Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 15th International Scientific and Practical Conference. Volume III, 217-220

Experimental Study of Turbulence in the Test Section of Wind Tunnel

Hristian Panayotov
Department of Transport and Aircraft Equipment and Technologies
Technical Univercity of Sofia, Plovdiv Branch
Plovdiv, Bulgaria
hristian@tu-plovdiv.bg

Stanimir Penchev
Department of Transport and Aircraft Equipment and Technologies
Technical Univercity of Sofia, Plovdiv Branch
Plovdiv, Bulgaria
spenchev@tu-plovdiv.bg

Martin Zikyamov
Department of Transport and Aircraft Equipment and Technologies
Technical Univercity of Sofia, Plovdiv Branch
Plovdiv, Bulgaria
martinzikyamov@gmail.com

Abstract. **The given report presents an experimental study using PIV methods (Particle Image Velocimetry) of the relative turbulence in the test section of the wind tunnel ULAK-1, located in the Laboratory of Autonomous Aircraft Aerodynamics in the Plovdiv Branch of the Technical University of Sofia. By means of the turbulence sphere method and by analysis of the flow in the test section in two perpendicular planes (parallel to the free-stream velocity and Trefftz plane), the turbulence factor and the relative turbulence were determined. The obtained results are important characteristics of the wind tunnel and will be used in future experimental studies. The same are compared with previous ones obtained by hot-wire anemometry measurements.**

Keywords: aerodynamics, turbulence, wind tunnel, particle image velocymetry.

I. Introduction

The experimental measurements in wind tunnels play an ever increasing role in aerodynamic investigations both to validate simulation results and to yield new ones that are complicated to simulate [1]. In order to obtain precise results corrections, need to be made to compare the aerodynamic characteristics of the model in wind tunnel to aircraft characteristics in atmosphere. Besides only following the similarity criteria, the relative turbulence in the wind tunnel test section has a significant impact on the experimental results [2]. The last must be compared to the relative turbulence of the atmosphere. Therefore, the aim of the present study is to experimentally determine the relative turbulence (later only turbulence) in the test section of ULAK-1 wind tunnel, located in the Laboratory of Autonomous Aircraft Aerodynamics in the Plovdiv Branch of the Technical University of Sofia. The main properties of the wind tunnel ULAK-1 are:

- Dimensions of the cross section of the test section (WxH): 600 mm x 400 mm;
- Length of the test section: 1000 mm;
- Maximum span of the model: 400 mm;
- Wind speed: 2-50 m/s.

Two methods are used to determine the turbulence in the test section – the method of the sphere using the transition from laminar to turbulent boundary layer and PIV (Particle Image Velocimetry) method where the mean velocity and its fluctuations are measured.

The turbulence in percents is defined by following formula [1]:

$$\varepsilon = \frac{\sqrt{\overline{v}^2}}{\overline{V}}100 \qquad (1)$$

where: $\sqrt{\overline{v}^2}$ is the mean squared fluctuation speed; $\overline{V}$ is the mean velocity of the flow.

The first method – the method of the sphere is focused on obtaining the critical Reynolds number of a sphere, located in the test section of the tunnel where the transition phenomenon occurs from laminar (S) to turbulent (T) boundary layer. This phenomenon is depicted in Fig. 1.

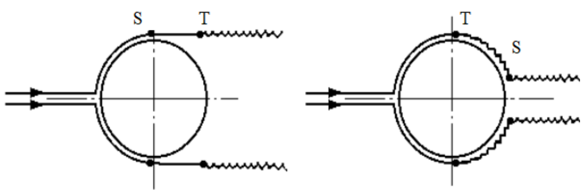

Fig. 1. Transition from laminar to turbulent boundary layer of a sphere.

In the present study transition is observed by PIV visualization of the flow field and is compared to previous studies that use obtaining the critical Reynolds number by measuring the drag of the sphere (Fig. 2). Before the transition of the boundary layer the pressure drag is much

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2024vol3.8118

higher than the friction drag. When transition occurs the drag coefficient drops due to lower pressure drag and this is also illustrated in Fig.2. Once the critical Reynolds number for the sphere in wind tunnel is determined the Turbulence factor (TF) can be calculated as the ratio of the critical Reynolds number of the sphere in wind tunnel and same in atmosphere [2].

The turbulence factor (TF) can be calculated using the following equation [2]:

$$TF = \frac{385000}{Re_{cr}} \tag{2}$$

where: 385 000 is the critical Reynolds number of the atmosphere; Re_{cr} is the critical Reynolds number of the wind tunnel.

