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# INVESTIGATION OF THE EFFECT OF GRIDS ON THE CHARACTERISTICS OF A TURBULENT FLOW

V. A. Lebiga, et al

Foreign Technology Division
Wright-Patterson Air Force Base, Ohio

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by

V. A. Lebiga, V. V. Chernykh



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| Block | Italic | Transliteration | Block | Italic | Transliteration |
|---|---|---|---|---|---|
| А а | *А а* | A, a | Р р | *Р р* | R, r |
| Б б | *Б б* | B, b | С с | *С с* | S, s |
| В в | *В в* | V, v | Т т | *Т т* | T, t |
| Г г | *Г г* | G, g | У у | *У у* | U, u |
| Д д | *Д д* | D, d | Ф ф | *Ф ф* | F, f |
| Е е | *Е е* | Ye, ye; E, e* | Х х | *Х х* | Kh, kh |
| Ж ж | *Ж ж* | Zh, zh | Ц ц | *Ц ц* | Ts, ts |
| З з | *З з* | Z, z | Ч ч | *Ч ч* | Ch, ch |
| И и | *И и* | I, i | Ш ш | *Ш ш* | Sh, sh |
| Й й | *Й й* | Y, y | Щ щ | *Щ щ* | Shch, shch |
| К к | *К к* | K, k | Ъ ъ | *Ъ ъ* | " |
| Л л | *Л л* | L, l | Ы ы | *Ы ы* | Y, y |
| М м | *М м* | M, m | Ь ь | *Ь ь* | ' |
| Н н | *Н н* | N, n | Э э | *Э э* | E, e |
| О о | *О о* | O, o | Ю ю | *Ю ю* | Yu, yu |
| П п | *П п* | P, p | Я я | *Я я* | Ya, ya |

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

## INVESTIGATION OF THE EFFECT OF GRIDS ON THE CHARACTERISTICS OF A TURBULENT FLOW

V. A. Lebiga and V. V. Chernykh

Certain structural measures, which make it possible to obtain a uniform flow in the test section with a low degree of turbulence, are specified during the design of wind tunnels. One of these measures is to set up grids in the prechamber of the wind tunnel. Wire grids are widely used both to equalize the fields of average speed and to reduce the intensity of turbulent fluctuations in speed. Besides the dampening and equalizing effects, the grids show substantial influence on the turbulence structure: spectral composition, scale of turbulent fluctuations, coefficient of anisotropy, etc.

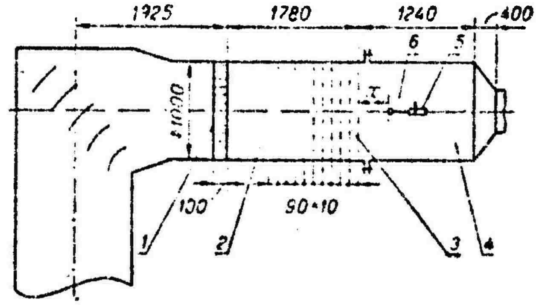


Fig. 1. Diagram of the prechamber for the T-325 wind tunnel. 1 - honeycomb; 2 - grid section; 3 - grids; 4 - traversing gear section; 5 - traversing gear; 6 - sensor.

A rumber of authors [1-3] have obtained, on the basis of certain assumptions, theoretical formulas for calculating the reduction in turbulence intensity during the passage of flow through a grid. However, results of measurements are in poor agreement with the calculation, especially in the region of high values of the specific resistance of the grid. A substantial divergence is observed also during comparison of the calculated and the measured values with installation of several grids in sequence. This article gives the results of an investigation on the effect of the specific resistance of the grid and of a number of grids installed in sequence on the reduction in the intensity of the turbulent fluctuations in speed. It gives some results of measurements of the turbulence structure generated by the grid.

TEST EQUIPMENT

The experiments were conducted in the prechamber of the T-325 [ITPM] (ИТПМ) [Institute of Theoretical and Applied Mechanics] wind tunnel (Fig. 1). The fundamental characteristics of the grids used are given in the table. A 55D00 DISA hot-wire anemometer, 55A06 DISA correlator, and a Brule and Kerr 2111-type 3-octave spectrum analyzer were used during the measurements.

