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EXPERIMENTAL DETERMINATION OF THE LEVEL OF INCIPIENT TURBULENCE IN THE WORKING PART OF THE T-1 WIND TUNNEL OF IVAN KOZHEDUB KHARKIV NATIONAL AIR FORCE UNIVERSITY

Abstract. The **subject** of the article is to determine the level of incipient turbulence in the wind tunnel T-1 which is based on the method of measuring the pressure drop. The **purpose** is to experimentally determine the level of incipient turbulence in the working part of wind tunnel T-1 of Ivan Kozhedub Kharkiv National Air Force University in preparation for aerodynamic testing of aircraft models. **Research methods**: the method of pressure drop on the surface of the sphere by drainage. The following **results** of experimental determination of the level of incipient turbulence in the wind tunnel T-1 were obtained. It is established that the wind tunnel T-1 has a level of incipient turbulence 0,5…0,9 %, which corresponds to the normal condition for further experimental studies. **Conclusions**. According to the results of studies of the incipient turbulence in the wind tunnel T-1 by the method of pressure drop, the main dependences are obtained, and the incipient turbulence of the flow for the wooden sphere ξ = 0,9 %, and for the metal sphere ξ = 0,5 %, is determined. Determining the pressure distribution and aerodynamic drag does not involve measures to balance the aerodynamic scales and their certification, which determines the necessary role in the obtained reliable results of the experimental study, and this favors the drainage method.

Keywords: incipient turbulence; wind tunnel; pressure drop; aerodynamic scales; experimental study; drainage method.

Introduction

A numerical aerodynamic experiment allows to investigate the general structure of flow and certain features of flow within the limits of certain models of gas at the change of parameters of research object. A numerical experiment takes advantage before a physical experiment and flying tests in an economy, especially at research of plenty of variants and change of different parameters, descriptions and terms. Thus periodically comparisons of results of numerical experiments must be made with data correctly done physical experiments. In case of unsatisfactory concordance of results the detailed research of divergences that arose up is executed [1]. Thus, experimental aerodynamics is the important constituent of verification of aerodynamics theoretical.

As is known, the results of experimental verifications of models in wind tunnels do not depend on this field experiment. This is to stream the models in the conditions to be created in the aerodynamic laboratory, and in kind are not similar. In order to obtain other characteristics, judging by other characteristics, it is necessary to know the laws of transition from models to nature [2].

Experimental installations and wind tunnels allow to determine aerodynamic characteristics with high accuracy and a wide range of measurement of parameters. A large number of works are devoted to the experimental study of the structure of gas flow in a model experiment [1-6].

The main factors that quantitatively affect the test results are the criteria for the perfection of the wind tunnel. [5]. When setting up any experiment, it is necessary to create the conditions under which it is possible to carry out an experiment that provides practical use of the results. A necessary condition for conducting an aerodynamic experiment is compliance not only with the criteria of geometric perfection, but also the equality of Reynolds, Mach, Struhal numbers and the degree of flow turbulence for the model under study [6].

The aim of the article is to experimentally determine the level of incipient turbulence in the working part of wind tunnel T-1 of Ivan Kozhedub Kharkiv National Air Force University in preparation for aerodynamic tests of aircraft models.

Main part

In the study of the flow of a viscous flow of bodies of various shapes, crisis phenomena are observed, which are associated with a sharp change in the nature of this flow. These phenomena are accompanied by the separation of the flow from the surface or occur with continuous flow [1].

A flat plate, which flows around the flow directed along it, is a standard for flow without separation of the boundary layer. [2]. With continuous flow around the plate, the crisis phenomenon consists of a sharp increase in resistance, due to the transition from the laminar boundary layer to the turbulent. The flow around the sphere will have a completely different character: due to the increase in the surface of the sphere boundary layer and inhibition, which is due to changes in pressure, there is a separation of this layer. The beginning of this separation coincides with the point on the surface where $\tau_{cm} = 0$. Defined as:

$$\mu_{cm}\left(\partial V_x / \partial y\right)_{y=0} = 0\,, \tag{1}$$

The separation of the boundary layer occurs downstream, where there is more friction stress on the walls, because in this case the fluid particles will travel a longer distance in the boundary layer along the surface of the body before τ_{cm} will be equal to zero. Thus, in the case of a laminar boundary layer, the separation will occur much higher downstream than in the case of a mixed boundary layer, when there is a turbulent boundary layer at the stern of the sphere. Scheme of flow separation during flow around the sphere by laminar flow (subcritical flow) is presented on Fig. 1. Scheme of flow separation at the flow around the sphere with mixed flow, supercritical flow is presented on Fig. 2. Distribution of pressure coefficients for the surface sphere is presented on Fig. 3.

