The unsteady turbulent flows structure study present status

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Abstract: *The processes of heat transfer and hydraulic plays a very important role in the design and prototyping of aerospace technology. In most cases this technique works under significant unsteady conditions. Steady approach for unsteady processes leads to high error in calculations. Models for unsteady processes calculation must be based on fundamental turbulent structure research. Experimental research data is very important to the matter as it has intrinsic reliability. This data can be used both independently for unsteady processes model creation and for theoretical model's verification. Moscow Aviation Institute National Research University (MAI) accomplishes unsteady turbulent flow structure since year 1985. An experimental facility was designed to provide acceleration and deceleration gas flow in isothermal and non-isothermal conditions. The results of experimental turbulent flow research demonstrate fundamental unsteady processes influence on the flow structure. The principal results of acceleration and deceleration flow experimental research evidence three specific zones in turbulent flow structure exist: wall area, maximal turbulent structure transformation and flow core. The results show significant distinction in turbulent viscosity ca 3 times between steady and unsteady approach ca 3 times. The discrepancy of steady heat transfer and hydraulic resistance coefficients to actual unsteady data reaches up to 2 times. Clearly, such considerable difference in heat transfer and hydraulic resistance coefficients is inadmissible for processes calculation in aviation and space technology. Other research teams observed the same trend in their experiments. The present paper describes a method of experimental research, methodology of data processing and unsteady turbulent flow structure deformation results. Flow acceleration comes to velocity profile deformation and turbulence pulsations increase. Flow deceleration leads to opposite results - reverse velocity profile deformation and turbulence pulsations decrease. Experimental data also are a reliable basis for further unsteady turbulent flow theoretical parameters research.*

Key Words: *turbulent flow structure, hydrodynamic unsteadiness, heat transfer at unsteady conditions, calculation models of unsteady flows*

1. INTRODUCTION

Unsteady thermal and hydrodynamic processes, are typical in almost all modern engineering systems and technical units. The creation of new systems or improvement of existing aircraft and space engines is possible with at least unsteadiness on thermal processes impact qualitative analysis. For engine parts, operates in significant unsteadiness in the mandatory assessment of the level of unsteady influences and, often, specific approach application. This specific approach includes of switching from steady or quasi-stationary models to unsteady ones.

A thermal and hydrodynamic processes become principal at creating new prototype of space and aviation techniques. The cause is in high thermal intensity of devices, operating modes requirements increasing and regulation modes of such systems. Safety and reliability in aviation and space area are most important. It's necessary to calculate an abnormal regime, which are mostly unsteady. Hence, a study of heat transfer and hydrodynamics unsteady processes and development of the calculation methods are extremely important for engineering practice.

Only integral combination of fundamental and empirical research is the most effective way for unsteady process precise model creation, and as a consequence for precise engineering calculations.

References to studies of unsteady conditions influence on the turbulent flows structure and on the thermodynamic parameters can be found in the research works of the 70s of the twentieth century [1-12]. Results of experimental research conducted in Moscow Aviation Institute hold a significant place among these results. In the mid of 90s, a scientific school of unsteady turbulent flows structure was founded in Moscow Aviation Institute by Professor Heinrich Dreitzer.

Turbulent flow structure research carried out in Moscow Aviation Institute have shown a significant impact of changes in flow, or in other words, hydrodynamic unsteadiness on the flow structure.

Most of these researches are purely experimental [3, 9, 11, 12], which is not only of practical calculation results, but also important primary data. This data is used in theoretical studies as a basis for theoretical hypotheses and models testing [11].

2. EXPERIMENTAL STUDIES OF THE HYDRODYNAMIC UNSTEADINESS EFFECT ON THE HEAT TRANSFER AND FLOW HYDRODYNAMICS PROCESS

2.1 Research methodology and experimental installation

The experimental equipment in Moscow Aviation Institute based on a hot-wire anemometer system and is able to measure an instantaneous axial and radial velocity and temperature of the gas flow.

These measurements can be done with frequency up to 1kHz. The Reynolds numbers range in experiments was from 3000 up to 30000.

Hydrodynamic unsteadiness was provided by flow acceleration and deceleration. The range of Reynolds number variation in unsteady processes achieved 3 times both for acceleration and deceleration processes.

Experimental equipment and experimental research methodology allow to identify the turbulent gas flows structure in also in isothermal and non-isothermal conditions. Hot-wire anemometer measurements data were recorded in real time in a database for subsequent decoding and analysis.

For turbulent parameters was applied a mixed averaging. The first component of mixed averaging is the averaging by number of iterations or other words by ensemble of realizations.

The second component – is the assumption of piecewise ergodicity on the time process and time of process τ was applied for components of the averaged turbulent parameters extraction. It was considered that period of time $\Delta\tau_0$ gas flow rate constant.

The time interval $\Delta\tau_0$ was determined by the fact that flow rate for $\Delta\tau_0$ cannot change more than 1%.

The value $\Delta\tau_0$ depended on the flow rate and was in the range 0.015...0.05s. The experimental research was carried by follow conditions: the working gas was an air, inner diameter of the pipe d=42 mm, the hydrodynamic unsteadiness was provided gas flow changes ($\partial G/\partial\tau \neq 0$), non-isothermal conditions provided by pipe's wall heating and maintaining constant temperature of the wall.

The experimental installation has the capability to provide hydrodynamic unsteadiness in the range of gas flow variation $|\partial G/\partial\tau|$=0.02 kg/s^2.

