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MEASUREMENT OF LOW TURBULENCE LEVELS WITH A THERMOANEMOMETER

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The most promising trend for decreasing the drag of aircraft is retention of laminar flow in the boundary layer over a large portion of the surface. Achievement of this goal requires that the laminar boundary layer be studied in all stages of its development. These studies can be performed only in streams with low turbulence [1], created in special wind tunnels. The low-turbulence wind tunnel for low subsonic velocities of the Institute of Theoretical and Applied Mechanics, Siberian Affiliate, Academy of Sciences, USSR, is suitable for such studies. However, significant difficulties have arisen in studying the parameters of the flow in this tunnel, and also in analogous foreign low-turbulence tunnels [2,3], related to the measurement of the low degree of turbulence of the flow. A thermoanemometer [hot-wire anemometer -- Tr.] is the most reliable instrument for measurement of these low levels of turbulence. One difficulty is that the level of the output signal, which corresponds to pulsations in flow velocity, is in this case comparable to the level of the natural electrical noise in the thermoanemometer. This article presents a method and results of measurement of very low (on the order of a few hundredths of 1%) levels of turbulence. /21*

*Numbers in the margin indicate pagination in the foreign text.

The experiments were conducted in the low-turbulence, low subsonic velocity wind tunnel of the Institute of Theoretical and Applied Mechanics, Siberian Affiliate, Academy of Sciences, USSR. This is a closed-type wind tunnel with a closed measurement section 1000×1000 mm in cross section. The low degree of turbulence of the flow in the measurement section is achieved by great constriction of the flow in a confusor (n=17.6), by a set of deturbulizing grids in the forechamber, by the small aperture angles of the diffusors, etc. The measurements were performed by installation of a grid of 0.3 mm-diameter wire in the forechamber with a mesh of 1 mm. The measurements were performed by a DISA type 55D00 constant-resistance thermoanemometer and type 55A22 transducers with a filament diameter of 5 μm made of gold-plated tungsten. The transducer was installed on a rigid holder at a fixed point on the axis of the measurement section of the wind tunnel. Only pulsations in the longitudinal component of the flow velocity were measured. The intensity of pulsations was calculated by the equation

$$\varepsilon = \frac{4U\bar{U}'}{U^2 - U_0^2} \, 100\% , \qquad (1)$$

where U is the output voltage of the thermoanemometer (voltage at the point of the bridge); $\bar{U}'$ is the mean square value of the amplitude of the pulsations in the output voltage, resulting from pulsations in the flow velocity; U_0 is the /22
standard voltage, corresponding to zero velocity of the flow (determined from the calibration graph of the transducer).

Since there is no correlation between the signal caused by turbulence and the noise of the thermoanemometer, the value of $\bar{U}'$ can be determined by the equation

$$\bar{U}' = \sqrt{\bar{U}_c'^2 - \bar{U}_n'^2}, \qquad (2)$$

where $\bar{U}_c'$ is the mean square value of the pulsation component of the output voltage of the thermoanemometer; $\bar{U}_n'$ is the level of natural electric noise in the thermoanemometer.

At low levels of turbulence, the value of $\bar{U}_c'$ differs little from $\bar{U}_n'$; therefore, precise determination of $\bar{U}_n'$ must be given particular attention. Curve 1 (Figure 1) shows the value of $\bar{U}_c'$ as a function of the operating band of frequencies of the thermoanemometer, set by the limiting filters, for a transducer in the stream, while curve 2 shows the level of noise, determined by the generally accepted "cap" method. In the 0-1 and 0-2 kHz bands, $\bar{U}_c'$ is practically equal to $\bar{U}_n'$, while with frequency bands of 0-5 and 0-10 kHz, $\bar{U}_c' < \bar{U}_n'$, which can only be a result of the incorrectness of this method of determination of the noise level.