Table.

| Label No. | H, мм | d, мм | K при $Re_d > 400$ | Material |
|---|---|---|---|---|
| 1 | 2.00 | 0.45 | 0.97 | Brass |
| 2 | 1.25 | 0.25 | 0.78 | Steel |
| 3 | 1.00 | 0.30 | 1.75 | Steel |
| 4 | 0.80 | 0.20 | 1.20 | Brass |
| 5 | 0.30 | 0.125 | 4.63 | Brass |
| 6 | 3.00 | 0.45 | 0.53 | Steel |

Note. d - wire diameter; H - distance between the wires.

Type 55A39 DISA X-shaped sensors with a 5 μm tungsten filament were used to measure the components u and v of the turbulent fluctuations in speed. Correlation measurements and measurements of the energy spectrum of the speed fluctuations were made by sensors with a 6 μm filament placed perpendicular to the direction of the averaged flow. The sensors were mounted on the traversing gear, whose mechanism provided two-coordinate displacement with an accuracy of ∿0.2 mm.

EXPERIMENTAL RESULTS

The damping effect of the grid on turbulent fluctuations in speed is usually connected with the magnitude of K, the grid specific resistance. The effect of the grid specific resistance on the reduction in the longitudinal component of the turbulent fluctuations in speed was studied in the range of K from 0.5 to 5.5. Figure 2 is a comparison of the results of calculation by the theoretical formulas in [1-3] with the experimental data of several authors [2, 4, 5]. Significant divergence is observed both in the calculation by the different theoretical formulas and in the calculation with the experiment, especially at high values of the specific resistance. Satisfactory coincidence of the calculation with the results of the measurements was obtained with the use of the empirical relationship

$$\frac{(\varepsilon_u)_0}{\varepsilon_u} = \sqrt{1 + 2{,}5K}, \quad (1)$$

where $(\varepsilon_u)_0$ and $\varepsilon_u$ - the degree of turbulence ahead of and behind the grid.

The dampening effect on the flow of several grids placed in succession is accumulative, i.e., for N grids the following correlation holds true:

$$\frac{(\varepsilon_u)_0}{(\varepsilon_u)_N} = \prod_{i=0}^{i=N-1}\left[\frac{(\varepsilon_u)_i}{(\varepsilon_u)_{i+1}}\right]. \quad (2)$$

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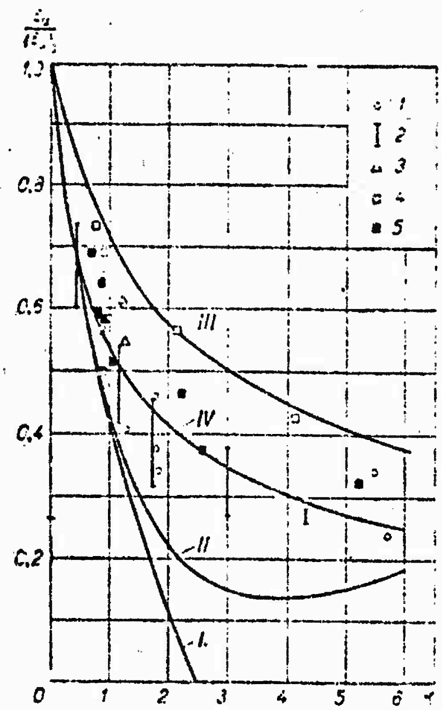

Fig. 2. The effect of the specific resistance of the grid. 1 - this article; 2 - [4]; 3 - [5]; 4 - ε [2]; 5 - $E_u$ [2]; I - [1]; II - [3]; III - [2]; IV - using formula (1).