Hydrodynamically unsteady processes were carried out during time from 2 up to 5 seconds.

The dimensionless parameter of hydrodynamic unsteadiness K_g* was implemented [3] for comparison with the results of other research and research of other authors.

$$Kg^* = \frac{\partial G}{\partial \tau}\frac{1}{G}\sqrt{\frac{d}{g}} \quad (1)$$

where G – gas flow rate, kg/s; τ – time, s; d – channel diameter, m; g – acceleration of gravity, m/s^2.

The variation range of hydrodynamic unsteadiness coefficient Kg^* =-0,111 - 0,111. Flow rates change during unsteady process presented on Fig. 1.

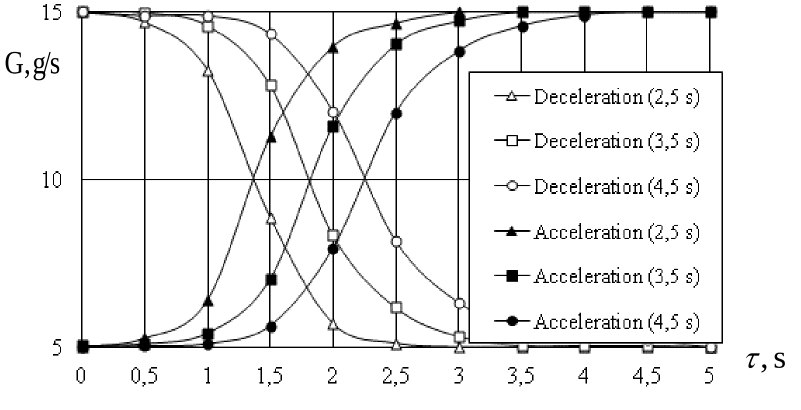

Fig. 1 Flow rates change during unsteady process.

The temperature coefficient T_w/T_f =1...1,18 was used for non-isothermal conditions consideration.

Where, T_w – wall temperature, T_f – flow temperature. More detailed description of the experimental installation, the data decoding methodology, calibration experiments methods presented in [6].

2.2 The impact of flow rate changes on the turbulent flow structure

Experimental research of turbulent flow structure by S. B. Markov [1] showed that axial averaged velocity profile becomes fuller during accelerating gas flow, and less full during decelerating.

Present research identified exactly the same effect. These profiles are presented in dimensionless form normalized corresponding stationary values $\overline{U}_{xo}$ on Fig. 2. Criteria $\overline{Ho}$ is a dimensionless time of unsteady process.

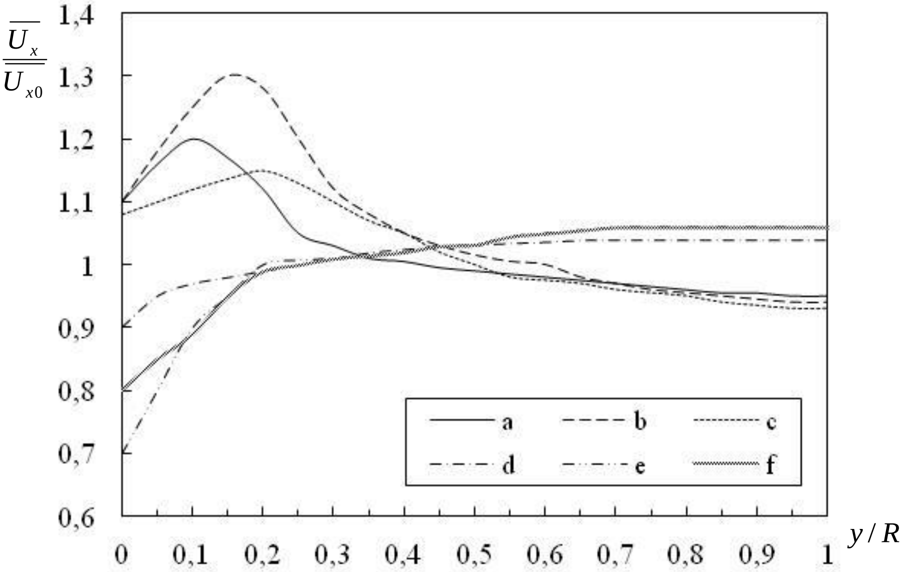

Fig. 2 Axial averaged velocity profiles, Re=3100...9300, T_w/T_f=1, a-($\overline{Ho}$=0.25, K_g*=0.088), b-($\overline{Ho}$=0.5, K_g*=0.111), c-($\overline{Ho}$=0.75, K_g*=0.088), d-($\overline{Ho}$=0.25, K_g*=-0.088), e-($\overline{Ho}$=0.5, K_g*=-0.111), f-($\overline{Ho}$=0.75, K_g*=-0.088)

Previous experimental research in Moscow Aviation Institute [3, 6, 7] fully confirm the hypothesis about hydrodynamic unsteadiness significant influence on the axial profile averaged velocity.

The difference between axial averaged velocity and steady conditions up to 10% in the flow core and 30% in the wall zone by acceleration was detected.

The flow deceleration had an opposite effect - averaged axial velocity profile becomes less full, i.e. dimensionless axial averaged velocity becomes higher in the core flow, and in the wall area - below their steady value.

The averaged velocity profiles analysis led to the conclusion about the specific areas where maximum change of parameters identified. We determined this area as “the zone of maximum change”.

