HiSST: International Conference on High-Speed Vehicle Science Technology
26–29 November 2018, Moscow, Russia

Sources and Structure of Fluctuations in High Speed Wind Tunnels

Vadim A. Lebiga[1], Vitaly N. Zinovyev[2], Aleksey Yu. Pak[3], Aleksandr I. Ivanov[4], Anton R. Gorbushin[5]

Abstract

The results of measurements of background fluctuations in various high-speed wind tunnels are presented. It is shown that the hot-wire method allows not only obtaining information on the total level of fluctuations of mass flow and the total temperature, but also determining the types of flow fluctuations (turbulence, acoustics, temperature inhomogeneity) and their contribution to the total intensity. While turbulent fluctuations and temperature inhomogeneities are carried by the flow velocity, acoustic disturbances can propagate at any direction, which can be determined with the help of the hot-wire anemometry method. It makes possible to identify sources of fluctuations, and therefore, if necessary, to control them purposefully. The characteristics of fluctuations in high-speed wind tunnels of various research centers were measured - TsAGI, ITAM SB RAS, ETW (Cologne, Germany), TWT (ASTRC NCKU, Taiwan). The fluctuation diagrams were obtained, representing the dependence of normalized output signal of the hot-wire anemometer on the probe overheating, and the signal spectra, which made it possible to determine the mode and spectral composition of the fluctuations. It is shown that in blow-down wind tunnels the most significant are the acoustic disturbances generated in the test section itself, while in wind tunnels with closed circuit the temperature inhomogeneities can be dominating, especially in cryogenic wind tunnels, and also in the absence of heat exchangers or its ineffectiveness.

Keywords *wind tunnel, hot-wire, flow fluctuations, turbulence, acoustics, temperature spottiness*

Nomenclature

Latin
F – hot-wire sensitivity to mass flow
G – hot-wire sensitivity to total temperature
M – Mach number
Re – Reynolds number
T – temperature
m – mass flow
f – frequency
p – pressure
$r = F/G$
u – velocity

Greek
$\alpha = [1+(\gamma-1)M^2/2]^{-1}$
$\beta = 2(1-\alpha)$
ρ – density
χ – angle between flow velocity and direction of disturbances propagation
ϑ – normalized hot-wire output
Subscripts
0 – stagnation value
1 – unit number
$*$ – specific value

1. Facilities and equipment for fluctuations measuring, the hot-wire technique

1.1. Facilities and equipment

The measurements were performed both in blow down wind tunnels (T-112 TsAGI, T-313, T-325 and T-325M ITPM, TWT ASTRC NCKU), and in closed-circuit installations (T-128 TsAGI, PETW ETW). Supersonic wind tunnels were equipped with rigid profiled nozzles, and the walls of the test sections of transonic wind tunnels were either slotted or perforated.

[1] *ITAM SB RAS, 630090, Institutskaya, 4/1, Novosibirsk, Russia, lebiga@itam.nsc.ru*
[2] *ITAM SB RAS, 630090, Institutskaya, 4/1, Novosibirsk, Russia, zinoviev@itam.nsc.ru*
[3] *ITAM SB RAS, 630090, Institutskaya, 4/1, Novosibirsk, Russia, pak@itam.nsc.ru*
[4] *TsAGI, 000000, Zhukovsky, Moscow region, Russia, ivanov_a_i@list.ru*
[5] *TsAGI, 000000, Zhukovsky, Moscow region, Russia, gorbushin@tsagi.ru*

The results described in this paper were obtained with the help of constant current anemometers CCA-6 developed at ITAM SB RAS and allowing measurements over a wide range of probe overheatings while maintaining the frequency range up to 200 kHz. Diameter of the probe tungsten wires was 6…10 microns.

1.2. Hot-wire technique

The method used in this work is based on the features of the hot-wire anemometry approach [1-7]. The voltage across the hot-wire probe depends on a set of parameters: flow velocity u, pressure p, and temperature T, the probe sensitivity coefficients F to the mass flow m and G to the total temperature T_0, the angle between the direction of the disturbances and probe's wire χ, the flow Mach number M, etc. The contribution of each of these parameters to the anemometer output in turn depends on the overheating of the probe.

At least eight overheatings were used to construct fluctuation diagrams, which are the dependence of the normalized hot-wire output ϑ on the function of the probe overheating r. The shape and characteristic points of the diagram determine the intensity and type of fluctuations (turbulence, i.e. velocity fluctuations $<u>$, temperature inhomogeneity $<T>$ or acoustic disturbances characterized by the intensity $<p>$ and the propagation angle χ, angle brackets <> means dimensionless RMS value).