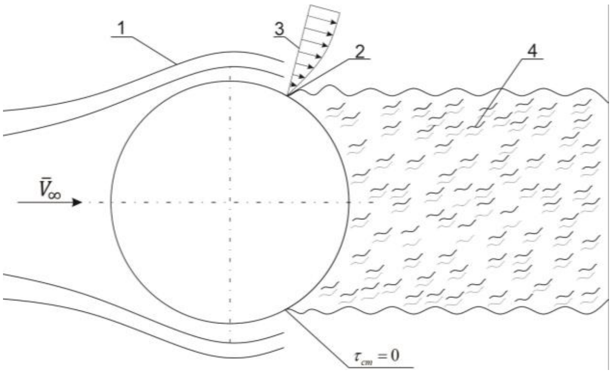

Fig. 1. The scheme of separation of a stream at a stream flow around a sphere by a laminar current: 1- current lines; 2 – the point of separation of the boundary layer; 3- plot of velocities at the breakpoint; 4 – vortex trace of the body

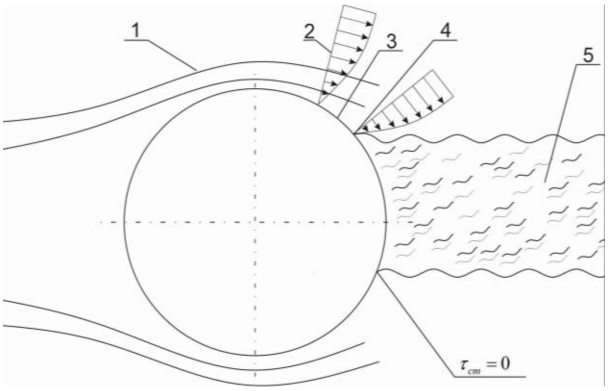

Fig. 2. Flow separation scheme with mixed flow: 1- current lines; 2 – plot of velocities in the boundary layer; 3 – the point of transition of the laminar boundary layer to turbulent; 4 – the point of separation of the boundary layer and the plot of velocities at the point of separation; 5 – vortex trace of the body

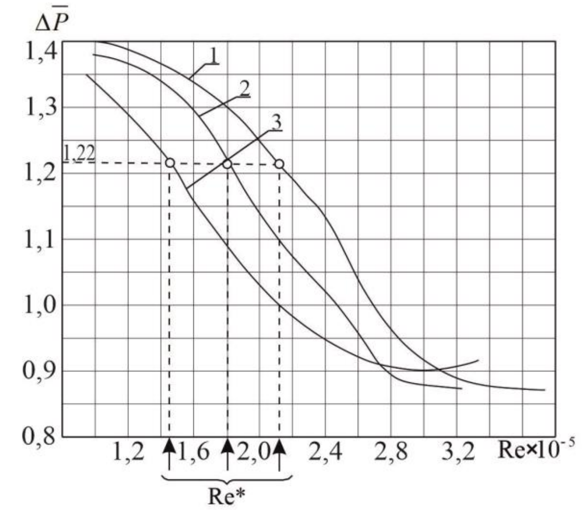

Fig. 3. Distribution of pressure coefficients on the surface of the sphere: 1- vortex-free flow with an ideal flow; 2 – subcritical flow; 3 – supercritical flow

The lower the flow separates the boundary layer, the greater the nature of the flow of the layer through the flow of viscous fluid to flow around the ideal medium. Therefore, despite the fact that the frictional resistance during the transition from the laminar boundary layer to the turbulent layer increases, the flow crisis leads to a decrease in the total value of the layer resistance due to the region of reduced pressure in the stern (Fig. 2). Crisis phenomena in the case of flow around the sphere, other things being equal, occur the faster (ie with a smaller Reynolds number), the greater the incipient turbulence of the flow. The sphere, due to the high sensitivity of the nature of its flow to the incipient turbulence, is used in experimental aerodynamics as a reference sample of the flow surface in determining the magnitude of this turbulence [1].

