fluid flow yields information about certain aspects of the temporal and spatial nature of the density fluctuations generated in the evolution of turbulent flow.

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FLOW DIAGNOSTICS IN A CYROGENIC WIND TUNNEL

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In the construction and setting up of a cryogenic wind tunnel an important consideration is to ensure good flow quality. This paper presents results of an experimental investigation to study the causes and conditions for the occurrence of two-phase flow in the T-04 cryogenic wind tunnel [1, 2], and to determine the operating flow regime of this facility to give the purest flow.

A schematic diagram of the T-04 facility is given in Fig. 1: 1) working section of dimensions 200 × 200 × 740 mm, 2) pressure chamber; 3) ejector; 4) return channel; 5) sprayer for atomizing liquid nitrogen; 6) compressed air tank; 7) diffusor; 8) noise-suppressing ventilation shaft; 9) liquid air tank; 10) regenerator bank.

Initial cooling of the tunnel body, the pipes, and regenerator fittings was performed by injecting liquid nitrogen into the stream. The cold regeneration system ensured cooling of the ejected air, and heating of the gas exhausted from the tunnel. Sequential switching of the three regenerators ensured that the flow cryogenic temperature is maintained for a long time with the sprayers switched off. The tunnel can be operated even without the cold regeneration system. In that case the air goes to the ejector, bypassing the regenerator bank, and gas is removed from the tunnel simultaneously through all the regenerators.

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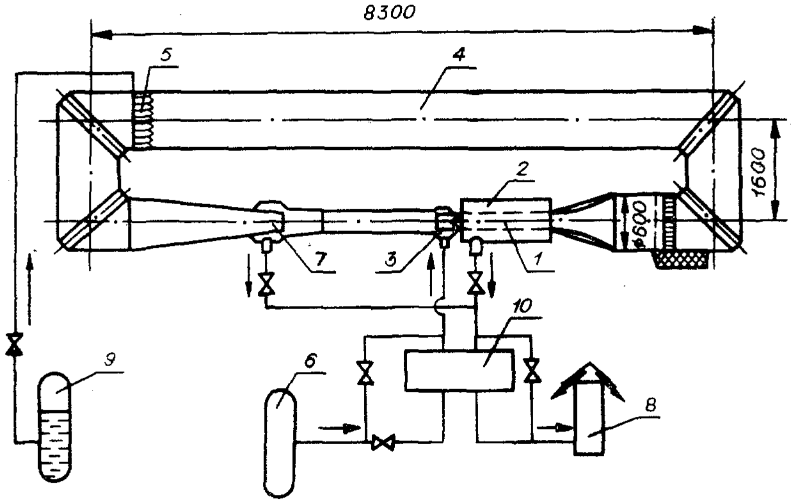

Fig. 1

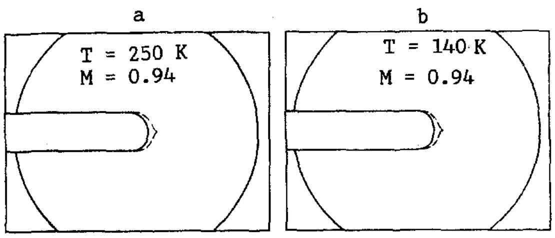

Fig. 2

During the experiments we measured the forechamber pressure, and the facility chamber pressure, and temperatures in the forechamber and the return channel. To determine conditions for the onset of two-phase flow in the tunnel cooling a laser shadowgraph system was used. The direct shadow method was used to visualize the flow near the model in the working section. The optical system for these methods was presented and described in [3].

Investigations of facility cooling with the cold regeneration system switched off have shown that it is quite impossible to operate the tunnel in this regime without supplementary drying of the ejected air. When a temperature of 280 K is reached a fluctuating fog appears in the flow, and when the temperature is reduced to 270 K the fog becomes continuous and snowflakes appear in the lower part of the flow. Further cooling of the flow leads to considerable freezing of the snow on the walls of elements of the flow-through part of the tunnel and the pipes of the gas removal duct, and choking of the total and static pressure tappings. Following heating of the facility water accumulated in the lower part of the tunnel, and this made it difficult to conduct the tests.

Observations of the flow state during simultaneous cooling of the facility and the regenerators from normal to cryogenic temperature have shown that fog forms in the flow and hoar-frost on the walls of the return channel at two times, at temperatures of 270 and 140 K, linked to freezing out of water and carbon dioxide, respectively, from the air. When the facility has been cooled completely and the sprayer is switched off the flow becomes visually transparent, since freezing out of H_2O and CO_2 vapor occurs on the cold fittings of the regenerators.

Analysis of photographs obtained using the direct shadow method have shown that during cooling of the tunnel ($P = 0.24$ MPa, $M \simeq 0.94$) a thin layer of hoar-frost appears on the optical windows and the lens, and a spike-shaped icicle appears on the blunt part of the model. This occurs twice and was seen first on pictures obtained at $T = 253$ and 143 K (Fig. 2a, b). With the help of the laser shadowgraph method it was observed that at flow temperature 260-190 K a uniform homogeneous fog was present in the flow. With further lowering of the flow temperature the fog density became noticeably less. For $T = 145$ K the fog again intensified, but became nonuniform and fluctuating. For $T < 140$ K there was a strong growth of hoar-frost on the interior surfaces of the windows and on the lens, which made flow diag-

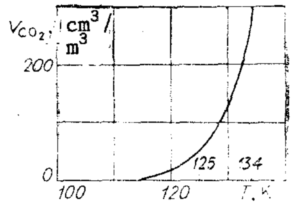

Fig. 3

nostics by optical methods impossible. When there was complete cooling of the facility and the low temperature was maintained in the range 110-120 K, as a result of switching on the regenerators the flow became optically transparent, and the optical windows and the lens were cleared of hoar-frost.

The conclusion that carbon dioxide crystallizes from the gas-tank air at $T < 140$ K is confirmed by the graph of Fig. 3. Atmospheric air, as is known, contains about 0.03% of CO_2 (300 cm^3/m^3) [4]. For $P = 0.24$ MPa the saturation of this amount of CO_2 occurs at $T = 134.5$ K. Lowering of the temperature leads to a sharp decrease of the content of the gaseous CO_2 phase, and an increase of the solid phase in the form of CO_2 crystals in the flow and hoar-frost on the windows. In the continuous cooling process the first appearance of a fluctuating fog at a mean flow temperature of 140 K can be explained by the presence of a zone with lower temperature in the wake behind the sprayer. At $T \lesssim 134$ K there is a sharp increase of the fog over the entire section of the return channel, since the condition for crystallization of CO_2 holds in the entire flow. Subsequent lowering of the temperature to 125 K leads to the formation of CO_2 hoar-frost on the tunnel windows. By way of illustration Fig. 3 notes the temperature range for sublimation of CO_2 with natural heating of the facility without flow. The process occurs in the temperature range 125-160 K, and after it is completed the CO_2 content in the gas in the tunnel channel may considerably exceed the level 0.03% typical of atmospheric air.

To avoid freezing of H_2O and CO_2 vapor in the T-04 tunnel the tests should begin only after complete cooling of the regenerators. For this reason in a cryogenic tunnel of this type it is preferable to have an autonomous system for cooling the regenerators.

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