The flow acceleration effect comes to formation of “the zone of maximum change” in the range of y/R=0,1...0,3 (where y/R is the dimensionless distance from the wall). Flow deceleration comes to “zone of maximum change” formation closer to the wall in the range of y/R=0,05...0,2.

At maximum acceleration (Kg^*=0,111) the difference between averaged velocity and their steady profile in the “zone of maximum change” reached 30%, and in flow deceleration (Kg^*=-0,111) - the difference was 25%.

The maximum of criteria Kg^* by flow rate acceleration and the minimum Kg^* during deceleration correspond to the moment of maximum flow acceleration/deceleration.

One of the important characteristics of turbulence and the characteristics of its intensity are the velocity pulsations (Fig. 3).

Experimental research confirmed that unsteady conditions affect significantly on the pulsation velocity components, namely axial and radial velocity pulsations. In the previous article [9] this subject was presented in detail.

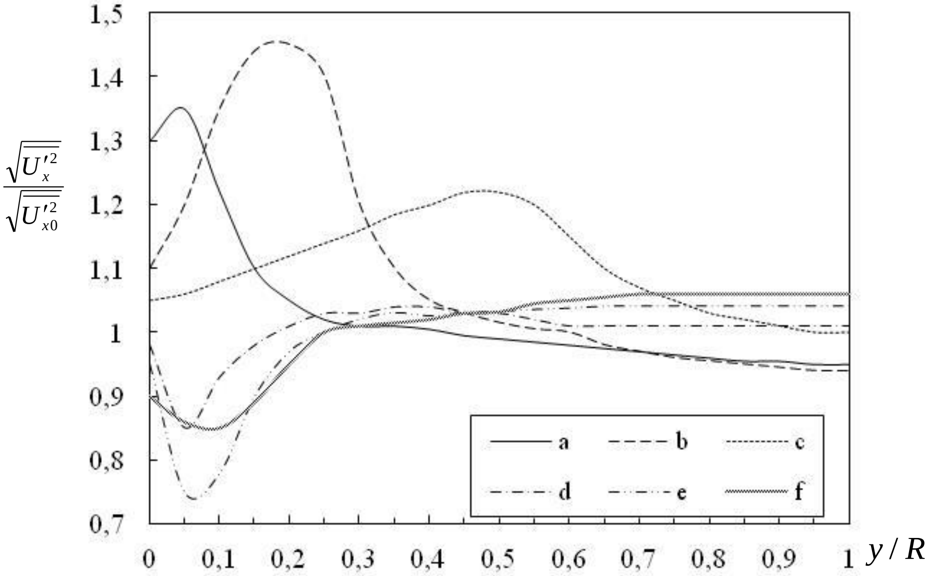

Fig. 3 Averaged axial velocity pulsation profiles at flow acceleration and deceleration, *Re*=3100...9300, T_w/T_f=1, a-($\overline{Ho}$=0.25, Kg*=0.044), b-($\overline{Ho}$=0.5, Kg*=0.088), c-($\overline{Ho}$=0.75, Kg*=0.044), d-($\overline{Ho}$=0.25, *Kg**=-0.044), e-($\overline{Ho}$=0.5, Kg*=-0.088), f-($\overline{Ho}$=0.75, Kg*=-0.044)

Let us summarize most important results – by flow acceleration axial and radial pulsations exceed in "zone of maximum change" their steady parameters 40% and 30% respectively at maximum =0,111. The flow deceleration at maximum deceleration moment (*Kg**=-0,111) comes to axial and radial pulsations intensity reduce in the "zone of maximum change" to 25% and 30%, respectively. The maximum of criteria *Kg** was identified at the moment of maximum flow acceleration, and minimum – at maximum flow deceleration.

Another interesting phenomenon for unsteady process [9], which consists of a maximum changes peak shift from the wall of the channel, was found.

In other words near the wall at the beginning of unsteady process turbulent profile deformation begins. During the unsteady process of the peak maximum changes moves from the wall to the flow core within the "area of maximum change".

In addition, another important parameter of the turbulent flow - correlation of axial and radial velocities pulsations $\overline{U'_x U'_r}$ was researched. Experimental research results demonstrate the pulsations correlations at maximum acceleration exceed a steady value more than 2.5 times, and at deceleration – up to 2 times lower the steady values. These changes were identified in the previously described "zone of maximum change". Also there is the shift of the peak correlations changes from the wall to the flow core during unsteady process. Note that after passing the non-stationary effect maximum, the structure of turbulent flow quite quickly returns to a steady state.

A detailed explanation of the reason for such significant changes in the correlations of pulsation was done in previous works [9, 12]. We indicated specific flow structure changers mechanism in unsteady conditions. Calculation of correlations was carried out by multiplying the fluctuation components of velocity, and then the data were averaged. It should be noted that this significant difference between unsteady data of pulsation temperature and velocity and their correlations were found earlier [9]. The fact is that the data on pulsation components are averaged, and in the calculation of correlations was first performed multiplication of pulsation and then averaged. This indicates a presence of a certain flow structure changing mechanism in unsteady conditions.

Moreover, the above mentioned correlations to determine heat transfer processes and hydrodynamics in turbulent flows.

Significant difference between steady and unsteady correlations is evidence of such strong changes of heat transfer coefficients and hydraulic resistance in unsteady processes [12].

