spectrum with the Infra 780A plates, whose peak sensitivity is in the range 7×10^{-7} to 8×10^{-7} m. In that case, the intensity of the radiation from the gas is much weaker than that from the surface. The results for T_s from one run in relation to x at successive instants $\tau = 1.5; 3.5; 5.5; 7.5; 9.5$ sec are shown in Fig. 3. These measurements show that there is a peak in the heat flux at the side surface, which appears to be due to a local area of detached flow (Fig. 1).

This one-dimensional inverse treatment for the graphite calorimeter is not applicable to turbulent heat transfer at a flat end, where the heat-transfer coefficient increases in accordance with a power law along the radius.

NOTATION

M, Mach number for incoming flow; T, temperature; q, heat flux; α, heat-transfer coefficient; τ, current time; x, longitudinal coordinate. Subscripts: 0, isentropic stagnation; w, wall; m, measured; s, side surface; l, laminar; t, theoretical.

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SMOOTHING SPLINES APPLIED IN THERMAL EXPERIMENTS

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Cubic smoothing splines are applied to heat transfer in a region of detached flow on a plate with a cylindrical obstacle.

The heat flow in the region around a cylindrical obstacle in a supersonic flow has been examined [1, 2] by means of thermal indicator coatings for models made of insulating material. It has been found that the longitudinal distribution of the heat flux $q(\bar{x})$ along the axis of symmetry of the model is of peaky type in this region.

The numerical method employed here for processing the results incorporates the nonstationary and two-dimensional characteristics of the heating, so it was possible to perform the study in an ordinary wind tunnel (with $M_\infty = 6.0$) on a model with a thin wall ($\delta = 10^{-4}$ m) made of conducting material fitted with thermocouples (Fig. 1). The number of thermocouples was raised to seven per 10^{-3} m [3, 4] in the region where the heat flux varied considerably. In the tests, the model was inserted rapidly (in 0.075 sec) into the flow. The readings from the thermocouples were recorded with high-sensitivity apparatus working with a light-beam oscillograph [5].

Figure 2a shows the longitudinal temperature distribution $t(\bar{x})$ along the symmetry axis $\bar{x}$ of the model at successive instants ($\bar{x} = x/d$, where $d = 3 \cdot 10^{-3}$ m is the diameter of the cylinder, while the axis of the cylinder passes through $\bar{x} = 0$, and the incident flow is directed from right to left).

The heat fluxes were computed with a BÉSM-6 computer from the measured temperature distribution $t(x, \tau)$ on the assumption that the wall was thin and with allowance for the heat leakage in the x direction:

$$q(x, \tau) = \delta\left(\rho c \frac{\partial t}{\partial \tau} - \lambda \frac{\partial^2 t}{\partial x^2}\right)$$

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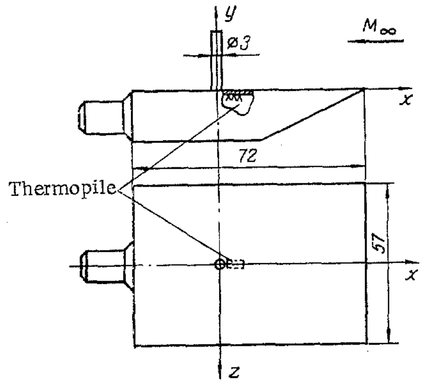

Fig. 1. The model.

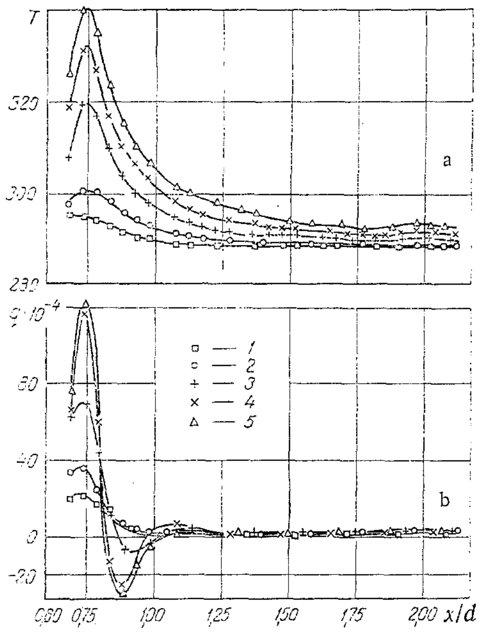

Fig. 2. Temperature distribution (a) and heat-flux distribution (b) along the symmetry axis of the model at successive instants: 1) τ = 0.02; 2) 0.04; 3) 0.08; 4) 0.12; 5) 0.16.

