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Infrared thermography and the numerical heat transfer analysis

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Abstract

A method which enables the use of the data obtained by the IR thermography in the numerical heat transfer analysis has been developed. The method was tested on the model created for the determination of the local heat transfer coefficients on the extended surfaces. The temperature fields on the single annular and square fins were measured by means of an IR camera. The values of the temperatures were used directly as the input data in the mathematical model developed for the calculation and graphical interpretation of the local heat transfer coefficients. The model is based on the method of control volumes and is adopted to be used on a PC.

Nomenclature

A	surface	m^2
r	radius	m
Q	heat flow rate	W
q_i	volumetric rate of heat generation	Wm^{-3}
t	temperature	K
t_o	ambient temperature	K
E, W, N, S, P	grid points	
e, w, n, s	control volume faces	
λ	coefficient of heat conductivity	$Wm^{-1}K^{-1}$
α	heat transfer coefficient	$Wm^{-2}K^{-1}$
Θ, φ	angle	rad

1. Introduction

The determination of the real temperature field on the extended surface is a primary condition for the calculation of the local heat transfer coefficients. Former investigations [3, 4] show that the temperature field which occurs on the fin surface differs from this calculated analytically. The experiments done show that the temperature field on the fin is biased in the direction of the air flow and is not symmetrical. In previous experiments, mostly the thermocouples were used for measuring temperature and that was the reason for a long duration of the measurements. In the experiment presented thermographic measurements of the temperature field have been applied, and the data obtained were directly used in the mathematical model. The model enables the calculation of the local heat transfer coefficients on the fin surface. The method has been tested on the single annular fin placed in the wind tunnel.

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2. Apparatus and procedure

2.1. Temperature field

The temperature field on the fin surface was measured with the thermographic system AGA 680 standard. A single fin fastened perpendicularly on a tube and placed in the working section of the wind tunnel was in stationary state. The measurements were carried out with the air stream velocities between 0,5 and 5 m/s and the fin base temperature between 30 and 80° C. The obtained temperature field has been used as the source of the input data into the mathematical model made to calculate the local heat transfer coefficients on the fin surface. The experimental rig and the thermograms of single annular and square fins are shown on *figures 1 and A*.*

2.2. Local heat transfer coefficients

For a thin annular fin being in a stationary state (*figure 2*) and made of high thermal conducting material, a differential equation describing the heat conduction through the fin can be given in the form:

$$\left(\lambda \frac{\partial^2 t}{\partial r^2} + \frac{\lambda}{r}\frac{\partial t}{\partial r} + \frac{\lambda}{r^2}\frac{\partial^2 t}{\partial \varphi^2}\right) + \dot{q}_i = 0 \qquad (1)$$

The data obtained by the thermographic measurements represent boundary conditions for equation (1). To solve the equation (1), a numerical method of control volumes has been chosen [5]. The problem was treated as two-dimensional (*figure 3*) and after the discretization of the equation (1) we get:

$$a_P t_P = a_E t_E + a_W t_W + a_N t_N + a_S t_S + b \qquad (2)$$

where

$$a_E = \frac{\lambda\, \Delta r\, z}{r_e\, (\delta\theta)_e} \;;\quad a_N = \frac{\lambda\, r_n\, \Delta\theta\, z}{(\delta r)_n} \;;\quad b = S_c\, \Delta V$$

$$a_W = \frac{\lambda\, \Delta r\, z}{r_W\, (\delta\theta)_W} \;;\quad a_S = \frac{\lambda\, r_s\, \Delta\theta\, z}{(\delta r)_s}$$

$$a_P = a_E + a_W + a_N + a_S + S_P\, \Delta V$$

and

* *The colour plates of this article **18** are located on page **VI** of the colour gathering, at the end of the book*

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ΔV control volume,
S_c is the constant part of the source term,
S_P is the dependant part of the source term.

If we write the equation (2) in the form:

$$a_E(t_P-t_E) + a_W(t_P-t_W) + a_N(t_P-t_N) + a_S(t_P-t_S) = \Delta V(S_c+S_P t_P) \quad (3)$$

after substitution, we obtain:

$$Q_e + Q_w + Q_n + Q_s = Q_P \quad (4)$$

which represents the heat balance of the control volume. Considering the fact that the temperature field is known from the measurements, we can write the expression for the heat transferred from the fin in the form:

$$Q_P = 2\ \alpha_l\ A_P(t_P - t_o) \quad (5)$$

Inserting the equation (5) in equation (4), we obtain the expression for the local heat transfer coefficient:

$$\alpha_l = \frac{Q_e + Q_w + Q_n + Q_s}{2\ A_P(t_P - t_o)} \quad (6)$$

Using the equations (2), (4), (5) and (6) the mathematical model for the calculation of the local heat transfer coefficients was made. The flow diagram of the mathematical model is shown on *figure 4*.