2.3 The impact of gas flow changes on the turbulent flow structure in non-isothermal conditions

Non-isothermal conditions were provided by channel's wall heating and is characterized by the temperature factor T_w/T_f=1...1,18. The profiles of axial averaged velocity during flow acceleration and deceleration presented in Fig. 4.

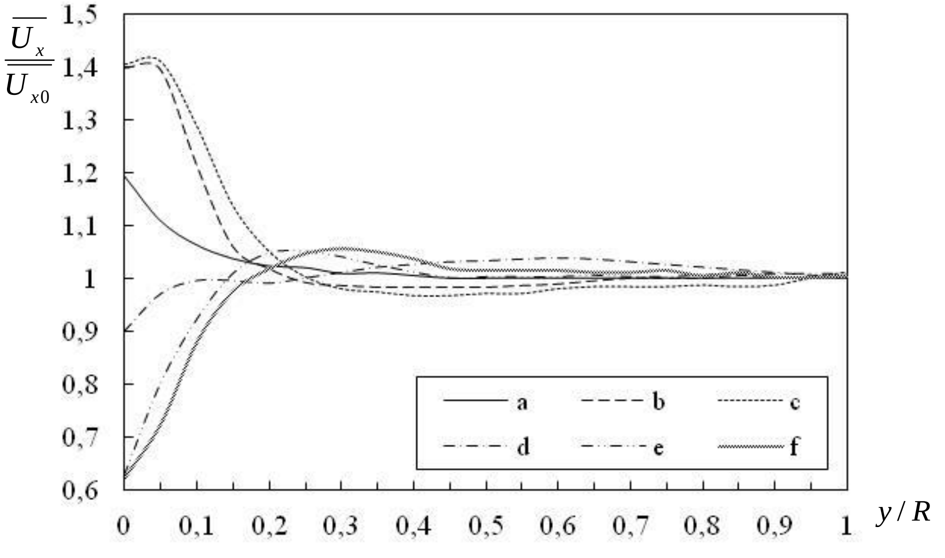

Fig. 4 Profiles of averaged axial velocity, Re=3100...9300, T_w/T_f=1.18, a-($\overline{Ho}$=0.25, K_g*=0.088), b-($\overline{Ho}$=0.5, K_g*=0.111), c-($\overline{Ho}$=0.75, K_g*=0.088), d-($\overline{Ho}$=0.25, K_g*=-0.088), e-($\overline{Ho}$=0.5, K_g*=-0.111), f-($\overline{Ho}$=0.75, K_g*=-0.088)

As well as in isothermal conditions, the acceleration of the flow profile of the axial averaged velocity becomes more completed was found.

During the flow deceleration the unsteady effect was opposite - averaged axial profile of the velocity becomes less full.

However, differences from the isothermal conditions was identified. Results show more significant turbulent flow deformation in non-isothermal conditions. Change in the axial velocity profile in "zone of maximum change" is more than 40%, whereas in the isothermal case is 30 %. Axial and radial velocity pulsations during the flow acceleration keep their behavior – they are higher than steady values.

During the flow deceleration there is a picture similar to isothermal flow. Despite the isothermal and non-isothermal processes similarity at the hydrodynamic unsteadiness, there are tangible differences. Above we noted that in isothermal conditions after the peak of the unsteady effect, the structure of turbulent flow fast returns to its original state. However, in non-isothermal conditions a similar return characteristic to the original steady state is significantly slower.

Another difference between non-isothermal conditions from isothermal is the lack of movement of the peak maximum changes from the channel walls to the axis.

3. TURBULENT FLOW STRUCTURE MODEL

3.1 Isothermal conditions

The experimental studies result of turbulent flows structure and the turbulent flow model in steady conditions [12] gave us an opportunity to formulate not only the hypothesis about the influence of specific external conditions on certain processes in the structure of turbulent flows, but also the turbulent flow model in unsteady and non-isothermal conditions.

Authors [12] segmented turbulent flow into three zones: zone viscous sublayer $0\leq\eta\leq5$, zone, area $15\leq\eta\leq30$ and area $\eta<30$. Where η - dimensionless distance from a wall:

$$\eta=Uy/\nu, \tag{2}$$

where U – average axial velocity, m/s; y – distance from a wall, m; ν – kinematic viscosity, m^2/s.

In the area of the viscous sublayer, where the predominant role is played by the viscous friction forces, the flow is not laminar.

This zone is periodically under the influence of pulsations coming from zone $5\leq\eta\leq15$. These pulsations represent large volumes of medium with negligible oscillation amplitudes [9]. The interaction of these pulsations viscous sublayer comes to the generation in area $5\leq\eta\leq15$ vortex structures.

New vortices move to the next area $15\leq\eta\leq30$, where there is an active vortical structures interaction with the main flow.

And outside area $\eta=70$ such vortex structures are no longer.

In the near-wall area, the emission and movement of the vortex structure causes a local flow deceleration with a thickness of $\eta\geq30$ and a slight velocity gradient.

At the same time the main stream has enough large mass and speed comparable to an average speed of layer currents. The interaction of these two structures – areas of slow flow and the main flow comes to intense ejection of vortices that form the basis of turbulent fluctuations [9].

The axial and radial velocities pulsations correlation (Fig. 5) show a special role of the zone of y/R=0.05...0.2 in the formation of a turbulent motion.

When accelerating the flow under isothermal conditions, the correlation increased to 2.5...2.7 times in the area of y/R=0.05...0.2. When decelerating - correlations are 0.4...0.5 from the steady values.