As is evident from formula (2), in the prechamber of the wind tunnel it is possible obtain a low level of turbulence by setting up a sufficiently large quantity of grids. However, it must be kept in mind that besides the filtered turbulence behind the grid there is also turbulence generated by the grid itself, i.e., grid turbulence. In the final calculation the turbulence generated by the last grid determines that minimum level of turbulence that can be reached in the prechamber of the wind tunnel. Figure 3 gives the results of the measurement of the longitudinal component of the degree of turbulence generated by the last grid at different values of the Reynolds number $Re_d$, which depends on the diameter of the grid wires. Six grids (No. 1, No. 4, and 4 No. 2 grids) were set up in the prechamber, and the intensity of the longitudinal component $(\varepsilon_u)_0$

of the degree of turbulence ahead of the grids did not exceed 1.5%. It is apparent from Fig. 3 that in the Reynolds number range $Re_d$ from 60 to 90 an increase in the level of turbulence is observed with an increase in $Re_d$. When $Re_d > 90$, only the grid turbulence was present in practice in this case. The magnitude of grid turbulence can be calculated with sufficient accuracy by the formula proposed by Batchelor and Townsend [6],

$$\varepsilon_c = \left(\frac{K}{C}\right)^{0,5} \cdot \left[\frac{x}{H} - \left(\frac{x}{H}\right)_0\right]^{-0,5} \cdot 100\%, \quad (3)$$

where c = 106; $\left(\frac{x}{H}\right)_0 = 10$; x - distance from the grid.

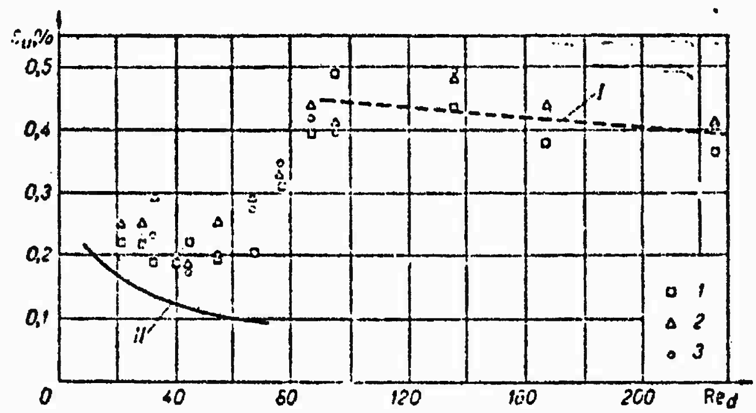


Fig. 3. Grid turbulence as a function of $Re_d$ number. Experiment: z = 100 mm (1), 150 (2), 200 mm (3); I - using formula (3); II - using formula (4).

When $Re_d < 60$ the grid turbulence can be disregarded, and acoustical noise contributes the most to the overall turbulence. Curve I was computed by the formula

$$\varepsilon_u = \sqrt{\varepsilon_p^2 + (\varepsilon_u)_X^2}, \quad (4)$$

where $\varepsilon_p = \frac{P'}{\rho a \bar{U}} \cdot 100\%$ - turbulence equivalent to pressure fluctuations; P' - measured root-mean-square value of the pressure fluctuations in the prechamber; $\rho$ - density, a - speed of sound; $\bar{U}$ - average flow rate; $(\varepsilon_u)_N$ - turbulence filtered by the grids.

These results make it possible to explain the deviation from the principle of cumulation which usually is observed during comparison of the results of calculation and measurements of the dampening effect of several grids placed in succession. The measurement results presented in semilog coordinates (Fig. 4) show the deviation from the linear dependence. The solid horizontal line corresponds to the level of turbulence behind 10 grids, i.e., when there is practically no turbulence passed by the grids. Calculation of the magnitude of turbulence generated by the last grid (broken line V) using formula (3) is in good agreement with these measurements. However, if it is assumed that the passed and grid turbulence do not correlate, it is possible to compute the magnitude of turbulence passed by the grids using the results of the measurements of overall turbulence $(\varepsilon_u)_\Sigma$

$$(\varepsilon_u)_N = \sqrt{(\varepsilon_u)^2_\Sigma - \varepsilon^2_c}. \qquad (5)$$

