EXPERIMENTAL HEAT TRANSFER INVESTIGATION
IN HEAT SHIELD MATERIAL TEST FACILITIES

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An experimental investigation has been made of the thermal interaction of the gas in a facility for testing heat shield materials. The results are presented in terms of the Nusselt number at the stagnation point of a flat plate, accounting for turbulent fluctuations of the oncoming stream. The data obtained are compared with the theory of reference [4].

A possible method of investigating heat shield materials is to test them on the flat rear cover plate of a small model solid or liquid fuel gas generator. To increase the velocity of the combustion products (and thereby increase the heat flux) one can use an intermediate channel of diameter less than that of the gas generator chamber, coupling the gas generator to a short pre-nozzle section.

Analysis of a qualitative picture of the flow in the short section has shown that a subsonic turbulent jet forms there, which interacts with the flat plate and discharges through the supersonic nozzles. In these circumstances, therefore, the interaction within the short section, in the vicinity of the stagnation point on the plate, reduces to the problem of flow of a subsonic turbulent jet over an infinite two-dimensional obstacle normal to the flow axis.

The heat flux from a subsonic jet to a two-dimensional infinite obstacle, within the entrance section, has been investigated in [1-4], where it was shown that the measured heat flux exceeds that predicted by known correlations (e.g., [5]), because the jet turbulence affects the heat transfer.

References [3, 4] used an analysis of experimental heat flux data and measured turbulence characteristics to derive a correlation for the heat transfer coefficient, allowing for the turbulence of the incident stream. Since one must know the turbulence intensity in order to apply the theoretical relations of [3, 4] to the above problem of the short pre-nozzle section, we attempted to determine the heat transfer from the gas to the wall, and also to measure the fluctuation characteristics along the axis of the jet discharging into a short section as shown in Fig. 1.

The investigation of the gasdynamic and thermal parameters of the flow in a model facility of this kind (Fig. 1) was carried out with cold air. Air from a high-pressure chamber 1 passed through channel 2 into a short section 3 of inside diameter 140 mm. To eliminate the effect of external conditions on the gas flow in the short section, the gas discharged to the surrounding space via the supersonic nozzles 4, which had an equivalent sonic throat diameter of 36 mm.

The surface for the heat transfer investigation was a flat plate, to whose inside surface was fastened a textolite obstacle carrying a strip heating element 5; the heater and the technique for determining the heat transfer coefficient are described in [4]. Two variants for the location of the heating element are provided for: in line with two nozzles, and in between nozzles, to allow us to obtain the distribution of local heat transfer coefficient in the most representative directions of the gas flow over the plate.

The velocity fluctuations of the flow were measured using a constant temperature hot wire anemometer.

The investigation was carried out in the following range of the basic parameters at the end of the
nozzle: \( \lambda_c = 0.17 \) to 0.58, stagnation pressure \( P_0 = (3 \text{ to } 21) \cdot 10^5 \text{ N/m}^2 \), Reynolds number \( \text{Re}_c = \lambda_c a_0 D_c P_0 / \mu = (0.8 \text{ to } 10) \cdot 10^6 \), channel diameter \( D_c = 37 \) to 70 mm, distance from end of nozzle to plate \( \tilde{L} = L / D_c = 1 \).

The distribution of local heat transfer coefficient \( \alpha \) over the plate surface is shown in Fig. 2. It can be seen that the distribution depends on the gas flow direction (between nozzles or in line with nozzles) and on the gasdynamic parameters in the channel entrance section. In the range of the basic parameters investigated a uniform distribution of heat transfer coefficient in the vicinity of the central point of the plate occurs for \( \tilde{r} = r / D_c < 0.3 \). This distribution results from the velocity gradient and the turbulent intensity being constant in this region, and also from the fact that the efflux of gas into the nozzles has little effect on the flow in the vicinity of the plate center. Thus, the region \( \tilde{r} < 0.3 \) can be used to test heat shield materials under uniform heat loading conditions.

For \( \tilde{r} > 0.3 \) the nature of the distribution of local heat transfer coefficient depends appreciably on both the flow direction and on the Reynolds number. The flow in this region is appreciably affected by efflux of gas into the nozzles, which accelerates the flow, thus increasing the velocity gradient, and in turn the heat transfer. The effect of the efflux on the heat transfer increases with increasing Reynolds number.

Figure 2 also shows (broken line) the distribution of \( \alpha \) over the surface of an infinite two-dimensional obstacle washed by a subsonic axisymmetric jet [4]. It can be seen that in the central region (\( \tilde{r} < 0.3 \)) the distribution of heat transfer coefficient agrees both quantitatively and qualitatively. For \( \tilde{r} > 0.3 \) the divergence in the distribution of \( \alpha \) arises, as was noted above, from the effect of efflux of gas into the nozzles, as well as from a number of other known peculiarities of flow of gas in the short section.

Analysis of the experimental data on heat transfer to the central part of the plate shows that the coefficients obtained are considerably larger than the calculated values according to [5], and that the excess increases with increase of Reynolds number. As was pointed out above, the derivation is associated with