The turbulence factor is an important characteristic of the wind tunnel, and it is used to compare the results, measured in the wind tunnel and those of aircraft flying in the atmosphere by calculating the effective Reynolds number of the model [2]:

$$Re_{eff} = Re_{model}TF \tag{3}$$

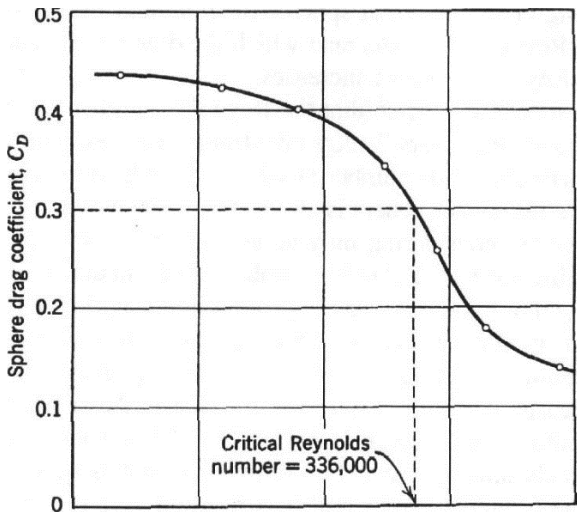

Fig. 2. Critical Reynolds number of a sphere.

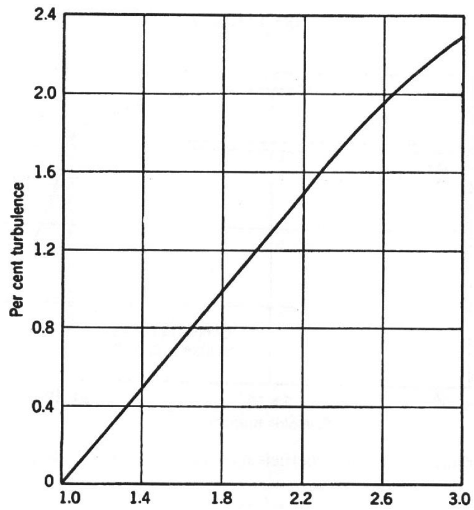

Fig. 3. Turbulence factor (horizontal axis) in relation with turbulence intensity.

The second method is focused on determining the turbulence by measuring the fluctuation and mean value of the velocity in the test section of the wind tunnel using PIV. The turbulence is calculated from formula (1). Then the turbulence factor is correlated from the graphic depicted in Fig. 3 – turbulent factor versus turbulence intensity in percent.

II. MATERIALS AND METHODS

The equipment used for the measurement besides the wind tunnel includes a PIV system that measures all three components of the velocity vector (3C) in a plane thus the flow field in two-dimensional (2D) plane. This type of PIV system is denoted as 3C/2D [3]-[5]. Fig. 4 depicts the PIV system mounted in the wind tunnel ULAK-1. In Fig. 4 a specialized laser creates a laser plane (sheet) that helps to visualize previously seeded particles in the flow in the test section. Two synchronized cameras generate a series of images that are used to define the components of the flow vectors in the area of interest. In the case of stereo PIV an a priori calibration of the cameras is needed. In the present study two different kinds of calibration and measurement are used (Fig. 4) – normal (the laser sheet is coplanar to the y-axis) and cross-calibration (the laser sheet is coplanar to the x-axis). Thus the flow field in the test section of the wind tunnel is measured in a plane parallel to the free stream velocity and a plane perpendicular to the free stream velocity (so called Trefftz plane).

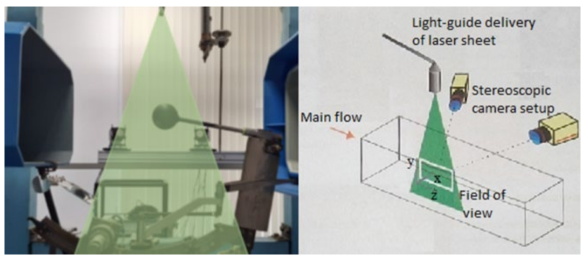

Fig. 4. PIV measurement layout and test bench

In [6] the density and dimension of particles are examined and in [7] different approaches and examples for use of PIV are illustrated.

As it was mentioned the first type of measurement of the turbulence in the test section is the sphere method, where the critical Reynolds number is defined by the transition of the boundary layer. In this case study the flow field around a sphere (Fig. 1) is measured in a plane parallel to the free stream velocity using PIV at different flow speeds to observe the velocity of transition ergo the corresponding Reynolds number. Both of PIV cameras generate a series of images of the induced particles in the flow in the area of interest (Fig. 5). Hence the critical Reynolds number and Turbulence factor (2) are defined for the wind tunnel.