It is seen that during unsteady process, the area of maximum correlations is gradually shifting to the axis.

3.2 Non-isothermal conditions

In case of wall heating ($T_w/T_f>1$) the mass of gas near the wall is additionally heated also and expands. As a result, surface contact with the accelerated mass of the main flow increases.

It comes to the intensification turbulent emissions and, consequently, to the turbulence generation.

Hydrodynamic unsteady conditions come to the velocity profile deformation. For example, during the flow acceleration, the averaged axial velocity profile becomes more completed, and during deceleration - vice versa. In turn, the velocity profile deformation comes to the edge zone "compression" by accelerating, and comes to "tension" by flow deceleration. The consequence of such exposure is greater (flow acceleration) or less active (flow deceleration) interaction of slow gas masses with the main stream.

As a result of these conditions, the turbulent vortices dissipation process is more intense by flow acceleration, and less intense by deceleration in comparison with the steady conditions.

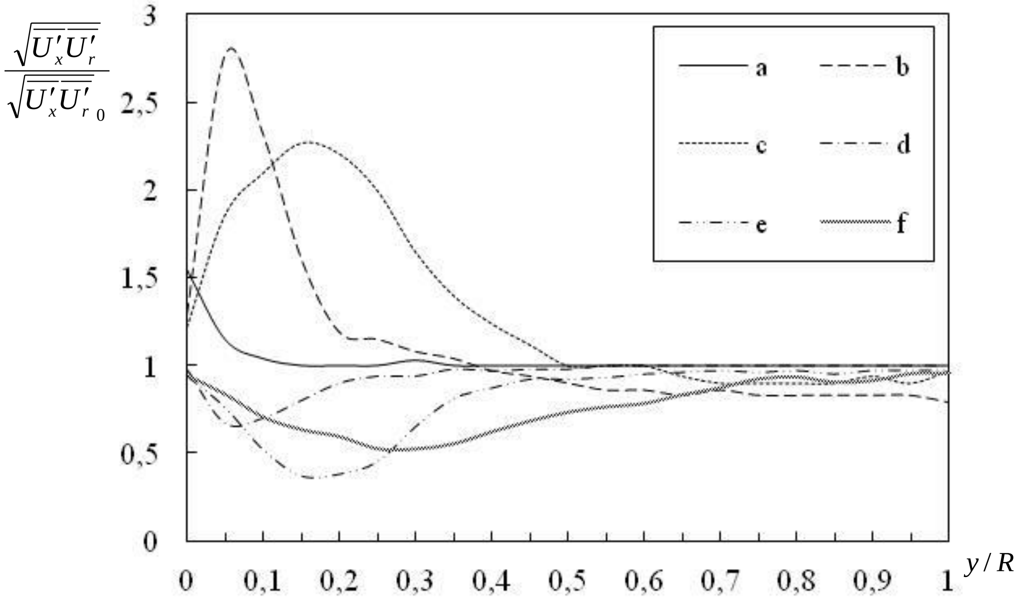

Fig. 5 The axial and radial velocities pulsations correlation,
Re=3100...9300, T_w/T_f=1, a-($\overline{Ho}$=0.25, K_g*=0.088), b-($\overline{Ho}$=0.5, K_g*=0.111),
b-($\overline{Ho}$=0.75, K_g*=0.088), d-($\overline{Ho}$=0.25, K_g*=-0.088), e-($\overline{Ho}$=0.5, K_g*=-0.111),
f-($\overline{Ho}$=0.75, K_g*=-0.088)

The axial and radial velocities pulsations correlation in non-isothermal conditions presented in Fig. 6.

From the point of view of the turbulent structure formation, the most important processes are the vortex structures generation and their motion from the wall of the channel toward the flow core.

These processes are random in their nature. The probability depends from local conditions.

To local features of the flow in non-isothermal and hydrodynamic unsteady conditions should include the Reynolds number (Re) and temperature factor (T_w/T_f), because these parameters affect the intensity and frequency of vortex structures generating.

Presented mechanisms of turbulent structures adjustment significantly affect the coefficients of turbulent viscosity and thermal conductivity, and they, in turn, determine the processes of heat exchange and hydrodynamics of turbulent flow.

The coefficient of turbulent viscosity changes rule in the hydrodynamic unsteadiness conditions described in detail in other papers of authors, for example [12].

The authors conclusions about turbulent flows restructuring show significant effects on heat transfer processes and hydrodynamics in unsteady conditions and are well matched by observations of experimental data and theoretical unsteady model calculation of hydraulic resistance by ourselves [12] and other authors [1, 5].