As we know, the noise level of a thermoanemometer is determined by many parameters: the noises of the transistors or tubes, the gain of the amplifiers, the operating frequency bandwidth, the ratio of the arms of the bridge, the time constant of the transducer, its heating, the voltage supplied to the transducer, and its temperature.

The noise level is influenced by induction from electrical interference, the "microphone effect" of the circuit when operating in a noisy room, thermoanemometer power supply voltage fluctuations, matching of the wave impedance of the cable of the transducer to the input impedance of the amplifiers, etc. The degree of variation of noise with each of these factors is determined by the design of the thermoanemometer and its adjustment and conditions of operation. It is

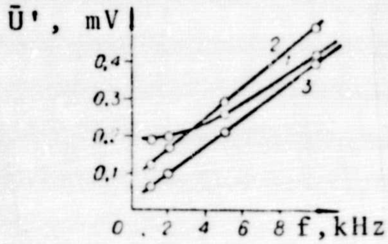

Figure 1. Variation of Indications of Thermoanemometer as a Function of Operating Frequency Band.

1, Transducer in stream, U=5.5 V;
2, Transducer under cap, U=3.5 V;
3, Transducer installed by the method of the authors (see Figure 2), U=5.5 V.

therefore clear that the measurement of the noise level must be performed under conditions as close as possible to the operating conditions. The "cap" method consists in that the transducer of the thermoanemometer is covered with a cap, the thermoanemometer is turned on and the output signal is measured. This signal is assumed to be the noise level of the thermoanemometer. However, when this method is used, the transducer power supply voltage is different from the operating voltage, since there is no stream of air moving around the transducer. We also know that the noise of a constant-resistance thermoanemometer depends essentially on the voltage.

DISA recommends an indirect method of estimating the natural noise of a thermoanemometer at a voltage equal to the output voltage during actual operations of the filament transducer [4]. The calculation method of DISA is represented by the equation

$$\overline{U}'_n = \overline{U}'_{0n} \sqrt{\frac{f_{C0} + f_{CF}}{f_{CV} + f_{CF}}}, \qquad (3)$$

which utilizes the following supplementary experimental data: /23
f_{C0} -- the maximum frequency in the operating band of frequencies of the thermoanemometer at zero flow speed; f_{CV} --

the maximum frequency of the operating band of frequencies of the thermoanemometer at a flow speed equal to the speed of the stream being studied; f_{CF} -- the limiting frequency established by the operator.

One shortcoming of this indirect method of determination of the natural noise of a thermoanemometer is the need for supplementary measurement operations, each of which is accompanied by significant experimental errors.

We suggest a method of direct measurement of the noise level of a thermoanemometer by means of the devices in the thermoanemometer itself under conditions corresponding to its operating conditions. The idea of this method is that a stabilized, fluctuation-free level of heat liberation from the transducer of the thermoanemometer is achieved, equal to the heat liberation in the airstream being studied. This means that the thermoanemometer and transducer are actually in their operating modes, but the variable component of the output signal is determined only by the natural electrical noise of the thermoanemometer.

The simplest means of achieving this method is to place the transducer in a cooled cuvette containing a thermally stable dielectric powder (Figure 2). After cleaning, the transducer can be used again for measurement of turbulence.

If a series of identical transducers is available, it is more convenient to use one of them only for determination of the noise level of the thermoanemometer. To do this, the sensing portion of the transducer is sealed into a glass or metal drop, after first applying a thin film of thermally stable dielectric to the sensing portion. Due to the greater heat conductivity of the medium and cooling, in comparison to a gas, sufficient heat liberation of the transducer is achieved, while the thermal inertia of the medium and the absence of turbulent movement in the medium assure stability of the heat liberation level. Various heat loss rates of the transducer can be achieved by changing the temperature of the transducer, the temperature of the cooling medium, by using substances in contact with the transducer with different heat conductivities. Curve 3 of Figure 1 shows the noise level as defined by this method as a function of operating frequency band of the thermoanemometer. A comparison of curves 2 and 3 shows clearly that the "cap" method yields artifically elevated noise levels, making it unsuitable for the measurement of low degrees of turbulence.