The second method involves measurement of the flow field of the test section without an object in two perpendicular planes – parallel and perpendicular to the free stream velocity. In this case, using a series of time separated PIV images the fluctuations and the mean value of the flow field are obtained and (1) yields the turbulence of the flow, hence the TF (Fig. 3) [1].

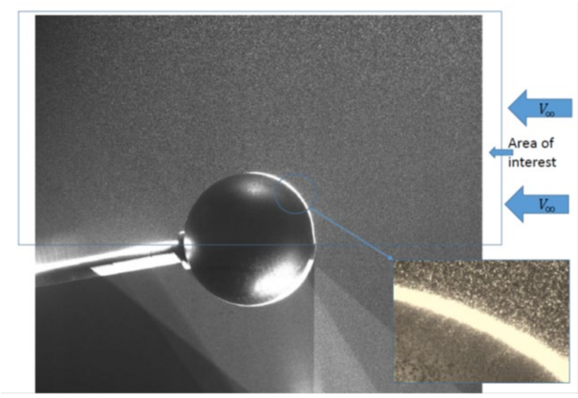

Fig. 5. Raw images of the particles induced in a flow around a sphere.

III. RESULTS AND DISCUSSION

To obtain the critical Reynolds number the flow around a sphere is measured for four different velocities: at 15 m/s, 28 m/s, 32 m/s and 37 m/s. Stereo PIV analysis is conducted at a plane parallel to the freestream velocity (Fig. 4 and Fig. 5). The results for the flow field – velocity and streamlines are shown in Fig. 6 to Fig. 9 at the given free stream velocities - V_∞.

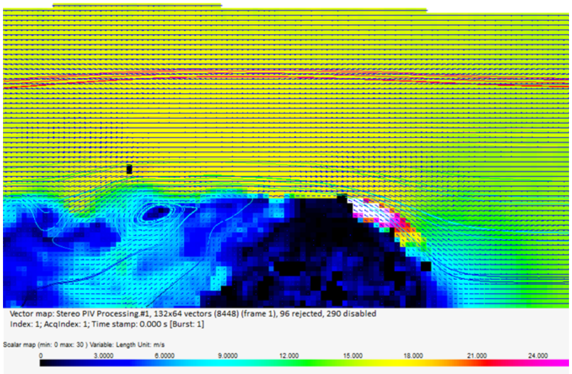

Fig. 6. Flow field around a sphere $V_\infty = 15\ m/s$.

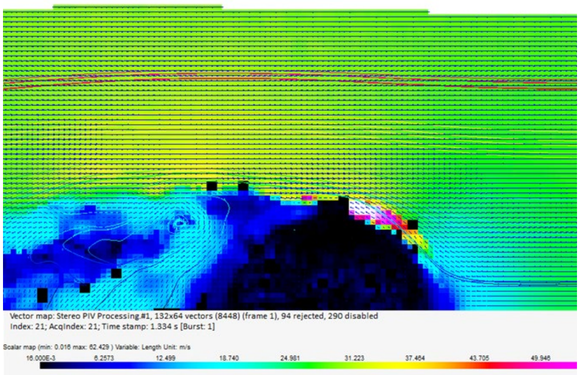

Fig. 7. Flow field around a sphere $V_\infty = 28\ m/s$.

From the results in Fig. 6 to Fig. 9 it is obtained that the transition of the boundary layer (Fig. 1) of the sphere occurs at approximately $V_\infty \approx 35 m/s$. The pattern of the flow in Fig. 6, 7, 8 shows that the transition point is near the middle section (Fig.1-left) whereas Fig. 9 shows the pattern similar to Fig.1-right. Provided we assume that the transition occurs at approximately $V_\infty \approx 35 m/s$ then the critical Reynolds number is:

$$Re_{cr} = \frac{\rho V_\infty d}{\mu} = \frac{1{,}149 \cdot 35 \cdot 0{,}1}{1{,}85 \cdot 10^{-5}} = 217380 \qquad (4)$$

where: ρ is the density of the air, kg/m^3; d is the diameter of the sphere, m; μ is the dynamic viscosity, Pa. s.