To determine the incipient turbulence of the flow in the working part of the wind tunnel T-1, an experimental method based on measuring the pressure drop on the surface of the sphere was used. The Reynolds number has the strongest effect on the pressure distribution in the aft part of the sphere. If before the onset of the "crisis" the sphere is dominated by rarefaction, then with the "crisis" flow in this area there is more pressure. The region that is most responsive to changes in the Reynolds number is determined by the polar coordinates $\theta = 150^\circ \div 210^\circ$ (Fig. 2). This feature of the flow around the sphere is used to determine the critical Reynolds number by the pressure drop in the main and aft parts of the sphere [1].

In the body of the sphere were made drainage holes, one of them at a critical point, and the other in the stern, at a point with coordinates $\theta = 157^\circ 30^{'}$. To increase the accuracy of the experiment, the holes are symmetrically placed (Fig. 4), the measured pressure was averaged using an integrated adapter and marked $p_к$.

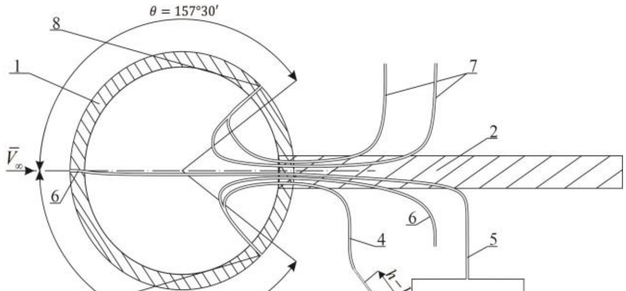

Fig. 4. Sphere model for determining the incipient flow turbulence by the surface pressure drop method: 1 – sphere; 2 – mounting sphere; 3 – liquid micromanometer; 4, 5, 6, 7 – air routes connecting drainage points with a micromanometer, 8 – drainage holes for measuring pressure

Changing the Reynolds number will significantly affect the pressure drop $\Delta \bar{p} = p_0 - p_к$ at these points and at the critical point. If you change the flow rate in the wind tunnel, measure the pressure drop, you can build a dependence on the Reynolds number (Re) to the pressure drop:

$$\vartriangle\overline{p} = \frac{2p_0 - p_к}{\rho_\infty V_\infty^2} = \frac{2\vartriangle p}{\rho_\infty V_\infty^2} = f(\mathrm{Re})\,, \qquad (2)$$

Value $\vartriangle\overline{p} = 1,22$ corresponds to the coefficient of drag at which the critical Reynolds number is determined. Thus, the dependence can be used to find this Reynolds number $\vartriangle\overline{p} = f(\mathrm{Re})$, on which the value of Re is the value $\vartriangle\overline{p} = 1,22$ [1].

Sphere with air drainage routes in the working part of the wind tunnel T-1 is presented on Fig. 5.

Drained sphere with a diameter $D = 13,7см$, mid-section area $S_{мід} = 0,0147м^2$ mounted on the fairing mounting in the working part of the wind tunnel T-1.

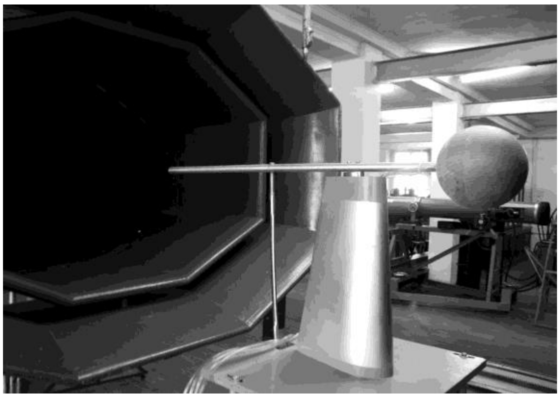

Fig. 5. Drained wooden sphere in the working part of the subsonic wind tunnel T-1

Before starting the wind tunnel, the barometric pressure was measured, and the incipient readings of the micromanometer were taken at the same time. Air density was defined as:

$$\rho_\infty = \rho_{MCA}\frac{p}{p_{MCA}}\frac{273 + t_{MCA}}{273 + t}\,, \qquad (3)$$

ρ_{MCA}, p_{MCA}, t_{MCA} – respectively density, pressure and air temperature in standard atmospheric conditions.