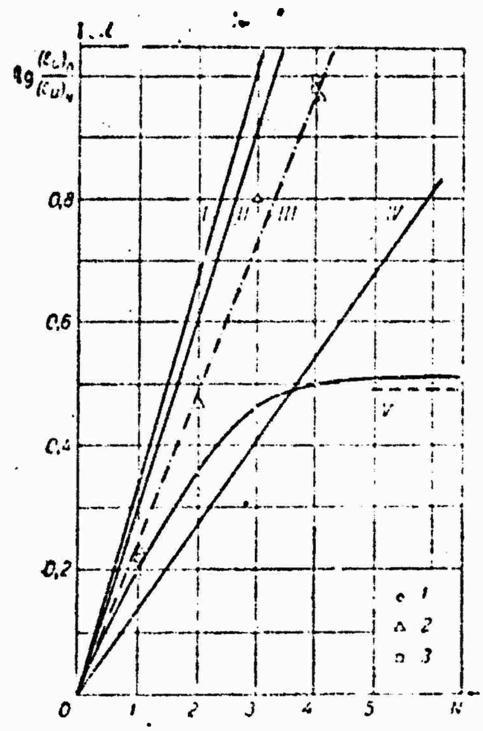


Fig. 4. Effect of the number of grids. Grid No. 2: K = = 0.86, $Re_{1\,м} = 0.7 \cdot 10^8$ $м^{-1}$. x = 450 мм: 1 - measured with $Re_d$ = 175; 2 - using formula (5); 3 - at $Re_d$ = 15-22; I - [1]; II - [3]; III - using formula (1); IV - [2]; V - using for formula (3).

The calculation of $(\varepsilon_u)_N$ using formula (5) agrees well with the calculation using formula (2), which utilizes empirical relationship (1). The results of calculation by the theoretical formulas of Batchelor, Dryden-Schubauer, and Taylor-Batchelor are given here for comparison. When $Re_d < 60$, i.e., when there is practically no $\varepsilon_c$, the results of the direct measurement of the magnitude of turbulence passed by the grids are in good agreement with the calculated value.

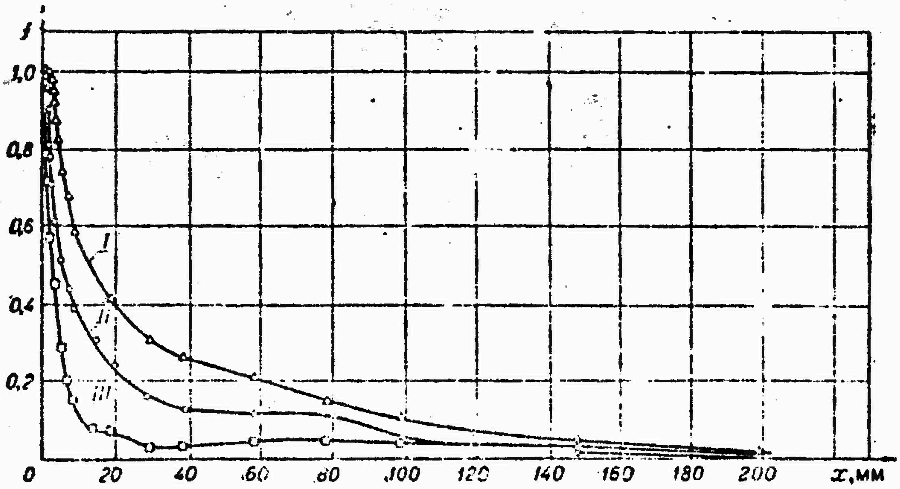


Fig. 5. Coefficient of longitudinal correlation for different grids. I - without the grids; II - grid No. 6 (K = 0.53); III - grid No. 5 (K = 5.54).