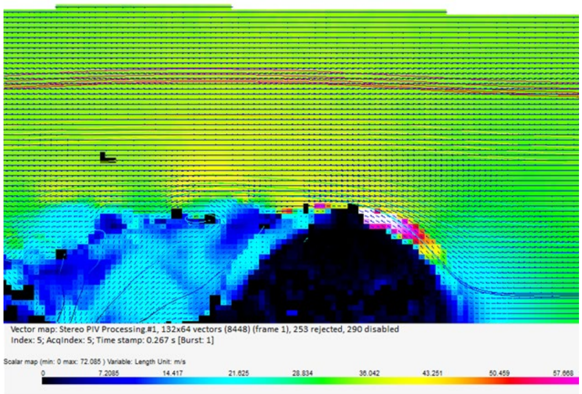

Fig. 8. Flow field around a sphere $V_\infty = 32\ m/s$.

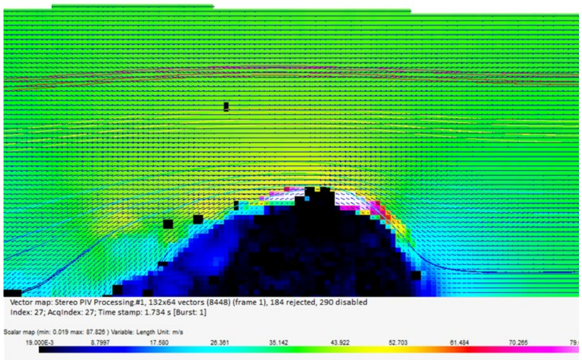

Fig. 9. Flow field around a sphere $V_\infty = 37\ m/s$.

Hence for the turbulent factor of the wind tunnel the value according to (2) is:

$$TF = \frac{385000}{217380} = 1{,}77. \qquad (5)$$

The TF is an integral characteristic for the turbulence in the test section of the wind tunnel. However, to yield the turbulence for the entire flow field a second method is used based on (1). Fig. 10 shows the mean velocity flow field in a plane parallel to the free stream velocity (25 m/s) of the test section. In this case no model is used. A series of 50 images is taken via the PIV system at laser frequency 15 Hz. Then the mean flow field is calculated and visualized as well as the mean squared fluctuation speed.

Formula (1) gives the turbulence in the test section in per cent which is depicted in Fig. 11.

In this case the TF can be correlated to the turbulence using curve from Fig 2b provided that turbulence is between 0,9 and 1.(cyan and blue color in Fig. 11). If done for the test section of the wind tunnel where the model (in this study sphere) is placed the TF is approximately between 1,75 and 1,80, which is an acceptable match with the result from (5).

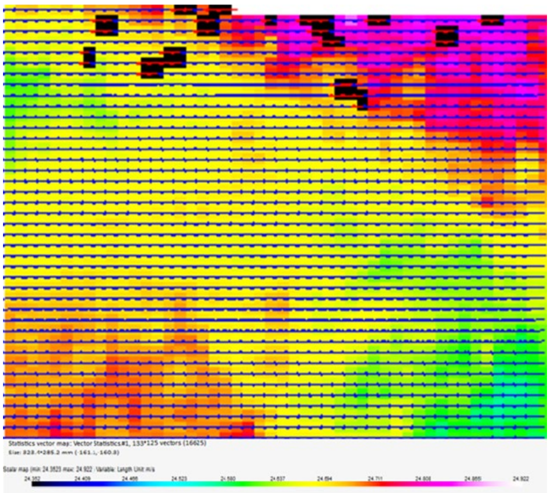

Fig. 10. Mean velocity flow field at $V_\infty = 25$ m/s.

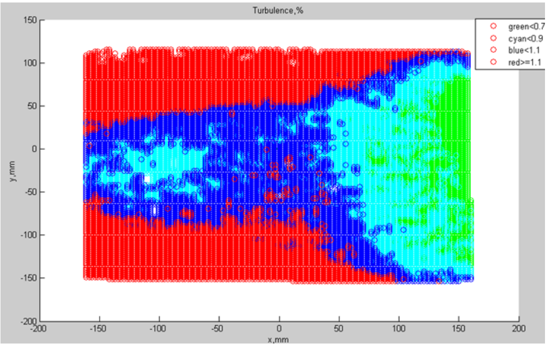

Fig. 11. Turbulence, test section. X-axis is parallel to $\overrightarrow{V_\infty}$

Finally, an additional measurement of the turbulence is conducted in a plane perpendicular to the free stream velocity in the test section at distance of 700 mm downstream of the nozzle end, a so called Trefftz plane – usually where the vortex system behind the model is formed. The methodology resembles the above-mentioned PIV measurements; however the PIV cameras are cross-calibrated. The results for the turbulence in the Trefftz plane are depicted in Fig. 12. The plane of symmetry of the test section is located at x=100 mm, where as x=-100 is the boundary of the test section.