The coefficient of dynamic viscosity of air is defined as:

$$\mu_\infty = \mu_0\left(t_{MCA}/t_0\right), \qquad (4)$$

$\mu_0 = 1,71\cdot10^{-6}кГ\cdot сек/м^2$; t_0 – measured temperature. The kinematic viscosity coefficient is defined as:

$$\nu_\infty = \mu_\infty/\rho_\infty\ . \qquad (5)$$

The flow rate in the working part of the viscosity wind tunnel is defined as:

$$V_\infty = \sqrt{\frac{2}{\rho_\infty}\left(h - h_0\right)\sin\beta\cdot\gamma\cdot\xi_T}\ , \qquad (6)$$

$\gamma = 0,8\,кГ/дм^3$ – the specific gravity of the liquid in the micromanometer; $\beta = 30^\circ$ – the angle of inclination of the plane of the measuring tube of the micromanometer; ξ_T – the coefficient of calibration of the nozzle of full pressure (its value is taken equal to one).

The velocity pressure of the incident flow:

$$q_\infty = \rho_\infty V_\infty^2/2. \qquad (7)$$

The Reynolds number is defined as:

$$\mathrm{Re} = V_\infty\,D/\nu_\infty. \qquad (8)$$

The speed of the oncoming flow V_∞ was determined using a full pressure tube and the braking pressure, which was measured at the frontal point of the sphere. The pressure drop was measured at points of the root part of the sphere using a micromanometer.

The pressure drop is defined as:

$$\vartriangle p = p_0 - p_k = \left(h - h_0\right)\sin\beta\cdot\gamma\cdot\xi_T. \qquad (9)$$

The corresponding dimensionless quantity:

$$\vartriangle\overline{p} = \vartriangle p/q_\infty\,. \qquad (10)$$

Similarly, for the five modes of operation of the wind tunnel T-1 definitions are presented in table 1.

Table 1. **Data on the pressure drop on the surface of a wooden sphere in wind tunnel T-1**

$V_\infty, м/с$	13,5	18	25	30	34	38
$q_\infty, кГ/м^2$	11,2	20,0	38,7	55,8	71,6	89,5
$\mathrm{Re}\cdot10^{-5}$	1,32	1,78	2,45	2,94	3,34	3,73
$h, мм$	40	70	110	125	145	185
$\vartriangle h, мм$	40	70	110	125	145	185
Pressure drop, $\vartriangle p$	16	28	44	50	58	74
Pressure drop, $\vartriangle\overline{p}$	1,41	1,39	1,13	0,89	0,8	0,82

According to the experiment, the dependence is constructed $\vartriangle\overline{p} = f(\mathrm{Re})$, according to which the critical Reynolds number is determined $\mathrm{Re}^* = 2,3\cdot10^{-5}$, that corresponds $\vartriangle\overline{p} = 1,22$ and presented on Fig. 6.

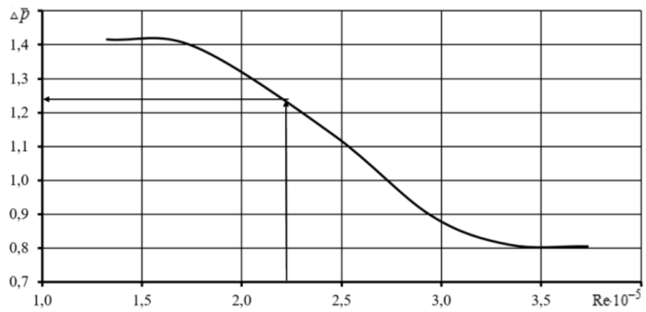

Fig. 6. Determination of the critical number Reynolds as a result of the experiment with a wooden sphere

The level of incipient turbulence is defined as:

$$\xi = \sqrt{\frac{1}{t}\int_{t_1}^{t_2}\Delta V^2 dt}\Bigg/\left(\frac{1}{t}\int_{t_1}^{t_2}V dt\right) \qquad (11)$$

According to the Reynolds number found $\mathrm{Re}^* = 2,3\cdot10^{-5}$, using dependencies $\xi = f(\mathrm{Re})$ [1], determined the incipient turbulence of the flow in the working part of the wind tunnel of Ivan Kozhedub Kharkiv Air Force University $\xi = 0,9\%$ (Fig. 7, 9).