2. Examples of measurement: results and analysis

2.1. Supersonic velocities

The main sources of acoustic disturbances in the test sections of supersonic wind tunnels are the boundary layer on the walls of the nozzle and the test section, as well as the imperfection of their surfaces. The method of fluctuation diagrams $\vartheta(r)$ makes it possible to distinguish them. As a determinative parameter serves the ratio of the total temperature fluctuations to the mass flow fluctuations $<T_0>/<m>$, where $<T_0> = \vartheta(0)$ and $<m> = d\vartheta/dr$ at $r \to \infty$.

If the main sources of acoustic disturbances are associated with surface defects creating stationary Mach waves, and the diagram passes through the origin, $<T_0>/<m>=0$. In the case when acoustic disturbances are generated by moving disturbance sources, the type of diagrams is determined by the sources velocity. The special case for moving Mach waves was obtained by Laufer [2], and some general cases were described in [7].

Fluctuation diagrams measured in test sections of supersonic wind tunnels of various sizes are shown in Fig. 1. In both cases, the disturbances are Mach waves, but for T-313 the ratio $<T_0>/<m>$ is much smaller and close to 0, which indicates the predominance of Mach waves generated by imperfections of the walls. For T-325M, the size of the test section is on order smaller, the contribution of the Mach waves radiated by the boundary layer on the walls predominates [5].

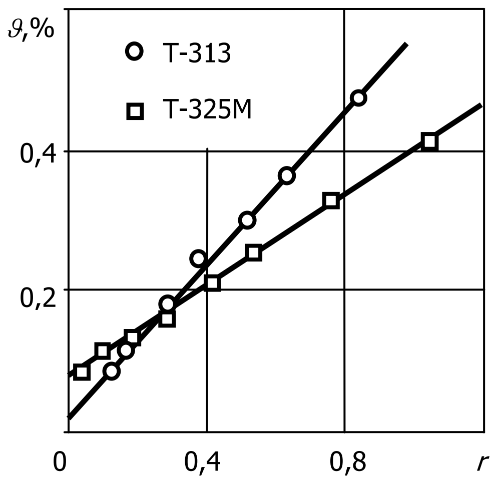

Fig 1. Fluctuation diagrams for acoustic disturbances

2.2. Transonic wind tunnels

All three types of fluctuations can take place in transonic wind tunnels. In this case, the total intensity of background disturbances is determined by the mass flow and the total temperature fluctuations, determined from the general fluctuation diagram. The intensities of background disturbances in a wide range of operating conditions of the TsAGI's facilities are obtained. Examples of such measurements in wind tunnels T-112 and T128 are shown in Fig. 2 [8].

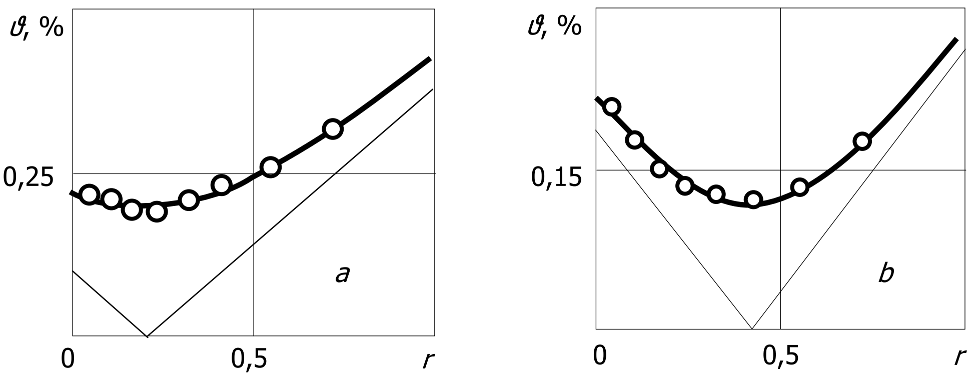

Fig 2. Fluctuation diagrams for wind tunnels T-112 and T-128

Since all three types of disturbances can present in closed-type high speed subsonic and transonic wind tunnels, it is desirable to separate and determine the contribution of each mode of fluctuations. In most cases this is possible, since different types of disturbances prevail in different parts of the frequency spectrum.

Examples of fluctuation diagrams for low frequencies (f <200 Hz), high frequencies (f > 200 Hz), and also in a narrow band for the peak in the spectrum (f = 4 kHz) measured in the PETW facility of the research center ETW (Cologne, Germany) [9] are shown in Fig. 3. At low frequencies, the fluctuation diagram is of a typical form for temperature inhomogeneity. This indicates extrapolating the straight line to the intersection with the abscissa at the point $r = -a$, corresponding to the entropy mode, see Fig. 3a. The main source of temperature spottiness is the facility injection system for liquid nitrogen.

