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MATHEMATICAL MODELING OF A THERMAL CONDITION OF AIRCRAFT COMPARTMENTS

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ABSTRACT

In solving various scientific and technical problems in the field of aircraft development and operation, the necessity is arisen to determine the thermal condition of compartments, to evaluate efficiency of the system providing their thermal condition and thermal insulation. At present, transfer of the centre of gravity from flight tests to mathematical modeling is advanced. It is connected with solution of direct and inverse heat exchange problems, whose realization is complicated by a number of unsolved questions.

In general case, it is proposed to represent the mathematical model of the compartments as a system of one-dimensional differential heat-transfer equations describing the process of thermal energy transfer through a thermal-insulation skin and ordinary differential equations describing radiation and convection heat transfer of the compartment components: the airborne equipment, people, skin and air medium. The radiation heat transfer coefficients of the compartment components are determined by Monte-Carlo method. The convection heat transfer coefficients of the skin surfaces and the compartment components are proposed to use the equations of the type

$$\alpha(t) = \vartheta_1 J^{\vartheta_2}(t), \tag{1}$$

where J is the air mass speed module; t is the time; ϑ_1 , ϑ_2 are the estimated coefficients of the model.

To determine the thermal condition of the compartments, the calculations are performed on the basis of the equations describing the process of the thermal energy transfer through the thermal-insulation skin and the radiation-convection heat transfer of the compartment components. For this, discretizition of one-dimensional differential equations for the skin is made over the spatial variable by the Galerkin method using piecewise-linear basis. Owing to this method, the solution is reduced to the numerical solution of a system of ordinary differential equations, where unknowns are the temperature values at the node points of the given mesh. The obtained ordinary differential equations for the skin, the equations

for the compartment components and air constitute a system of ordinary differential equations, which in general form can be written as follows:

$$Y_t = f(Y, t, \Theta), \quad t \in (0, T),$$

$$Y(0, \Theta) = Y_0 \quad , \quad f,\ Y \in R^s \quad , \quad \Theta \in R^r \quad ,$$

where Y is the temperature vector of the skin, compartment components and air; $\Theta = [\vartheta_l]_{l=1}^{r}$ is the vector of the model's coefficients.

The calculation of the temperatures Y is carried out using an algorithm based on application of the Rosenbrok second order approximation method. The calculation of the system (2) at one numerical integration step occurs as follows:

$$Y_{n+1} = Y_n + a\, K_1^Y + (1 - a)\, K_2^Y \,, \quad a = 1 - 1/\sqrt{2} \quad ; \tag{2}$$

$$(I - a\, h\, f_Y)\, K_1^Y = h\, f\, (Y_n, t_n + a\, h, \Theta); \tag{3}$$

$$(I - a\, h\, f_Y)\, K_2^Y = h\, f\, (Y_n + aK_1^Y, t_n + 2ah, \Theta), \tag{4}$$

where h is the integration step, which is generally chosen depending on a required accuracy of integration; f_Y is Jacobian matrix of the system (2); K_1^Y, K_2^Y are the auxiliary vectors. They are determined from the equations (3), (4).

The coefficients, of the model are evaluated by minimizing the sum of squared residuals between the temperature values Y measured in experiment and the corresponding values $Y(t,\ \Theta)$, calculated by equations of the models.

The results of checking adequacy of the thermal condition model for Embraer 190 crew cabin are presented as an example.

So, the proposed method allows to carry out mathematical modeling the thermal condition for different compartments in solution of direct and inverse heat-transfer problems. The results of mathematical modeling of the thermal condition of a pressurized thermal-insulated compartment of the real aircraft are presented.