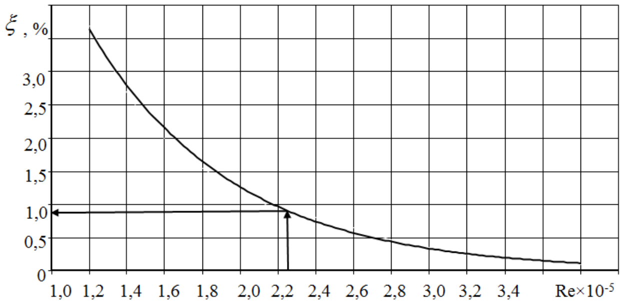

Fig. 7. Dependence of the critical number Reynolds from the incipient flow turbulence for a wooden sphere

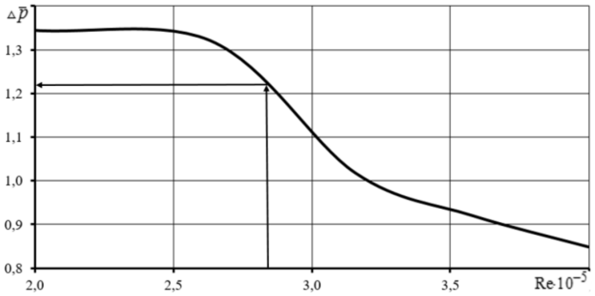

Fig. 8. Determination of the critical number Reynolds as a result of the experiment with a metal sphere

The incipient turbulence was also determined for the metal sphere is presented on Fig. 9.

Fig. 9. Drained metal sphere in the working part of the subsonic wind tunnel T-1

For the five modes of operation of the wind tunnel T-1 determination $\triangle\overline{p}$ definitions are presented in table 2. According to the Reynolds number found $\mathrm{Re}^* = 2,7 \cdot 10^{-5}$, using dependencies $\xi = f(\mathrm{Re})$ [1], determined the incipient turbulence of the flow in the working part of the wind tunnel of Ivan Kozhedub Kharkiv Air Force University $\xi = 0,5\%$ (Fig. 10).

Table 2. **Data on the pressure drop on the surface of the metal sphere in wind tunnel T-1**

$V_\infty, м/с$	13,5	18	25	30	34	38
$q_\infty, кГ/м^2$	11,2	20,0	38,7	55,8	71,6	89,5
$\mathrm{Re}\cdot 10^{-5}$	1,42	1,89	2,63	3,15	3,57	4
$h, мм$	43	68	128	142	165	190
$\triangle h, мм$	43	68	128	142	165	190
Pressure drop, $\triangle p$	17,2	27,2	51,2	56,8	66	76
Pressure drop, $\triangle\overline{p}$	1,52	1,35	1,32	1,01	0,92	0,84

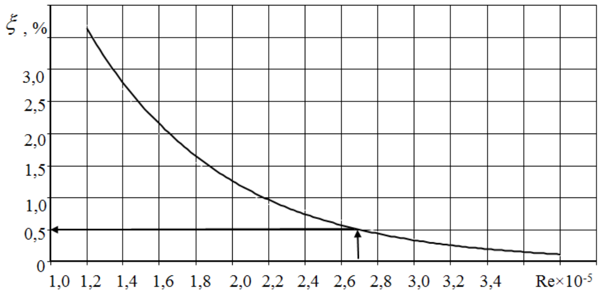

Fig. 10. Dependence of the critical number Reynolds from the incipient flow turbulence for the metal sphere

Conclusions

According to the results of studies of the incipient turbulence in the wind tunnel T-1 by the method of pressure drop, the main dependences are obtained, and the incipient turbulence of the flow for the wooden sphere $\xi = 0,9\%$, , and for the metal sphere $\xi = 0,5\%.$, is determined.