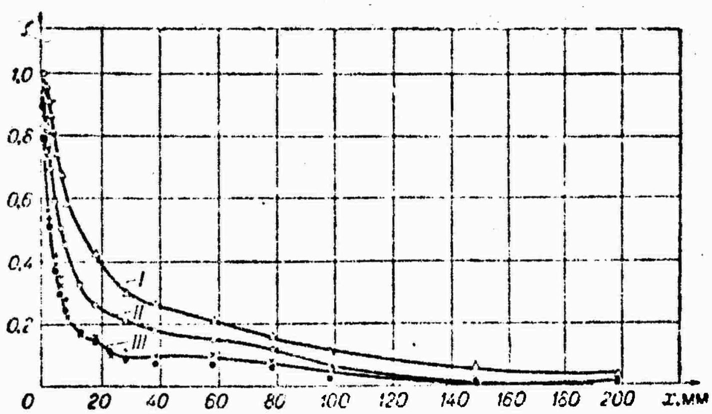


Fig. 6. Effect of the number of grids on the coefficient of longitudinal correlation. I - without the grids; II - one grid No. 2; III - two grids No. 2.

It is known that the dampening effect of the grids is based on a reduction in the scale of turbulent fluctuations. Very small-scale turbulence dampens faster than large-scale turbulence. This leads to the fact that at a sufficiently large distance from the grid there is a reduction in the intensity of turbulence. Figures 5 and 6 give the results of the measurements of longitudinal correlation coefficient f for the fluctuations in speed in the prechamber with different types and number of grids. The grids do not have an identical effect on the components of turbulent fluctuations in speed. This leads to the substantial anisotropy of the flow in the immediate vicinity of the grid. However, as is evident from Fig. 7, there is a strong tendency for the anisotropic flow to go to isotropy. As has been shown, with a sufficient number of grids in the prechamber of the T-325 wind tunnel there is practically only turbulence generated by the last grid, which at large distances from the grid is close to isotropic turbulence. This makes it possible to use the theoretical formulas for the calculation of certain turbulence characteristics. Thus, if the results of the measurements of the function of the longitudinal correlation coefficient are used, it is possible to calculate the function of the lateral correlation and the energy spectrum of the fluctuations. As an illustration, in Fig. 8 the results of calculation using the theoretical formula (see [6]) and of direct measurements are compared with the results of calculation and measurements made by A. Favor. Theoretical spectral distribution $E_u(n)$ is constructed using the formula

$$\frac{\bar{U}E_u(n)}{4\overline{u'^2}\Lambda_f} = \frac{1}{1+\frac{4\pi^2 n^2}{\bar{U}^2}\cdot\Lambda_f^2}, \qquad (6)$$

where $\Lambda_f$ - the turbulence macroscale; n - frequency.

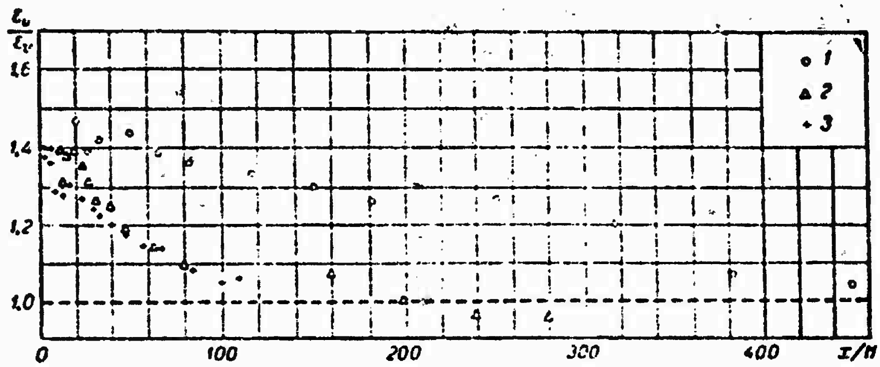


Fig. 7. Coefficient of turbulence anisotropy behind grids. 1 - grid No. 5; 2 - grid No. 2; 3 - grid No. 6.

It is possible to draw the following conclusions from the above:

1. During the calculation of the dampening effect of the grids on the turbulent fluctuations in speed, it is necessary to take into account the turbulence generated by the last grid (grid turbulence).

2. The magnitude of the grid turbulence depends upon the Reynolds number, which depends upon the diameter of the grid wires.