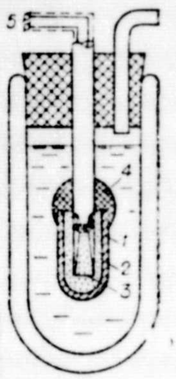

Figure 2. Diagram of installation of transducer for determination of natural electrical noise of a thermoanemometer.

1, Capsule; 2, Corundum powder; 3, Transducer filament; 4, Sealing cap; 5, Output to thermoanemometer

Figure 3 (curves 1 and 2) shows the noise level of a DISA 55D00 thermoanemometer as a function of output voltage at a fixed frequency. Our attention is drawn by the noticeable drop in noise level with increasing output voltage U, which explains the elevated noise levels determined by the "cap" method. Figure 3 was obtained by calculation by DISA. We can see from the graph that this method yields a thermoanemometer noise level elevated by approximately 20%.

In determining the variation of noise level with output voltage U, the voltage was varied by changing the temperature of the cooling medium and of the transducer. The noise levels, measured with the same power supply voltage but with different temperatures of the transducer and medium, coincided. This indicates that the level of natural noise of the thermoanemometer depends only on voltage U. /24

The transducer was calibrated directly in the measurement portion of the wind tunnel. The turbulence was measured at flow speeds of 2-45 m/s in the 0-1 and 0-5 kHz frequency bands. The results of the measurements were processed using equations (1) and (2) and curves 1 and 2 of Figure 3. It was assumed that the fluctuations in temperature of the stream were negligible. The results, shown in Figure 4, show the variation of the longitudinal component of the degree of turbulence with mean stream speed. We can see from this graph that the level of turbulence in the 5-45 m/s speed range is 0.02-0.03%, increasing to 0.042% as the speed decreases to 2 m/s.

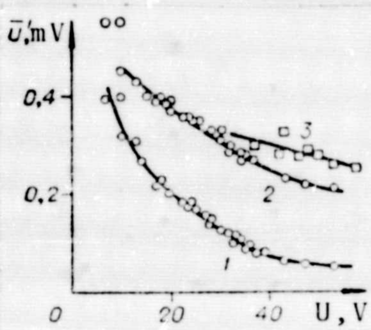

Figure 3. Thermoanemometer noise as a function of output voltage.

1, 0-1000 Hz operating frequency band, method of the authors;
2, 0-5000 Hz operating frequency band, method of the authors;
3, 0-5000 Hz operating frequency band, calculation method of DISA

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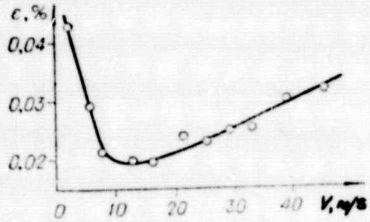

Figure 4. Level of turbulence as a function of flow speed in measurement portion of low-turbulent wind tunnel of ITAM, SA AS USSR

Since it is difficult to perform frequency analysis, due to the low level of the signal of the thermoanemometer, a rough analysis was performed using the filters in the thermoanemometer. It showed that the primary portion of the turbulence occurs in the infralow frequency band at 0.5-20 Hz, with an insignificant portion in the 20-200 Hz band.

Conclusions

1. Measurement of very low levels of turbulence (below 0.1%) requires that a method be used to determine the level of noise of the thermoanemometer under its operating conditions. The "cap" method is unsuitable for the measurement of low degrees of turbulence.

2. The level of turbulence in the measurement section of the low-turbulence subsonic wind tunnel of the Institute of Theoretical and Applied Mechanics, Siberian Affiliate, Academy of Sciences, USSR is 0.02-0.03% in the 5-45 m/s speed range.

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