For high frequencies the diagram has a minimum at $r = \beta$, see Fig. 3b, which corresponds to the turbulent mode.

The acoustic disturbances generated by localized sources correspond to rather narrow peaks in the fluctuation spectra observed at measurements in PETW. The fluctuation diagram, see Fig. 3c, corresponds to the acoustic mode, and the value $r=r_* \neq \beta$ for this case indicates that the waves propagate in the direction of flow, $\chi = 0°$, which means that these acoustic waves come into the test section from the settling chamber, and, as it was shown in [9], their frequency is determined by the operating mode of the fan.

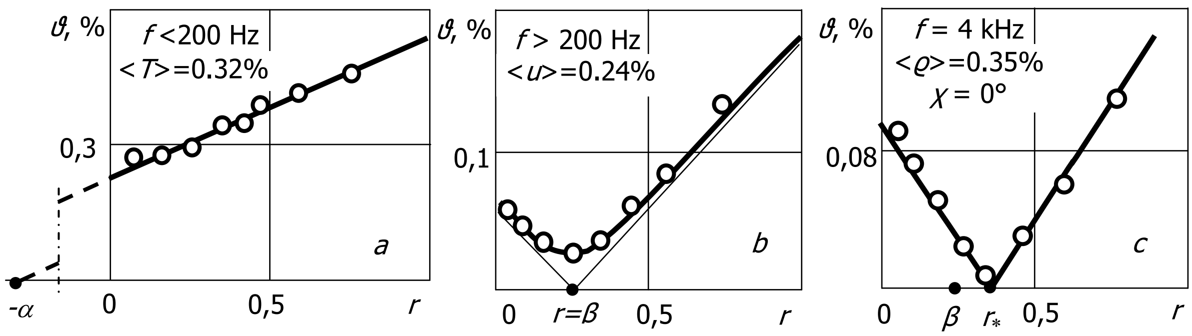

Fig 3. Fluctuation diagrams for different frequency ranges

Conclusion

Thus, the hot wire anemometry method makes it possible to determine the contribution of each types of fluctuations to background disturbances in test sections of wind tunnels, and also to point out the possible sources and location of these disturbances. Therefore, the data on the mode composition, the fluctuation intensity can be used as initial data, while taking into account the effect of different modes of fluctuations on the transition to turbulence and the separation in the boundary layer on models tested in wind tunnels. Also, this information is very important for optimization the design of wind tunnels, because it makes possible to deal and control purposefully and effectively with unwanted sources.

References

1. Kovasznay, L.: The hot-wire anemometry in supersonic flow. J.A.S., V. 17, 565–572 (1950)
2. Laufer, J.: Some statistical properties of the pressure field radiated by a turbulent boundary layer. Phys. Fluid, V. 7, No 8, 1191–1197 (1964)
3. Zinov'ev, V., and Lebiga, V.: Measurements of fluctuations for high subsonic velocities using a hot-wire anemometer. Plenum Publishing Corp. Novosibirsk. Translated from Zhurnal Prikladnoi Mekhanikii Teckhnicheskoi Fiziki, 3, 80-84 (1988)
4. Lebiga, V. Hot-wire anemometer in a compressible subsonic flow. Plenum Publishing Corp. 923-928 (1992). Translated from Izvestiya Akademii Nauk SSSR, Mekhanika Zhidkosti i Gaza, No 6, 160-167 (1991.)
5. Lebiga, V. Hot-wire anemometry of compressible flows. NSTU Edition, Novosibirsk (1997) – in Russian
6. Lebiga V., Zinoviev V., Pak A.: Using a Hot-Wire Anemometer for Measurement of Characteristics of a Random Acoustic Field in Compressible Flows. Journal of Applied Mechanics and Technical Physics, V. 43, No. 3, 488–492 (2002)
7. Lebiga V., Zinoviev V., Pak A.: Hot-wire measurements of acoustic waves propagating in compressible flows. Thermophysics and Aeromechanics. V.9, No 3, 339-349 (2002)
8. Lebiga, V., Pak, A., Zinovyev, V., Chernyshev, S., Gorbushin, A., Ivanov, A. Background flow fluctuations in test sections of transonic wind tunnels. 17th Inter. Conf. on Methods of Aerophysical Research. Novosibirsk, Russia. Part II, 121 (2014)
9. Zinovyev, V., Lebiga, V., Pak, A., Quest, J. Preliminary results of flow fluctuation measurements in the cryogenic transonic wind tunnel. In: Reijasse, Ph., Knight, D., Ivanov, M., Lipatov, I. (eds.) Progress in Flight Physics, V. 3, pp. 3–14, EUCASS (2012)