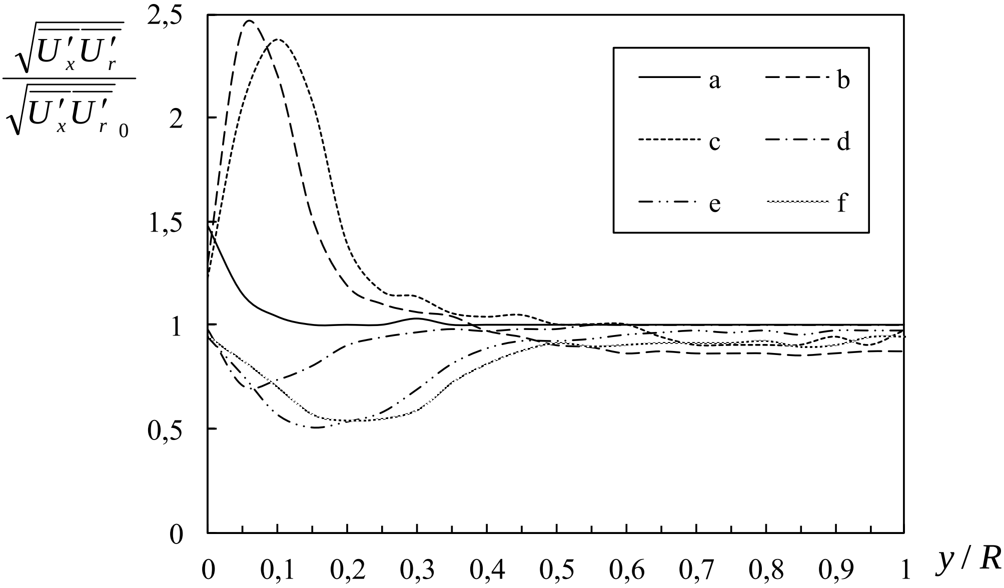

Fig. 6 The axial and radial velocities pulsations correlation in non-isothermal conditions, Re=3100...9300, T_w/T_f=1.18, a-($\overline{Ho}$=0.25, *Kg**=0.088), b-($\overline{Ho}$=0.5, *Kg**=0.111), c-($\overline{Ho}$=0.75, *Kg**=0.088), d-($\overline{Ho}$=0.25, *Kg**=-0.088), e-($\overline{Ho}$=0.5, *Kg**=-0.111), f-($\overline{Ho}$=0.75, *Kg**=-0.088).

4. HYDRODYNAMIC AND HEAT TRANSFER IN UNSTEADY CONDITIONS

4.1 Unsteady heat transfer coefficient

Based on unsteady turbulent flow structure data and analysis unsteady heat transfer coefficient was calculated by Lion's integral

$$\frac{1}{Nu_f} = 2\int_0^1 \frac{\left(\int_0^R \frac{U_x}{\overline{U}}\overline{R}d\overline{R}\right)^2}{\left(1+\frac{\lambda_T}{\lambda}\right)\overline{R}}d\overline{R} \qquad (3)$$

where λ - heat conductivity coefficient, W/(mK); λ_T- turbulent heat conductivity coefficient, W/(mK); U_x - axial velocity, m/s; $\overline{U}$ - averaged axial velocity, m/s; $\overline{R}$ - dimensionless radius.

A significant difference between the turbulent viscosity coefficient in unsteady and steady values up to 3 times was identified.

During flow acceleration the turbulent viscosity coefficient increases the steady values. At flow deceleration process– contrariwise.

The comparison of calculated heat transfer coefficients by (3) with the calculations performed by the quasi-stationary approach at flow acceleration and deceleration presented on fig. 7 and fig. 8.

The graphics demonstrate significant difference up to 2 times between quasi-steady and unsteady approaches for *Re*=3100…9300, *Kg**=-0.111…0.111 and T_w/T_f=1.18.

These results have a good agreement with heat transfer experimental data of other authors [1, 5].

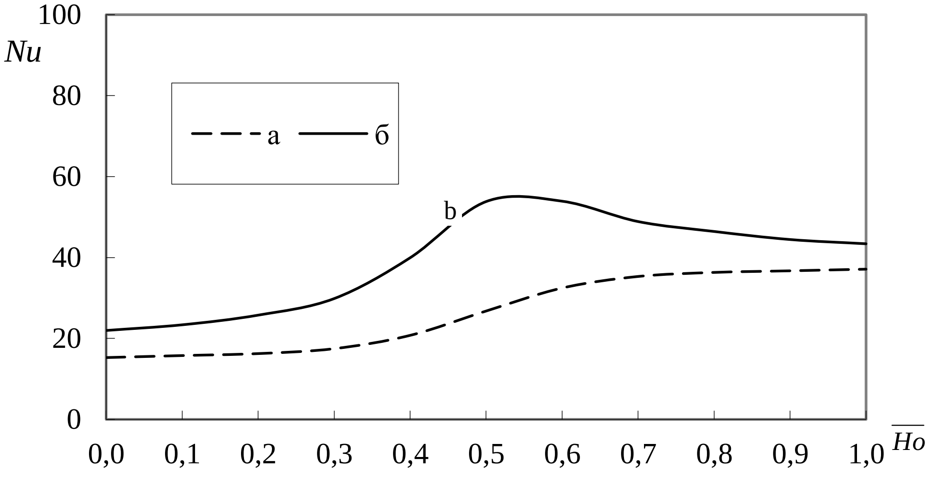

Fig. 7 Flow acceleration influence on heat transfer coefficient. *Re*=3100...9300, T_w/T_f=1.18:
a - quasi-stationary approach, b – unsteady approach calculation Moscow Aviation Institute model