3. Results

The results obtained for one measurement are shown on *figure 5* together with the measuring parameters.
The values of the local heat transfer coefficients include convection and radiation. From the local heat transfer coefficients, the average one has been calculated for the whole fin and the results compared with those given in [2]. The comparison shows good mutual accordance (*figure 6*) which leads to the conclusion that the thermographic method can be successfully applied to the analysis of the temperature fields and the heat transfer from the fin surface.

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4. Conclusion

Thermographic method enables a quick determination of the real temperature field on the single fin surface. Supplied with the adequate software it enables the calculation of the heat transfer parameters such as the local and average heat transfer coefficients and the heat transferred from the fin. On the basis of such analysis the coefficient of performance for various fin shapes can be easily done. The graphical interpretation of one temperature field and the field of local heat transfer coefficients are given on *figure 7.* It can be concluded that the thermographic measurements of temperature fields can be successfully used as the basis of many research works dealing with the heat transfer problems, specially when the numerical analysis is applied.

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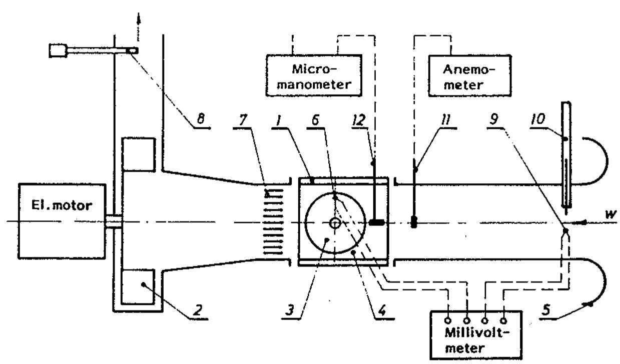

1. Perspex working section
2. Fan
3. Annular fin
4. PVC foil
5. Air inlet
6. Thermocouple
7. Honey comb
8. Throttle valve
9. Thermocouple
10. Glass thermometer
11. Anemometer
12. Pitot-tube

Fig. 1. - Experimental rig

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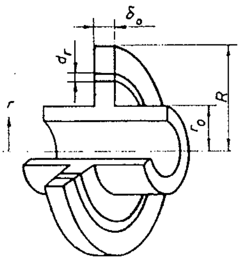

