The progress of modern science and technology has put before hydrodynamicists many new problems. Of special interest are problems connected with the design of pneumatic devices, noise generation in turbulent boundary layers, heat exchange, mass exchange, and boundary layer control. These problems cannot be solved without using the latest achievements in measuring techniques and metrology. A multitude of turbulent-flow measurements are now being performed throughout the world. The new problems not only make it necessary to improve the accuracy and sensitivity of instruments, but also considerably expand the number of quantities to be measured. While measurements of velocity fluctuations were formerly the main source of information on the turbulence characteristics, liquid flow measurements presently include measurements of the constant components and turbulent fluctuations of pressure, temperature, shearing stresses, thermal flow, the heat exchange coefficient, optical and electric characteristics, and impurity concentrations. Besides mastering an ever-increasing number of the quantities to be measured in turbulent flows, there is continued need for expanding the measurement range, especially toward small values.

Hydrodynamic parameters cannot be measured without utilizing the methods and means of the most diverse types of measurement: mechanical, thermal, temperature, electric, optical, etc. Therefore, the present quality of measurement of individual quantities in turbulent flows depends primarily on the state of metrology regarding the individual types of measurement. However, this still does not ensure the unity of hydrodynamic measurements, since no allowances are made for the specific features of the turbulence phenomenon.

A peculiarity of hydrodynamic measurements is the intimate physical relationship, the intrinsic unity, between the individual quantities measured in turbulent flows, which is due to the turbulent nature of the development of fluctuations. This relationship manifests itself, for instance, in the equality of the spatial and the time scales of fluctuations of the quantities to be measured, which imposes certain requirements on the dimensions and the dynamic characteristics of measuring transducers if comparable results are to be obtained (especially in correlation measurements).

The turbulent origin of fluctuations determines the mutual relationship between the amplitude and the frequency ranges of various quantities. Thus, on the basis of the well-known definition of turbulence as a “superposition of vortices of diminishing dimensions,” it can be expected that, due to the effect of viscosity in any turbulent flow, there will be a statistical limit to the dimensions of the smallest vortex, which, in combination with the mean flow velocity, actually determines the maximum frequency of fluctuations sensed by the transducer.

It follows from these considerations that, in each individual case, there is a relationship between the statistical lower limits of the peak value of turbulent fluctuations of the parameters to be measured.

It is clear that the actual possibility of measuring minimal values of hydrodynamic parameter fluctuations is to a considerable extent determined by the quality of the measuring techniques, the efficiency of the measuring circuits, the noise level in the electronic units of the equipment, and many other factors. Thus, for instance, the noise level in the best laboratory heat-loss anemometers limits measurements of turbulent velocity fluctuations to a value of the order of 0.05-0.1%, which is obviously higher than the lowest possible fluctuation intensity.

Nevertheless, the determination of the extremal values of the physical quantities measured in turbulent flows is one of the most pressing problems of the present-day turbulence metrology, since, obviously, only the consideration and analysis of all the factors connected with the nature of the process will make it possible to formulate phys-
ically substantiated and consistent specifications for measuring instruments, standard measuring devices, and calibration and testing methods. Only a complex approach to the development of measuring instruments and metrology, with an allowance for all the peculiarities of the physical phenomenon and the present level of measurement techniques, would secure authentic unity of hydrodynamic measurements and yield results satisfying modern standards.

Work on hydrodynamic metrology is pursued in the following basic directions:

1. Development of theoretical principles of measurement in turbulent flow, investigation of errors, and development of methods for minimizing them.

2. Development of methods and equipment for the calibration and testing of measuring instruments.

3. Development of methods and equipment for the reproduction of fluctuations of hydrodynamic quantities for the purpose of investigating the operating and standard measuring instruments.

In the field of general theory of measurement in turbulent flows, it is first of all necessary to generalize and systematize the voluminous material on theoretical and experimental investigations of errors in measuring turbulent fluctuations. Of special interest here is the further investigation and improvement of the spatial and the time resolving power of measuring transducers.

In contrast to measurements in laminar liquid flow, where the dimensions of the transducer's sensing element are of no great importance, the transducer dimensions in turbulence measurements must be matched with the spatial characteristics of fluctuations.

The few papers on the effect of the transducer's dimensions on the accuracy in measuring the root-mean-square values, the spectra, and the correlation functions of turbulent fluctuations are mainly theoretical in character and are insufficiently supported by experimental data. The various methods recommended in these papers for correcting the measurement results for the transducer dimensions also need experimental verification.

The above also applies to investigations of the dynamic characteristics of transducers. The complexity of the physical phenomenon and the need for complicated, costly equipment for investigating an apparently simple piece of equipment, such as a transducer for measuring turbulent fluctuations, lead to the fact that most investigators restrict themselves to theoretical investigations of the dynamic characteristics (with a minimum number of simple experiments, which only qualitatively confirm the theoretical conclusions).

Nevertheless, interesting results were obtained in a number of theoretical papers. Under certain conditions, these results could be used for considerably reducing the measurement errors. For instance, in a paper devoted to an investigation of the dynamic characteristics of thermal receivers [1], it was shown that, in measuring the temperature of turbulent flows by means of resistance thermometers in the presence of fluctuations of the convective heat-exchange coefficient that are statistically related to the flow temperature fluctuations, the variance of the thermal receiver readings can be not only lower than the variance of the ambient temperature (as is usually assumed for a constant heat exchange coefficient), but also higher than the variance of the ambient temperature, characteristics of the thermal receiver, and the turbulence intensity. This error can be determined accurately only if the dynamic characteristics of the thermal receiver are well known. This and many other examples show that further improvement of the accuracy in measuring turbulent parameter fluctuations depends on the development of experimental methods for determining the dynamic characteristics as well as the spatial resolving power of transducers. It is also necessary to carry out further investigations of the accuracy of transducers of different shapes, oriented in different directions in the flow, in measuring turbulent fluctuations.

A large amount of work on the metrology of heat-loss anemometry in water flow is necessary. Due to their good spatial resolving power, broad frequency range, and high sensitivity, heat-loss anemometers occupy a special place among the instruments for turbulence measurements. Heat-loss anemometers are still the only instruments whereby three components of turbulent velocity fluctuations can be measured. Heat-loss anemometers have been used lately for measuring shearing stresses at the surface of circumfluous bodies. Techniques of heat-loss anemometry in liquid flow are being vigorously developed. Essentially, all the basic experimental data concerning the statistical turbulence theory are now obtained by means of heat-loss anemometers. The use of heat-loss anemometers for measurements in water has its own specific features.

First of all, it is impossible to provide sufficient overheating of the filament because of the possibility of electrochemical effects, which would lead to considerable instrumental errors due to changes in the ambient temperature. The presently used methods for the temperature compensation of heat-loss anemometer readings by means of an additional compensating transducer are imperfect, while the applicability and errors of these methods have not been sufficiently investigated.