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Interferometric Research of Heat Transfer at Air Jet from Ventilating Outlets

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Introduction

When designing the outlets for the ventilation or hot-air heating of particular spaces, we meet usually the problems to specify a form and reach of the air jet and a distribution of velocities and temperatures in the space followed. In practice the calculations of non-isothermal air jets are made using a number of calculation relations to be found e.g. in lit. (1) and other. But when applying the analogical relations derived by different authors we can find out considerable differences in results. This contribution is aimed at an experimental research of power and speed distribution in free lightly non-isothermal air jets from horizontally situated circular outlets. The experiments are carried out using Mach-Zehnder interferometer and CCD camera connected to PC.

Theoretical Analysis of Problem

In theoretical solution of free, lightly non-isothermal jet problems, we can say that in the space with the same static pressure, the heat flow and thereby even the enthalpy flow will be, in the direction of flow, related to the ambient environment parameters ΔH [W] constant and will equal to the heat power of the ventilating outlet W_o [W]. The following relation is valid

$$W_o = \Delta H_o = w_o \cdot A_o \cdot \rho_o \cdot c_p [T_o - T_i] \cdot \\ = \Delta H(x) = w(x) \cdot A(x) \cdot \rho(x) \cdot c_p [T(x) - T_i] \quad (1)$$

where ΔH_o [W] is an enthalpy flow in the mouth of ventilating outlet and $\Delta H_o(x)$[W] is an enthalpy flow in the distance x from the mouth of ventilating outlet in the jet direction. Furthermore in the equation, (1), c_p [J.kg^{-1}.K^{-1}] indicates a mean value of specific heat capacity under a constant pressure in the area followed, w_o, $w(x)$ [m.s^{-1}] a mean flow velocity based on the cross-section in the ventilating outlet mouth and in the distance x, A_o, $A(x)$ [m^2] an area of ventilating outlet cross-section and jet cross-section in the distance x, ρ_o, $\rho(x)$ [kg.m^{-3}] a mean flow density in the ventilating outlet mouth and in the distance x and T_i, T_o, $T(x)$ [K] ambient environment temperature, a mean jet temperature based on the flow rate in the mouth of the ventilating outlet and a mean flow temperature based on the flow rate in the place x. The equation (1) can be modified by introducing a mean value of the change of the volumetric enthalpy density in the place x $\Delta h_v(x)$ [J.m^{-3}] and a mean value of the change in a linear enthalpy density in the place x $\Delta h_x(x)$ [J.m^{-1}] to the form

$$W_o = w(x) \cdot A(x) \cdot \Delta h_v(x) = w(x) \cdot \Delta h_x(x) \quad (2)$$

The distribution of enthalpy can be obtained effectively from interferometric records of air jets. The change in linear enthalpy density is given by the relation (2)

$$\Delta h_x(x) = -\lambda \frac{c_p \cdot T_i}{K} \int_{y_1}^{y_2} \Delta S(x,y)\, dy \tag{3}$$

where λ [m] is a wave length of light, K [$m^3.kg^{-1}$] is a Gladstone-Dale constant, $\Delta S(x,y)$ [-] is a change in interference order, y_1 and y_2 are y co-ordinates of the flow boundaries in the section x.

Results of Research

The interferometric research of enthalpy distribution in lightly non-isothermal air jet has been performed with horizontally placed circular ventilating outlet of $d_o = 30$ mm. The typical interferogram of air jet is given on the Figure 1. This interferogram is processed by means of *Interfer* 2.0 software (3). The change in interference order $\Delta S(x,y)$ in the jet can be obtained from a relative shift of interference fringes towards the reference grid of fringes.

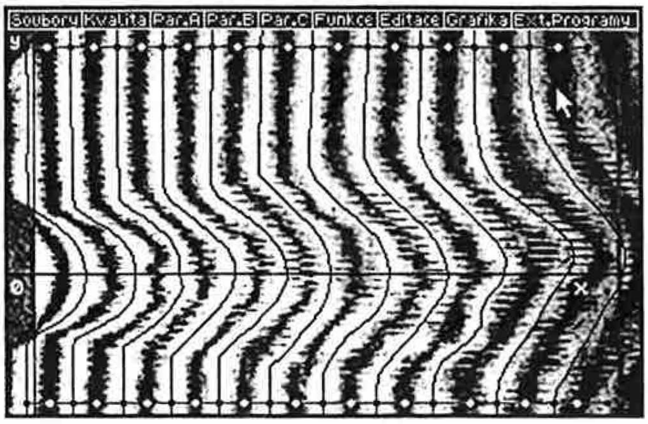

Figure 1 Interferogram of air jet
w_o= 7.7 m.s^{-1}, t_o= 55.0°C,
t_i = 22.0°C, p_i = 97840 Pa