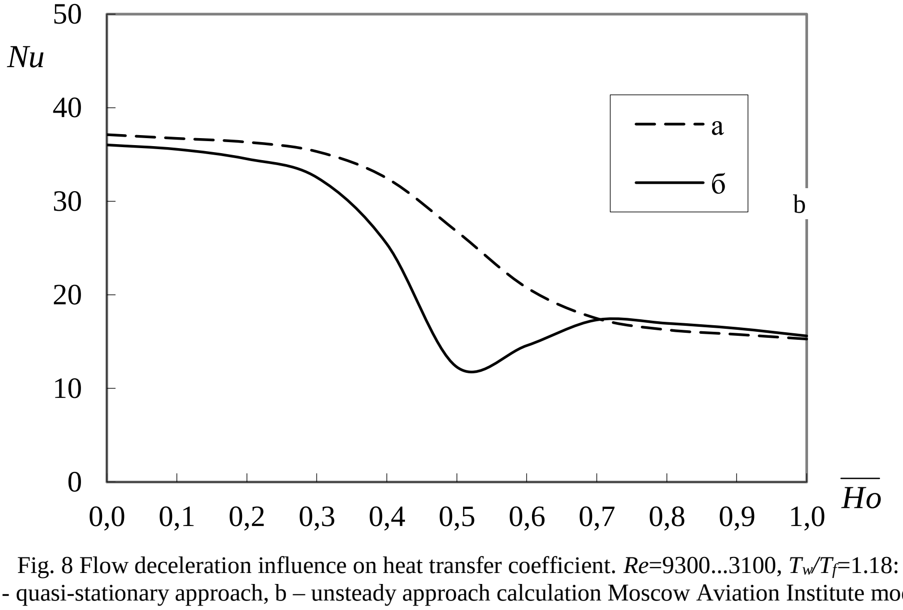

Fig. 8 Flow deceleration influence on heat transfer coefficient. *Re*=9300...3100, T_w/T_f=1.18:
a - quasi-stationary approach, b – unsteady approach calculation Moscow Aviation Institute model.

4.2 Unsteady hydrodynamic resistance coefficient

The results of hydrodynamic resistance coefficient calculation presented on fig. 9 and 10 for acceleration and deceleration cases.

Dimensionless hydrodynamic resistance coefficient was calculated as

$$\frac{\xi}{\xi_0} = \frac{\overline{U'_x U'_r}}{\left(\overline{U'_x U'_r}\right)_0} \tag{4}$$

where $\overline{U'_x U'_r}$ - axial and radial velocity correlation in unsteady conditions, m²/s²; $\left(\overline{U'_x U'_r}\right)_0$ - axial and radial velocity correlation in steady conditions, m²/s².

On these graphics also presented quasi-steady calculations and experimental results other authors [1, 5].

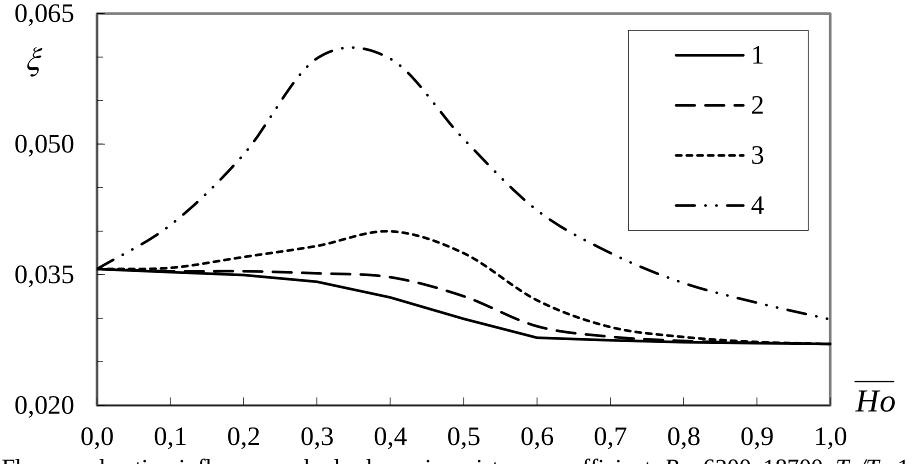

Fig. 9 Flow acceleration influence on hydrodynamic resistance coefficient. *Re*=6200..18700, T_w/T_f=1:
1 - quasi-steady approach, 2 – experimental data [5], 3 - – experimental data [12],
4 – unsteady approach calculation Moscow Aviation Institute model.

The comparison reflects very good qualitative agreement between hydrodynamic resistance coefficient calculated with unsteady turbulent structure data and experimental data of between hydrodynamic resistance.

However, there's quantity differences during unsteady process. We explain that fact by different substance in present research and [1, 5]. The authors used water, but in present research we used air.

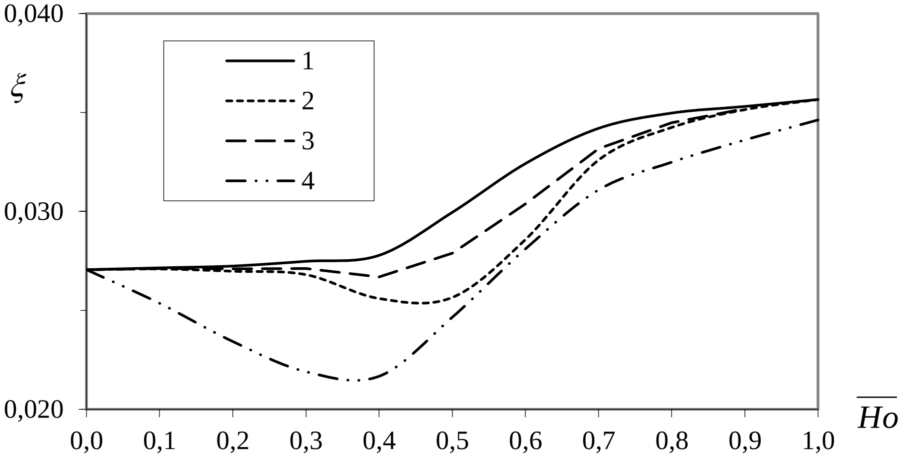

Fig. 10 Flow deceleration influence on hydrodynamic resistance coefficient. *Re*=18700..6200, T_w/Tf=1:
1 - quasi-steady approach, 2 – experimental data [5], 3 - – experimental data [1],
4 – unsteady approach calculation Moscow Aviation Institute model.

