Model

Let's consider a volume V, in which there is air of mass m with an enthalpy broken flow:

$$i_0 = i + \frac{w^2}{2},$$

where $i = u + \frac{p}{\rho}$ – enthalpy, J/kg; u – specific interior energy, J/kg; p – static pressure, Pa: ρ – density, kg/m^3; $\frac{w^2}{2}$ – specific kinetic energy, J/kg.

Inside of a volume air is fed by a mass $m^{(1)}$ with an enthalpy of braking

$$i_0^{(1)} = i^{(1)} + \frac{w^{2(1)}}{2}$$

and air is discharged

$$i_0^{(2)} = i^{(2)} + \frac{w^{2(2)}}{2}.$$

For small period $d\tau$ in a volume the energy is fed dQ also it is discharged dL. On the basis of an energy conservation law we shall record in a differential form a variation of parameters of air inside a volume as follows

$$\frac{dQ}{d\tau} - \frac{dL}{d\tau} = \frac{d(i_0 m)}{d\tau} - \frac{d\left(i_0^{(1)} m^{(1)}\right)}{d\tau} + \frac{d\left(i_0^{(2)} m^{(2)}\right)}{d\tau} \quad (1)$$

Let's take

$$B = \frac{dQ}{d\tau} - \frac{dL}{d\tau}.$$

A variation of a mass of substance in the chosen volume it is determined from an equation

$$\frac{dm}{d\tau} = G^{(1)} - G^{(2)}, \quad (2)$$

where $\frac{dm^{(1)}}{d\tau} = G^{(1)}$ – rate of flow of incoming air; $\frac{dm^{(2)}}{d\tau} = G^{(2)}$ – rate of flow of outcoming air.

After conversions of an equation (1) we have

$$m\frac{di_0}{d\tau} = B + i_0^{(1)} G^{(1)} - i_0^{(2)} G^{(2)} - i_0\left(G^{(1)} - G^{(2)}\right) + D,$$

where $D = m^{(1)} \frac{di_0^{(1)}}{d\tau} - m^{(2)} \frac{di_0^{(2)}}{d\tau}$.

Let's express an enthalpy of braking in therms of temperature of braking:

$$i_0 = C_p T_0,\ i_0^{(1)} = C_p T_0^{(1)},\ i_0^{(2)} = C_p T_0^{(2)}.$$

We have

$$mC_p \frac{dT_0}{d\tau} = B + B_1 - C_p T_0\left(G^{(1)} - G^{(2)}\right) + D_1, \quad (3)$$

$$B_1 = C_p T_0^{(1)} G^{(1)} - C_p T_0^{(2)} G^{(2)};$$

$$D_1 = m^{(1)} C_p \frac{dT_0^{(1)}}{d\tau} - m^{(2)} C_p \frac{dT_0^{(2)}}{d\tau}$$

where C_p – specific heat of air at constant pressure, J/ (kg·deg).

Let's assume, that parameters of braking air in a volume are described by an equation of a condition:

$$P_0 = RT_0 \frac{m}{V};$$

$$P_0 = P\left(1 + \frac{k-1}{k}\frac{m}{VP}\frac{W^2}{2}\right)^{\frac{k}{k-1}},$$

where P_0 – full pressure, Pa; P – static pressure, Pa; R – universal gas constant, J / (kg·deg).

We differentiate an equation of a condition with respet to time and after conversions it is obtained:

$$\frac{dT_0}{d\tau} = \frac{P_0}{R}\left(\frac{1}{m}\frac{dV}{d\tau} - \frac{V}{m^2}\frac{dm}{d\tau}\right) + \frac{V}{mR}\frac{dP_0}{d\tau}. \quad (4)$$

Let's insert an equation (4) in (3):

$$C_p \frac{V}{R}\frac{dP_0}{d\tau} = B + C_p T_0^{(1)} G^{(1)} - C_p T_0^{(2)} G^{(2)} + D_2, \quad (5)$$

where $D_2 = D_1 - C_p \frac{P_0}{R}\frac{dV}{d\tau}$.