3. Only grid turbulence takes place when sufficiently large number of grids are installed in the prechamber of the wind tunnel. Thus, in the prechamber of the wind tunnel the lower level of turbulence is determined by the magnitude of turbulence generated by the last grid. In connection with this, it is not advantageous to further increase the number of grids in a case where the filtered turbulence becomes rather low in comparison with the turbulence generated by the last grid (less than $\sim 0.5\ \varepsilon_c$).

4. Grid turbulence becomes practically isotropic when $\frac{x}{H} \geq 400$. This makes it possible to calculate certain characteristics of turbulence using the theoretical formulas for isotropic turbulence.

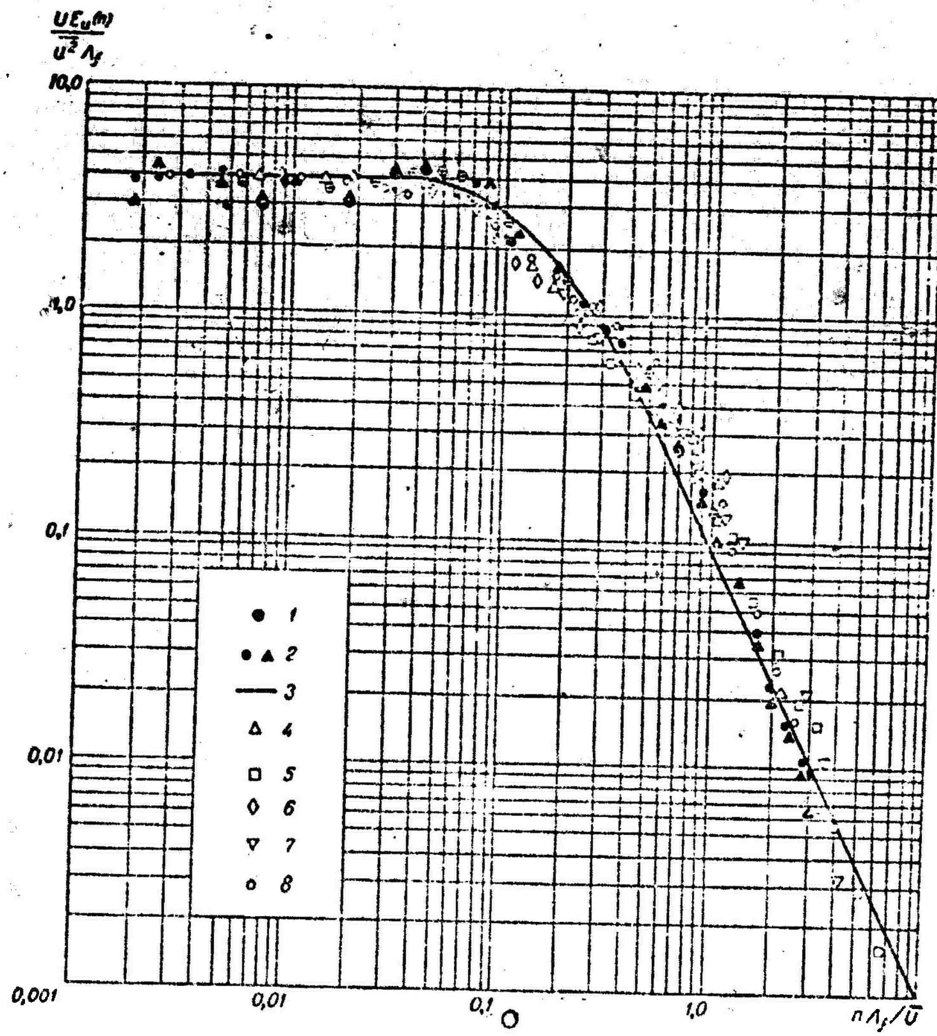


Fig. 8. Energy spectrum of turbulence. Data of [6]: 1 - computed with respect to f(x), 2 - measured, 3 - theoretical curve. This article. Without grids: 4 - computed with respect to f(x), 5 - measured; grid No. 2; 6 - computed with respect to f(x), 7 - measured; two No. 2 grids; 8 - computed with respect to f(x).

Institute of Theoretical and Applied
Mechanics, Siberian Department of
the Academy of Sciences, USSR
Novosibirsk

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