Determining the pressure distribution and total aerodynamic drag does not involve measures to balance the aerodynamic scales and their certification, which plays an important role in obtaining reliable results of the experimental study, and is an advantage of the drainage method.

According to the determined incipient turbulence, the turbulence factor is determined, which will allow to compare the results of tests in wind tunnels T-1 with the results of tests in other wind tunnels [7-13]. According to the results of the experimental study, it was found that the wind tunnel T-1 meets the normal conditions for further experimental studies of unmanned aerial vehicles with hybrid engines.

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Експериментальне визначення рівня початкової турбулентності в робочій частині аеродинамічної труби Т-1 Харківського національного університету Повітряних Сил імені Івана Кожедуба

В. В. Бездєльний, С. О. Шевченко, І. О. Грідасов

Анотація. Предметом статті є визначення рівня початкової турбулентності потоку в аеродинамічній трубі Т-1, що базується на методі вимірювання перепаду тиску. **Метою** статті є експериментальне визначення рівня початкової турбулентності в робочій частині аеродинамічної труби Т-1 Харківського національного університету Повітряних Сил імені Івана Кожедуба при підготовці до аеродинамічних випробувань зразків літальних апаратів. **Методи дослідження**: метод перепаду тиску на поверхні сфери шляхом дренажу. **Отримані наступні результати** експериментального визначення рівня початкової турбулентності в аеродинамічній трубі Т-1. Встановлено, що аеродинамічна труба Т-1 має рівень початкової турбулентності 0,5…0,9 %, що відповідає нормальним умовам для подальших експериментальних досліджень. **Висновки**. За результатами досліджень початкової турбулентності в аеродинамічній трубі Т-1 методом перепаду тиску отримано основні залежності перепаду тиску від числа Рейнольдса. Встановлено, що початкова турбулентність потоку для дерев'яної сфери ξ = 0,9 %, для металевої сфери ξ = 0,5 %. Визначення розподілу тиску та повного аеродинамічного опору не передбачає проведення заходів балансування аеродинамічних вагів та їх сертифікації, що грає важливу роль в отриманні достовірних результатів проведення експериментального дослідження, та є перевагою дренажного методу.

Ключові слова: початкова турбулентність; аеродинамічна труба; експериментальний метод; перепад тиску; експериментальне дослідження.

Экспериментальное определение уровня начальной турбулентности в рабочей части аэродинамической трубы Т-1 Харьковского национального университета Воздушных Сил имени Ивана Кожедуба

В. В. Бездельный, С. А. Шевченко, И. А. Гридасов

Аннотация. Предметом статьи является определение уровня начальной турбулентности потока в аэродинамической трубе Т-1, базирующейся на методе измерения перепада давления. **Целью** статьи является экспериментальное определение уровня начальной турбулентности в рабочей части аэродинамической трубы Т-1 Харьковского национального университета Воздушных Сил имени Ивана Кожедуба при подготовке к аэродинамическим испытаниям образцов летательных аппаратов. **Методы исследования:** метод перепада давления на поверхности сферы путем дренажа. **Получены следующие** результаты экспериментального определения уровня начальной турбулентности в аэродинамической трубе Т-1. Установлено, что аэродинамическая труба Т-1 имеет уровень начальной турбулентности 0,5…0,9 %, что соответствует нормальным условиям для дальнейших экспериментальных исследований. **Выводы.** По результатам исследований начальной турбулентности в аэродинамической трубе Т-1 методом перепада давления получены основные зависимости перепада давления от числа Рейнольдса. Установлено, что начальная турбулентность потока для деревянной сферы ξ = 0,9 %, для металлической сферы ξ = 0,9 %. Определение распределения давления и полного аэродинамического сопротивления не предусматривает проведения мероприятий балансировки аэродинамических весов и их сертификации, что играет важную роль в получении достоверных результатов проведения экспериментального исследования и является преимуществом дренажного метода.

Ключевые слова: начальная турбулентность; аэродинамическая труба; экспериментальный метод; перепад давления; экспериментальное исследование.