The system of differential equations (2), (4), (5) describes process of variation of pressure and temperature of air inside a volume in terms of parameters of braking at input dQ and output dL of energy, at presence of feed into $G^{(1)}$ and discharge $G^{(2)}$ air, under variation of a volume dV. We shall consider some particular solutions which follow from the obtained set of equations. If process of air flowing from a volume is accompanied by a variation of a volume from an equation (5) follows, that with other condition being equal there is air pressure decrease in a volume at $\frac{dV}{d\tau} \succ 0$ or air pressure increase in a volume at $\frac{dV}{d\tau} \prec 0$.

At the of air flowing from the big volume ($T_0 = T, P_0 = P$) and constant temperature of air in a volume $\left(\frac{dT_0}{d\tau} = 0, T_0 = \text{const}\right)$ the equation (4) will be transformed to an equation according to publication [6]:

$$\frac{dP}{d\tau} = \frac{RT}{V}\left(G^{(1)} - G^{(2)}\right). \quad (6)$$

Taking into account additional condition:

$$B = 0;\quad \frac{dT_0^{(1)}}{d\tau} = 0;\quad \frac{dT_0^{(2)}}{d\tau} = 0$$

the equation (6) will be transformed to an equation

$$\frac{dP_0}{d\tau}=\frac{R}{V}\left(T_0^{(1)}G^{(1)}-T_0^{(2)}G^{(2)}\right). \qquad (7)$$

From the comparative analysis of models (6) and (7) follows, that model (7) is preferable as it takes into account temperature of fed and discharge air.

Air pressure variation in the big volume ($P_0=P, T_0=T$) at a supply and extraction of air with constant temperature

$$\left(\frac{dT_0^{(1)}}{d\tau}=0, T_0^{(1)}=\text{const}\right);$$

$$\left(\frac{dT_0^{(2)}}{d\tau}=0, T_0^{(2)}=\text{const}\right)$$

and a constant volume ($V=\text{const}$) the equation (6) will be transformed to an equation for adiabatic process according to publication [5]:

$$\frac{dP}{d\tau}=\frac{k-1}{k}\frac{1}{V}\left(\frac{dQ}{d\tau}-\frac{dL}{d\tau}+C_pT^{(1)}G^{(1)}-C_pT^{(2)}G^{(2)}\right),$$

where $\frac{k}{k-1}=\frac{C_p}{R}$; k – ratio of specific heats.

Researches of this mathematical model and its field of application is shown in publication [11].

Thus, the system of differential equations (2), (4), (5) is the generalized model of the of air flowing from a compartment. To solve the system of differential equations the ratc of flow is calulatid by formula

$$G=F\frac{P_{01}}{RT_{01}}\left(\frac{P_2}{P_{01}}\right)^{\frac{1}{n}}W;$$

$$W=\sqrt{2}\sqrt{\frac{Rn}{n-1}(T_{02}-T_{01})+b};$$

$$b=C_p\left[T_{02}\left(\frac{P_1}{P_{02}}\right)^{\frac{n-1}{n}}-T_{01}\left(\frac{P_2}{P_{01}}\right)^{\frac{n-1}{n}}\right]+q-l,$$

where n – polytropic exponent; q – the specific input energy, J/kg; l – a specific output energy, J/kg.

The polytropic exponent is determined according to resistance to interference methods [12; 13].

Experiment

Experimental researches of processes of air flowing from compartments of an airplane were carried out. At one operation altitude of flight (h = 5000 м) depressurization of an airplane was carried out. Measurement of air pressures in compartments of an airplane during depressurization was performed with the help of the airplane equipment. Results of such researches in a compartment is shown in fig. 1.