The evaluation of enthalpy distribution from recorded interferograms is performed from the data measured during the record of interferograms d_o, w_o, t_o, t_i, p_i, from the wave length of light λ, from the scale of representation, from automatically specified positions of fringes in the reference area and from automatically specified behaviours of interference fringes passing through non-isothermal air jet examined. For the evaluation of the enthalpy distribution, a specially developed software *Enthalpy* working with these data is used which can be started directly from the *Interfer 2.0* software. The example of the enthalpy distribution evaluated from the interferogram on the Figure 1 is given on the Figure 2. At the top to the left there are the values of data measured at the record of interferogram and at the bottom to the left there are degrees of polynomials applied for the evaluation (can be changed by an user). In the middle part at the top there is a picture for checking the correct interleaving of fringes and under it there are the evaluated courses of jet diameter *D(x)*, trajectory of jet axis *y(x)*, change in the linear enthalpy density $\Delta h_x(x)$, but also a mean flow velocity based on the cross-section *w(x)* based on the equation (2). At the top to the right there is Archimedean number and a heat power of the ventilating outlet, at the bottom then the ranges of a diagram and values of quantities in a chosen section *x*.

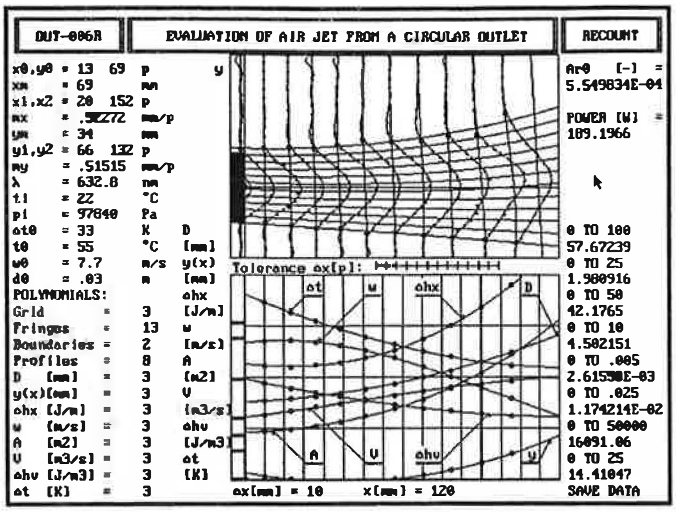

Figure 2. Evaluation of air jet interferogram from the Figure 1

When the lightly non-isothermal air jet flows from the circular outlet it can be presupposed that the air jet in a free space has a circular cross-section, too. The experiments have demonstrated that even free jets from a rectangular and slot ventilating outlet pass over in some distance to a circular jet. Under this presupposition it is possible, in addition to above given dependencies, to express also the jet cross-section behaviour $A(x)$, distribution of the mean change of the volumetric enthalpy density $\Delta h_v(x)$, distribution of the volumetric flow $V(x)$ [$m^3.s^{-1}$] and distribution of the mean difference of temperatures $T(x)$ - T_i which are given in the Figure 2, too.

Conclusion

The contribution specifies possibilities of the interferometric research of enthalpy distribution in a free, lightly non-isothermal air jet from different ventilating outlets, which can be useful not only for the flow power balance, but even for the research of other flow parameters, such as velocity, volumetric flow or mean flow temperature. The results of the interferogram evaluation are curves of jet boundaries, curve of jet axis, distribution of linear enthalpy density, distribution of mean flow velocity, behaviours of jet cross-section, distribution of volumetric enthalpy density, distributions of volumetric flow and distributions of mean temperature difference in the air jet towards the environment. The works have been realized within the project solution COST - G3 "Investigation of temperature fields in industrial buildings with various manners of ventilation and heating" and within the project solution of the Ministry of Education "Numerical and physical modelling of problems of thermofluid mechanics, mechanics of solids and phase changes".

References

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