for which purpose cubic smoothing splines were employed. The program was checked out on the exact solution for the two-dimensional heat conduction in a particular case, where the observed values of $t(x, \tau)$ were provided by a random-number generator.

The partial differential equation was obeyed for temperatures averaged over the wall thickness. The numerical analysis on the two-dimensional model showed that the maximum error due to deviation of the mean temperature from the measured value was not more than 1-2%. The error in the computation arising from differentiation of the observed distribution $t(x, \tau)$ was 8% at the points of maximum and minimum in the heat flux.

No allowance was made for the heat leakage in the transverse z direction, because the isotherms near the peak ahead of the cylindrical obstacle were of large radius of curvature r_0 [1, 2]. The error in the distribution of the heat flux $q(x, \tau)$ arising from neglecting the term shown below in the expression

$$q(r, \varphi, \tau) = \delta\left[\rho c \frac{\partial t}{\partial \tau} - \lambda\left(\frac{\partial^2 t}{\partial r^2} + \frac{1}{r}\frac{\partial t}{\partial r} + \frac{1}{r^2}\frac{\partial^2 t}{\partial \varphi^2}\right)\right],$$

namely

$$\lambda\left(\frac{1}{r}\frac{\partial t}{\partial r} + \frac{1}{r^2}\frac{\partial^2 t}{\partial \varphi^2}\right)\delta = \lambda\frac{1}{r_0}\frac{\partial t}{\partial x}\delta,$$

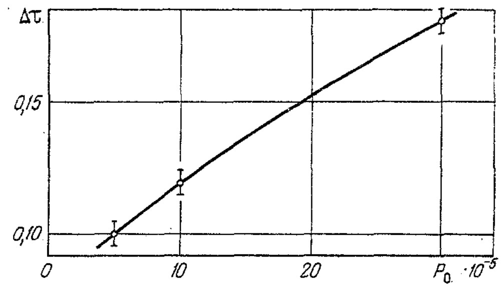

Fig. 3. Relationship between heat-transfer buildup time in the region of detached flow and total pressure in the incident flow.

was not more than 4% as estimated near the peak.

Figure 2b shows the resulting distributions of the heat fluxes $q(\bar{x})$ for the instants $\tau = 0.02; 0.04; 0.08; 0.12; 0.16$ sec; this smoothing-spline method demonstrates substantially nonstationary behavior in the region of flow detachment in front of the cylindrical obstacle, and the time $\Delta\tau = 0.15\text{-}0.20$ sec needed to establish the flow is about two orders of magnitude larger than the time needed to establish the boundary layer on the plate [6] and is dependent on the total pressure P_0 in the incident flow (Fig. 3).

Figure 2b shows that $q(\bar{x})$ in the peak region is represented in places by a negative flux with the smoothing spline; a positive value is obtained only if one assumes that the curvature of the isothermal lines is fairly large.

The dip in the heat flux ahead of the $q(\bar{x})$ peak is due to the temperature discontinuity at the wall [7]. However, this involves assuming a countercurrent towards the peak temperature $t(x)_{max}$, i.e., that there is a local region of secondary detachment ahead of the cylindrical obstacle. Here we merely note that this agrees well with the gradient pressure distribution [8] in this flow region. This problem will be discussed in more detail in the Proceedings of the Central Aerodynamics Research Institute.

NOTATION

M_∞, Mach number of incoming flow; t, temperature; q, specific heat flux; λ, thermal conductivity; c, specific heat; ρ, density; x, longitudinal coordinate; $\bar{x}$, relative longitudinal coordinate; z, transverse coordinate; r, φ, cylindrical coordinates; r_0, radius of curvature of isothermal lines; τ, current time; Δτ, transient-state duration; d, cylinder diameter; δ, wall thickness.

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