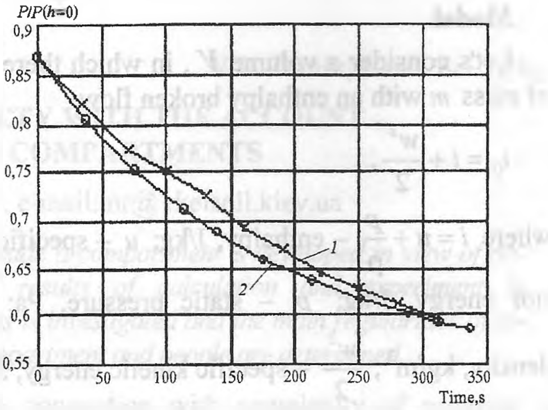

Fig. 1. Comparative estimation of results of calculation and experiment of air pressure variation in a compartment $P/P(h=0)$ concerning a standard atmosphere with respect to the time:
1 – experiment; *2* – calculation

The developed system of differential equations (2), (4), (5) describes process of air flowing from compartment and reflects character of pressure variation of air in a compartment. The error of result of calculation of a full air pressure in a compartment does not exceed 11 %. Significant errors of results of calculation were noticed on transient regimes of flow of air that is stipulated by inertia properties of the airplane measuring equipment. The accuracy of measurement of an air pressure essentially depends on sizes of a compartment. For the big volumes the location of sensors of measurement of an air pressure did not influence indications of sensors. With reduction of sizes of a compartment, when values of full and static pressure do not coincide ($P_0 \neq P$), indications of sensors was influenced by dynamic component ($\rho W^2/2$) of a flow. Therefore for such compartments it is required to produce an integration of a system of differential equations for an estimation of concreteness of results of calculation with respect to a volume. The carried out calculations with application of numerical methods have confirmed the influences of dynamic component a flow in a compartment on results of measurements. Measurements of air pressures in compartments was conducted also at other operation altitudes of flight. Results of calculation according to a system of differential equations had steady estimations.

Numerical researches

On the basis of a system of differential equations (2), (4), (5) numerical researches of a variation of parameters of air inside compartments during of air flowing between compartments were carried out. On the basis of parameters of air the estimation of influence of processes of flow of air on a structure of an airplane and people which were accomodated in compartments was provided. The estimation was performed by the limit values. For a structure limit pressures at which the structure withstood effect of a flow were set. For people the limit pressure on a level of acoustical pressure equal to 2×10^3 Pa. If during flow of air parameters of a flow reached limit values calculation of parameters of air was performed from an initial state of process of the flowing. Thus, parameters of devices for air flowing varied (with the given integration step) or the limit value of a structure was increased. The method of searching of the solution of such problem was set in the beginning of calculation. At excess of parameters of limit pressure flow with respect to level of sound pressure there were changes only in parameters of structure for air flowing or parameters of feed and discharge air. Wave propagation velocity is determined under the formula

$$W_в = \sqrt{\frac{dP}{d\rho} + \rho W \frac{dW}{d\rho} + \frac{W^2}{2}\frac{dP_0}{d\rho}}. \qquad (8)$$

The equation (8) determines a velocity of a wave in stable air depending on static and full pressure, a velocity and density, dynamic component a moving flow. At a supply and extraction of air from a compartment dynamic components render essential influence on formation of disturbances in a compartment.

Optimization of parameters of process under examination and selection of a preferable structure is made until parameters of a moving flow do not exceed limit values. It is necessary to notice, that a structure of a compartment and people are affected by the processes of air flow through parameters of the broken flow. Character of interaction of a flow and a structure depends on value $dV/d\tau$, static and dynamic component of a flow, elastic properties of a structure.

The carried out researches of processes of flow of air between compartments at altitudes of flight up to 12 km show, that maximum effect of a moving flow on a structure of a compartment and people is determined by maximum pressure differentials of air between compartments and conditions of air flow altitude. Maximum effect of a flow may be reached not necessarily on a maximum altitude of flight. So for some versions of a structure maximum effect is obtained at altitudes of flight of 6…7 km. Such effect is provided by variation of a condition of flow in the critical area. In many cases the solution of such problem is reduced to searching the preferable solution at all operation altitudes of flight.