The last measurement (Fig. 12) features greater values of the turbulence than Fig. 11, but one should bear in mind that Fig. 12 shows the turbulence at 300 mm downstream from the most end value in Fig. 11.

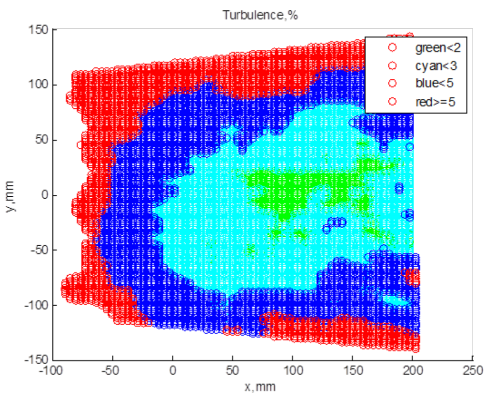

Fig. 12. Turbulence, Trefftz plane, PIV. X-axis is the lateral axis, Y-axis is the vertical axis.

IV. Conclusion

In [8] Penchev et al. measure the turbulence in the Trefftz plane at the same station (700 mm downstream of the nozzle end) of the test section using hot-wire anemometry. The results are given in Fig. 13.

A comparison can be made between the hot-wire anemometry results and PIV results for the turbulence in Trefftz plane. With enough accuracy it can be assumed that the match of the results for both methods is more than acceptable.

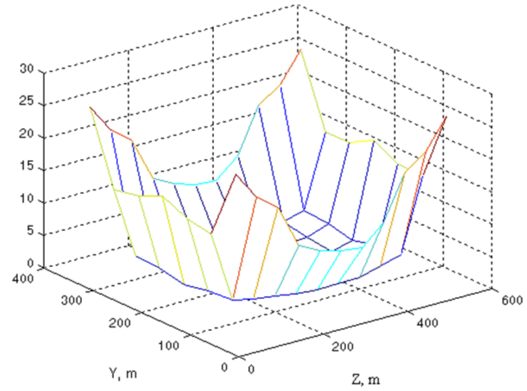

Fig. 13. Turbulence, Trefftz plane, hot-wire anemometry. Z-axis is the lateral axis, Y-axis is the vertical axis.

The present paper encloses a PIV analysis of the turbulence in the test section of ULAK-1 wind tunnel. The given result will be used for aerodynamic corrections in future experiments in the Autonomous Aircraft Aerodynamics laboratory of the Plovdiv Branch of the Technical University of Sofia. The results and the measurement methodology can also be used for comparison to similar aerodynamic experiments. This type of measurement of the turbulence are new for Bulgarian wind tunnel laboratories and can contribute for other researchers to obtain similar results for other types of wind tunnels.

Acknowledgments

The authors thank to the Scientific and Research Sector at the Technical University of Sofia project 232PD0019-24 for funding this publication.

References

[1] C. Britcher, D. Landman, *Wind Tunnel Test Techniques*, Academic Press, 2023.

[2] J. B. Barlow, W.H. Rae, Jr. and A. Pope, *Low-speed wind tunnel testing*. New York: John Wiley & Sons Inc., 1999.

[3] Dantec Dynamics A/S, *2D PIV. Reference Manual*, Publication no.: 9040U1753, Skovlunde, Denmark, 2016.

[4] Dantec Dynamics A/S, *Stereo PIV. Reference Manual*, Publication no.: 9040U4117, Skovlunde, Denmark, 2017.

[5] M. Rafel and C. Wilert, *Particle Image Velocimetry. A Practical Guide*, Springer Verlag, 2018.

[6] J. Zhang, et al, "Study on Motion and Deposition of Particles in a Wind Tunnel", *Procedia Eng.*, vol. 121, pp. 450 – 458, 2015, DOI:10.1016/j.proeng.2015.08.1092

[7] B. Leclaire, et al, "Planar Particle Image Velocimetry for Aerospace Research at ONERA", *AerospaceLab J.*, vol 12, pp. 1-12, 2016 , DOI: 10.12762/2016.AL12-07.

[8] S.I. Penchev, D.T. Seyzinski and D.S. Kolibarov, "Research of the characteristics of the flow in the work section of the wind tunnel UT-1", *Mech. of Machines*, vol. 62 (or vol.14, no.1), pp. 9-12, 2006.