Fig. 2. - Annular fin

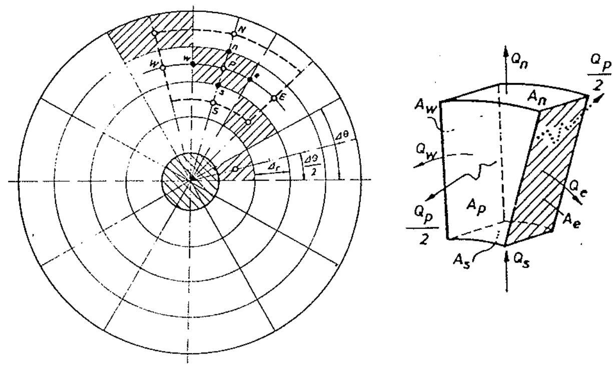

Fig. 3. - Control volumes

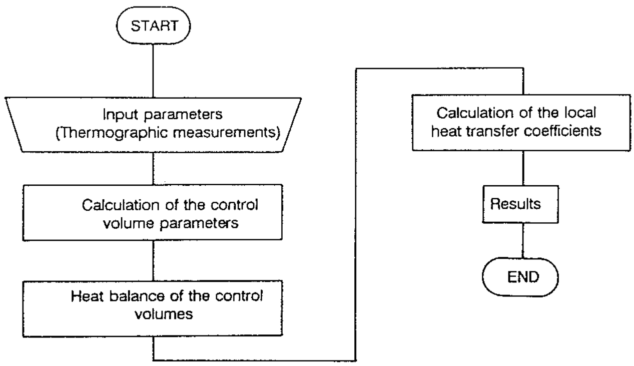

Fig. 4. - Flow diagram

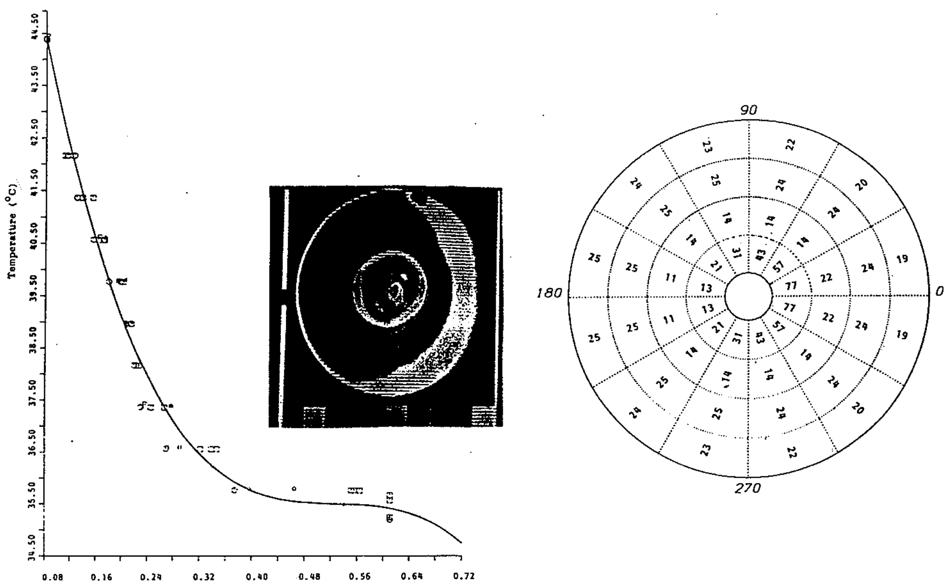

Fig. 5. - Thermogram, function of temperature distribution and the local heat transfer coefficients

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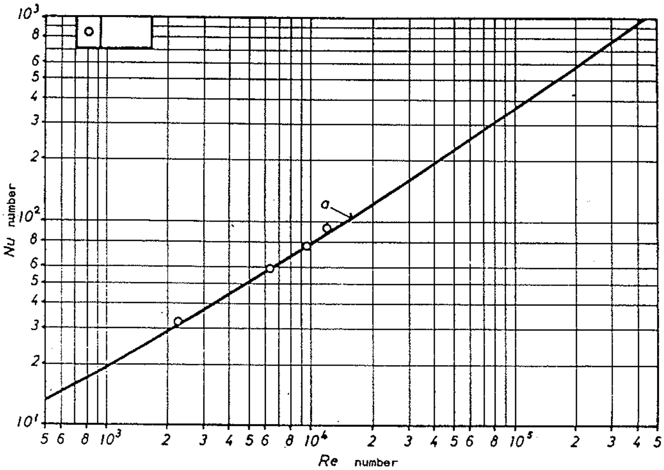

Fig. 6. - Average heat transfer coefficients (results obtained from the four measurements and compared with those given in /2/)

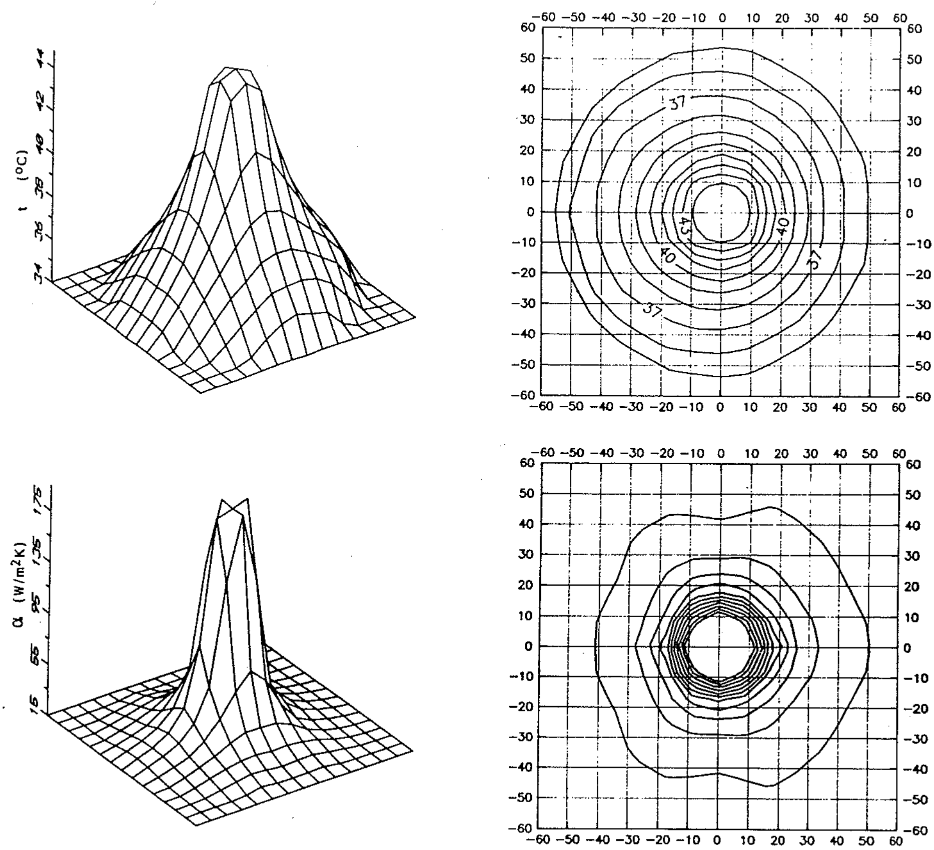

Fig. 7. - Temperature field and the local heat transfer coefficients