Pressure variation of air in a compartment in climb of an airplane with different relative slots (F0-relation of area of a slot to area of the outlet valve) in a compartment is shown fig. 2. Sizes of a slot and character of slot forming influences the pressure variation of air in a compartment. Essential influence on people and a structure provides the initial moment of the air flowing from a compartment. It is possible to explain it by unstabilite of process of the of air flowing from a compartment.

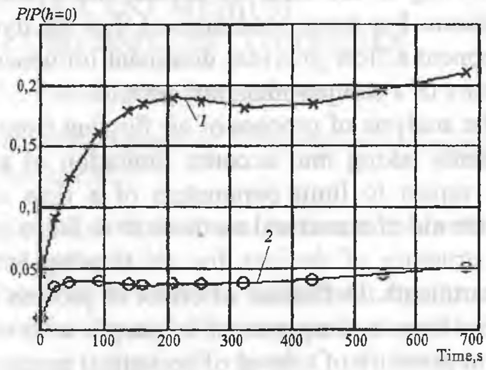

Fig. 2. Air pressure variation in a compartment $P/P(h=0)$ concerning a standard atmosphere with respect to the time:
$1 - F_0 = 0{,}45$; $2 - F_0 = 0{,}97$

The feeding and discharging of air from a compartment influences not only air pressure variation in a compartment, but also variation of air temperature. So the tapping of warm air from a compartment reduces the temperature of air in a compartment. From this regularity of examined process the method of cooling of a compartment may be used by tapping the warm air.

Effect of processes of air flowing on people is especially exhibited on transient regimes of air flow or at different kinds of damage of a structure of a compartment. Such kinds of damages are structural failures of a compartment, damage of partitions between compartments, failures in devices intented for air flowing between compartments. Significant effect on people is rendered with different cases of depressurization of compartments of an airplane in connection with sudden opening of doors, hatches, skin as the critical conditions of flow started. In these cases the pilot feels maximum acoustic effect of an airflow and at this time he is required to make the decision on safety control of an airplane. Therefore selection of parameters of devices on air flowing between compartments(atmosphere) is determined for each airplane individually and to minimize effect of a flow on the pilot is one of the important problems on safety provision for an airplane.

Conclusions

Thus, the mathematical model of the of air flowing from a compartment is developed subject to parameters of braking of feed and discharged air. The mathematical model describes wider class of problems and describes with sufficient for practice accuracy process of the air flowing from of a compartment.

On the basis of mathematical model the numerical researches of processes of air flowing between compartments are carried out. Essential influence on a structure and people is provided the processes of air flowing in the field of critical and overcritical conditions. For these conditions of flow the dynamic component a flow provides dominant influence on a structure of a compartment and people.

The analysis of process of air flowing from compartments taking into account limitation of a flow with respect to limit parameters of a flow allows with the aid of numerical methods to define a preferable structure of devices for air flowing between compartments. Definition of effect of process of air flowing from a compartment on people with respect to limit pressure of a level of acoustical pressure essentially simplifies a problem to be solved. Such method of a problem solution reduces a noise level in a source of its formation and does not consider the ways of its propagation.

The carried out experimental and numerical researches shows, that it is necessary to continue works on study of processes inside compartments at the point application of the energy, suddenly varying parameters inside a compartment. To conduct researches of influence of velocity vector and dynamic component a flow on processes of air flowing from a compartment.

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В.Д. Доник

Забезпечення безпеки польоту з урахуванням перетікання повітря між відсіками літака

Розроблено математичну модель визначення параметрів повітря всередині відсіку літака з урахуванням параметрів підвідного і відвідного повітря. Проведено зіставлення результатів розрахунку і експерименту. Вивчено механізм перетікання повітря між відсіками і визначено основні закономірності впливу параметрів потоку на конструкцію відсіку і людей.

В.Д. Доник

Обеспечение безопасности полета с учетом перетекания воздуха между отсеками самолета

Разработана математическая модель определения параметров воздуха внутри отсека самолета с учетом параметров подводимого и отводимого воздуха. Проведено сопоставление результатов расчета и эксперимента. Изучен механизм перетекания воздуха между отсеками и определены основные закономерности влияния параметров движущегося потока на конструкцию отсека и людей.