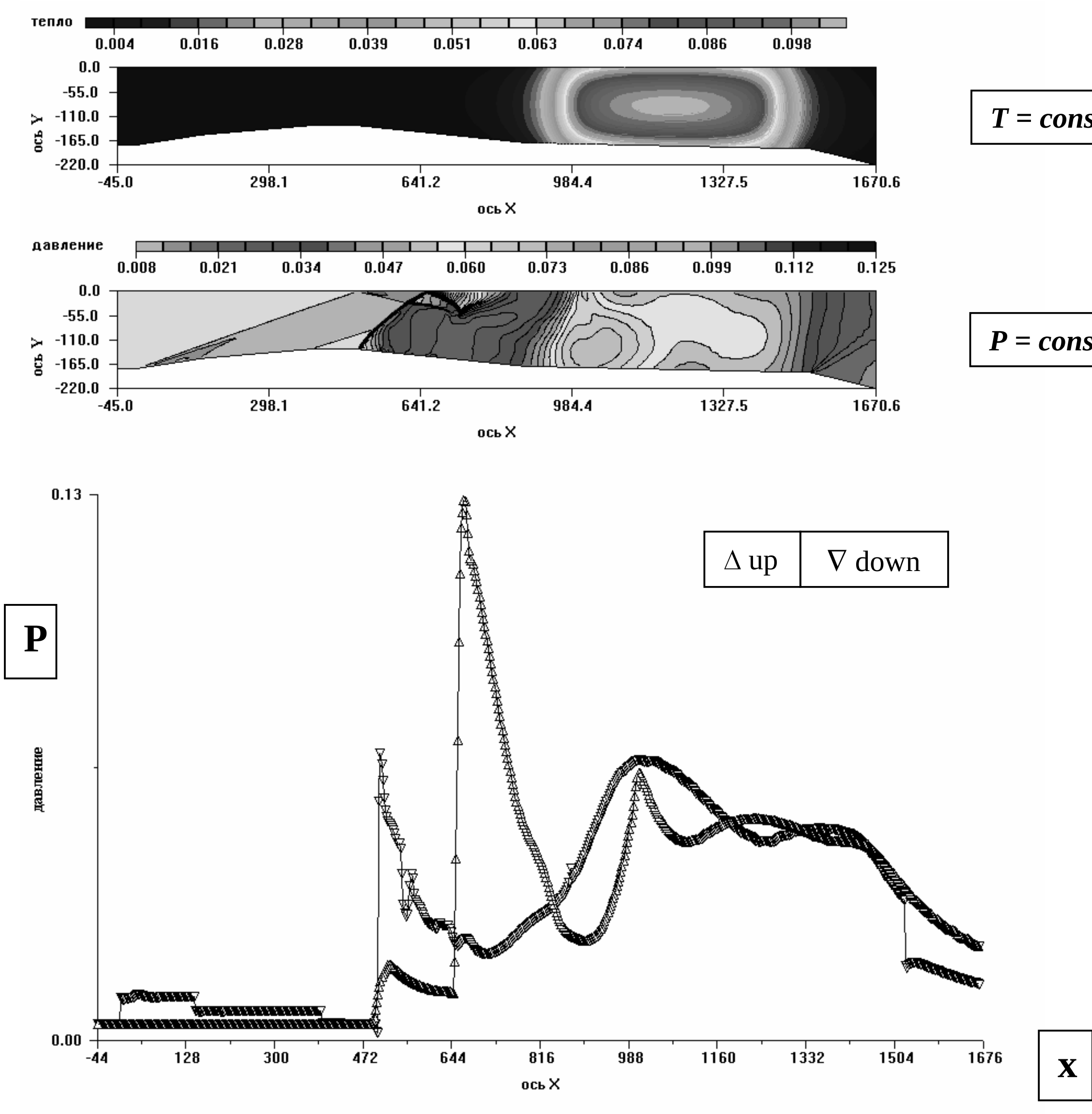

Figure 2. Pressure distributions in channel with intensive heat addition and radiation effects