On the basis of the revealed significant influence of hydrodynamic and thermal unsteadiness on the flow hydrodynamics the calculated relations are obtained.

When accelerating the flow, the coefficient of hydraulic resistance exceeded the corresponding quasi-stationary value by more than 2 times, and when slowing down, it was less by 35%.

5. PRESENT RESEARCH OF UNSTEADY PROCESSES

As noted above, the results of experimental research are reliable basis for theoretical studies that are carried out in the Moscow Aviation Institute [13]. Let us formulate the most basic conclusions. The existing high-Reynolds turbulence models are in principle unable to take into account the effect of unsteadiness. Of the turbulence models considered in [13], only the Shear Stress Transport (SST) Menter model, which is low-Reynolds model, gives results similar to the experimental data. In principle, high-Reynolds turbulence models are not able to take into account the effect of unsteadiness in any way. More detail description of unsteady simulation method presented in [14]. Although the SST model gives results similar to experimental data, it significantly overestimates the unsteady effect in some modes. In the course of the work, universal analytical expressions for the hydraulic resistance coefficient and its derivative in the parameter for the flow in channels for smooth and rough pipes were obtained for the first time. Generalizing dependences for engineering calculations of unsteady hydraulic resistance and heat transfer coefficients at gas flow acceleration and deceleration are received. Authors [15] successfully used Large Eddy Simulation (LES) approach for unsteady turbulent flow calculation. They found LES is less costly in comparison to the Direct Numerical Simulation (DNS) method.

A feature of the dependences is the possibility of their application for any monotone flow curve and good convergence with the experimental data on the hydrodynamically unsteady flow of gases in the channels [1]. Based on the analysis of experimental data, an empirical model of the vortex viscosity in the channel was compiled. By the physical nature of its form, the obtained dependence for the vortex viscosity is similar to a traveling wave that occurs on the wall and goes to the core of the flow. With the increase in the Reynolds number, the peak amplitude of this wave decreases, and its width and shift relative to the channel wall increase both for acceleration and for deceleration of the flow. The obtained model is applicable for the range of Reynolds numbers from 3000 to 30000 and absolute values of the unsteadiness criterion Kg^* from 0 to 0.111. The influence of hydrodynamic unsteadiness on the turbulent Prandtl number is established. In [11] the formulas for calculating the turbulent Prandtl number depending on the acceleration or deceleration of the flow are proposed. In this case, the acceleration of the flow increases the turbulent Prandtl number, and the deceleration decreases. A non-cost mathematical model of turbulence has been obtained and tested, which is capable of adequately performing calculations of hydrodynamically unsteady turbulent gas flows in the channels, both in the presence and in the absence of heat exchange. This model is compared with experimental data for the range of Reynolds numbers from 3000 to 30000 and absolute values of the criterion of unsteadiness Kg^* from 0 to 0.111 and showed a sufficient degree of convergence of the calculated data and the experiment.

Among the works of theoretical character in the first place should highlight the research of Professor Igor Derevich. In [10] the gas flow is considered at monotonic decrease or increase of the flow rate. The gas flow has a turbulent character, the Reynolds number Re flow in the entire range of flow changes is significantly higher than the critical value. A noticeable part in the pressure drop is the work of the friction forces associated with the processes of turbulent momentum transfer and depending on the intensity of chaotic velocity fluctuations. The dynamics of the turbulent energy behavior is different for the cases of increasing and decreasing the gas flow rate. The change in the level of turbulent energy causes a difference between the friction coefficients and their stationary values. In [10] the theoretical analysis of the influence of the flow rate change on the parameters of turbulent momentum transfer is carried out. It is shown that depending on the relationship between the time scales of turbulence and the characteristic time of flow change, there are different approaches to the analysis of the problem of unsteadiness. A qualitative comparison of the calculation results and a number of experimental data is presented. Discusses the causes of the error data of calculation and experiment.

Thus, the discrepancy in the results of experimental and theoretical studies was revealed. Only new experimental studies in a wide range of regime parameters will provide new information, and therefore material for further discussions, understanding of the ongoing non-stationary processes and new models of non-stationary turbulence. The results of numerical simulation and experimental study of the structure of unsteady flows in pipes with different cross sections are presented in the article [16]. Steady vortex structures are observed in pipes with cross sections in the form of a square and an equilateral triangle. It was found that these secondary flows have a significant impact on gas flows in pipes of complex configuration.

Authors [17] in modeling research found large-scale vortexes oscillation. These large-scale vortexes plays very important role because of high energy. For further unsteady turbulence research is necessary to analyze frequency spectrum of pulsation [18, 19].

The most recent article [20] shows the central problem of turbulence research, is to understand the law large-scale vortexes generation in wall area and they evolution. This processes understanding is much more useful for unsteady processes. We suppose the unsteady influence on vortexes evolution process is a basis of significant changes in hydraulic and heat transfer. In this direction of present research the frequency analysis of unsteady flow will be done.

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